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Kwaslema Malle Hariohay

Human-wildlife interactions in the Ruaha-Rungwa Ecosystem, Central Tanzania

Doctoral thesis

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NTNU
Norwegian University of Science and Technology
Thesis for the Degree of
Philosophiae Doctor
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ISBN 978-82-326-3924-3 (printed ver.)
ISBN 978-82-326-3925-0 (electronic ver.)
ISSN 1503-8181

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Printed by NTNU Grafisk senter

Preface and acknowledgements

Numerous people and institutions have contributed to the success of my studies and, therefore, my PhD award. I would like to start with my academic supervisor, Professor Eivin Røskaft, for his tireless support and supervision, for his endless patience, for always being available and for providing advice whenever it was required. I further would like to thank Professor Eivin Røskaft for his visits on more than one occasion to the Rungwa Game Reserve over the course of my data collection fieldwork in Arusha and the Serengeti in supervising my PhD research and thesis. My appreciation are further extended to my co-supervisor in this study, Professor Jafari R Kideghesho, who had always been available for comments and criticisms aimed at improving my PhD work. I thank Dr. Robert D. Fyumagwa, the Director of the Serengeti Wildlife Research Centre (SWRC), for providing the much needed logistical support during the fieldwork component of this research.

NTNU, and Norwegian Institute for Nature Research (NINA) staff - Dr. Craig Jackson and Dr. Peter S. Ranke provided invaluable inputs in during the preparations of manuscripts. Gine Roll Skjærvø and Henriette Vaagland are thanked for their administrative procedures of *AfricanBioServices* Project that helped to finance my studies.

Thanks are also due to the Norwegian University of Science and Technology (NTNU) for providing me the opportunity to undertake my PhD studies and offering the necessary logistical support. The Department of Biology at NTNU hosted me during the entire period of my stay in Norway.

Additionally, my PhD studies would have not been possible without the financial and logistical support from *AfricanBioServices* Project grant via EU-Horizon 2020 through grant agreement 641918. The Management of Tanzania Wildlife Research Institute (TAWIRI) granted me a study leave and research clearance to undertake this study. Free entry permit to conduct my fieldwork in Ruaha National Park and Rungwa-Kizigo-Muhesi Game Reserves were provided by Tanzania Wildlife Management Authority (TAWA) and Tanzania National Parks (TANAPA), respectively.

I am grateful for support rendered to me by the Serengeti Wildlife Research Centre staff members, and the village leaders of the Manyoni, Chunya, and Sikonge Districts. Moreover, special thanks go to my enumerators, who assisted me with data collection in the area.

Wilbright A. Munuo, Patrice Richard, Samwel Pere Mollel, Mwinyijuma Lukindo, and Rajabu Kamota are thanked for their support and cooperation throughout the data collection period of my fieldwork. I also appreciate the good times enjoyed with my fellow students at NTNU and Drs. Mominul Islam Nahid, Joseph Mukeka, Franco Peniel Mbise, and Monica Shilereyo; the visiting students Flora Felix Manyama, Mosses Kyando, and Agnes Kisanga; and other Tanzanians and Norwegians for their academic and social companionship.

Apart from academic life, during our stay in Norway we occasionally enjoyed social gatherings organized at Eivin Røskaft and mama Berit Røskaft's home. Mama Berit Røskaft is thanked for dedicating valuable time to preparing Tanzanian food for us. We greatly enjoyed "Asante sana mama".

Last, but by no means least, I extend my acknowledgement to my beloved late father Malle; may almighty God Rest his soul in Eternal peace. I thank my beloved mother Agnes, beloved wife Ursula, daughter Agnes, son Emanuel, and all of my brothers and sisters who continued to pray for me throughout my studies. I hope that I have mentioned and thanked all who assisted me in one way or another in making my dreams a reality, but to anyone who I might have forgotten, "THANK YOU VERY MUCH. TUSEN TAKK".

Trondheim *Kwaslema Malle Hariohay*

June 2019

Content

Summary

Human wildlife interactions pose the challenges to life and livelihoods of humans living around wildlife protected areas (PA). Similarly, these interactions affect wildlife negatively, thus undermining the conservation efforts. This Thesis seeks to understand how human wildlife interactions affect human beings and wildlife in the Ruaha-Rungwa Ecosystem (RRE) in central Tanzania. This understanding is important in devising effective management interventions as authorities and agencies seek to ensure a beneficial and harmonious coexistence between humans and wildlife.

The first part of this Thesis is composed of three published papers: *An Assessment of crop and livestock losses caused by wild animals* (Paper I), *Human-elephant interactions* in areas surrounding the Rungwa, Kizigo, and Muhesi Game Reserves, central Tanzania (Paper II), *Awareness and Attitudes of Local People towards Wildlife Conservation* in the Rungwa Game Reserve in Central Tanzania (Paper III).

This study has established that the incidences of livestock depredation and crop damage were found to be higher in areas closest to the reserve boundary (Paper 1). Crop losses caused by wildlife in the area averaged 430 kg (equivalent to US$ 126) per household per year for households reporting to have incurred such losses. Maize crops were identified as the main food crops cultivated by farmers in the study area, which were mostly raided by wild animals. Other types of crops cultivated and reported to have been damaged by wild animals include bean, groundnut, sunflower, and other mixed crops. The African elephant (*Loxodonta africana*) was the most reported problem animal and was responsible for more than 96% of crop losses (Paper I).

Livestock depredation by large carnivores resulted in an average loss of 1.9 animals per household per year. Over the last 12 months, a total of 39 cattle, 26 goats, 14 sheep and 4 donkeys were reported to have been killed by large carnivores. The average economic losses of livestock in the area are equivalent to US $243.25 per household per year. The most commonly referenced large carnivore was the spotted hyena (*Crocuta crocuta*), followed by the lion (*Panthera leo*) and leopard (*Panthera pardus*) (Paper I). The most significant contributing factor was found to be distance to the PA, as most reporting livestock depredation incidences were from the villages located closest to the Game Reserve.

Crop damage caused by African elephants considerably increased with less distance from the reserve boundary. Farmers residing close to the PA’s borders reported crop damage much

more frequently than those with farms farther from the boundary (Paper II). In more distant villages, people were more likely to support the conservation of wildlife than those residing in the closest villages (Paper III). The most important factor influencing people's attitudes towards wildlife conservation in the area was found to be the distance from the reserve boundary and areas in which a person farmed. Other factors identified include the farmer's age, immigration status, occupation and education level and incidents of crop damage and livestock depredation (Paper III).

The second part of the thesis examines the effects of human activities on wild animals, such as trophy hunting (Paper IV) and the illegal harvesting of wildlife resources (Paper V). Paper IV establishes that trophy hunting affects animal behaviour by rendering hunted animals more vigilant, by increasing flight initiation distance (FID), and by decreasing group sizes and calf ratios. The effect of trophy hunting on ungulate behaviours was examined by comparing the behaviours of the impala (*Aepyceros melampus*) and greater kudu (*Tragelaphus strepsiceros*) in hunted populations of the Rungwa Game Reserve (RGR) and in non-hunted populations of Ruaha National Park (RNP) of Central Tanzania. In the adjoining RNP, the only permitted tourism activity is photographic tourism, and thus, it served as a control site. The observed differences were ascribed to the direct and indirect effects of trophy hunting in the RGR. Residents in the study area also engage in the illegal harvesting of forest resources and wild animals (Paper V). The results of Paper V show that people who do not own land or livestock, unemployed, and young males are more likely to commit conservation crimes in the area. Furthermore, those who own livestock but lack land for pasture or grazing areas are more likely to move their livestock into the RGR.

The encroachment for agriculture into areas adjacent to the RRE has been a major cause of escalating conflict due to crop damage and livestock depredation by problem animals, as most conflicts occur in areas close to the boundaries of the PA. Mitigation measures have involved the use of traditional and simple methods of noise creation, aversive crop planting (chilli), and beehive establishment around farm boundaries, but such methods have not been effective in controlling the damage caused by problem wild animals. In ensuring the continued coexistence of wildlife and human beings in the study area, this work makes the following recommendations.

Conservation education on appropriate mitigation measures for controlling crop and livestock losses by wild animals must be provided. Education will foster local knowledge and enhance the awareness of and attitudes toward co-existence with wildlife. Land use planning is also recommended, as currently most of the known wildlife dispersal areas in the area are not established or zoned, which risks their future destruction and loss. We also recommend farmers to avoid farming in areas close to the PA, as our findings and experience from other ecosystems show that crop farms positioned close to PA boundaries tend to be the most heavily affected. Strengthening law enforcement as a deterrence measure. Development of entrepreneurship skills. This will enhance employment as a means of limiting the illegal harvesting of wild animals and forest resources.

Lists of papers

The thesis consists of the following five papers:

I. **Hariohay KM**, Fyumagwa RD, Kideghesho JR, Røskaft, E. 2017. Assessing crop and livestock losses along the Rungwa-Katavi Wildlife Corridor, South Western Tanzania. International Journal of Biodiversity and Conservation Vol. 9(8), pp. 273-283; https://doi.org/10.5897/IJBC2017.1116.

II. **Hariohay KM**, Munuo WA, Røskaft, E. 2018. Human-elephant interactions in areas surrounding the Rungwa, Kizigo, and Muhesi Game Reserves, central Tanzania. Oryx Fauna & Flora International (Accepted).

III. **Hariohay KM**, Fyumagwa RD, Kideghesho JR, Røskaft, E. 2018. Awareness and Attitudes of Local People towards Wildlife Conservation in the Rungwa Game Reserve in Central Tanzania. Journal of Human Dimensions of Wildlife; https://doi.org/10.1080/10871209.2018.1494.

IV. **Hariohay KM**, Craig J, Fyumagwa RD, Røskaft, E. 2018. Trophy hunting versus ecotourism as a conservation model? Assessing the impacts on ungulate behaviour and demographics in the Ruaha-Rungwa Ecosystem, central Tanzania: Environment and Natural Resources Research 8(2) 2018; https://doi.org/10.5539/enrr.v8n2p33.

V. **Hariohay KM**, Ranke PS, Fyumagwa RD, Kideghesho JR, Røskaft, E. 2019. Drivers of conservation crimes in the Rungwa-Kizigo-Muhesi Game Reserves, Central Tanzania. International Journal of Global Ecology and Conservation 17 (January 2019). https://doi.org/10.1016/j.gecco.2019.e00522.

Declaration of contribution

Eivin Røskaft contributed ideas, helped plan the research and fieldwork, participated in data collection and data analyses and commented on all of the manuscripts (Papers I - V). Robert D. Fyumagwa contributed ideas and commented on four manuscripts (Papers I, III, IV and V), and Jafari R. Kidghesho contributed ideas and contributed to three manuscripts (Papers I, III and V). Wilbright A. Munuo contributed ideas and collected data for one manuscript (Paper II) and Peter S. Ranke contributed to one manuscript (Paper V). Craig Jackson contributed ideas, facilitated analysis and commented on one manuscript (Paper IV).

Introduction

The transformation of wildlife habitats outside of protected areas (PA) into cropland, settlements, roads, railways and grazing land for livestock increasingly threatens the future survival of wild animals. Protected areas are becoming ecological islands, thus subjecting the migratory species to imminent risk of extinction through inbreeding depression (Woodroffe, 2000; Hariohay and Røskaft, 2015; Buxton et al, 2018). Rapidly expanding human populations have been correlated with the decline of wildlife populations including carnivores and especially in human dominated landscapes occupied by pastoralists and agro-pastoralists settlements (Woodroffe, 2011; Watson et al, 2015; Kutal et al, 2016). The decline is more pronounced for wildlife with wide home ranges such as large carnivores and the African elephant (*Loxodonta africana*) inhabit large areas, rendering them heavily exposed to external pressures as their requirements conflict with the interests of local inhabitants (Watson et al, 2015), resulting in their frequent contact with humans. When these species wreck or are likely to wreak havoc to crops, livestock and human life, communities resort to retaliatory or pre-emptive killing (Holmern et al, 2007; Hazzah et al, 2009; Ontiri et al, 2019).

Negative impacts of human-wildlife interactions include property damage to crops, livestock depredation, lowered student school attendance and market/shopping centre use rates, infrastructure damage to water pipes and houses and injuries and losses of human life (Balme et al, 2010; Watson et al, 2015). Indirect impacts to humans include changes in lifestyle (e.g., changes to sleeping hours and time devoted to protecting farms in cases involving crop raiding elephants). Thus, residents may need to sleep during day rather than at night, though this depends on the type of problem animal involved, as some of crop raiding also occurs during the day. Impacts made also include direct economic costs (e.g., paying watchmen to guard crop farms and constructing livestock enclosures) or indirect costs (e.g., foregoing other cash income generating activities) (Dickman et al, 2014; Green et al, 2018). Thus, in a broader sense these negative interactions with wildlife might lead to the deepening of poverty levels in communities surrounding protected wildlife areas due to the loss of crops and livestock, which functionally act as equivalent to income for businessmen and formally employed persons. These negative losses in terms of crop and livestock depredation by problem animals have caused farmers and pastoralists to develop negative attitudes towards wildlife conservation in their communities (Kideghesho et al, 2007; Bauer et al, 2010;

Balakrishnan and Belay, 2017; Veldhuis et al, 2019). Thus, it is important to understand residents' attitudes to ensure the success of wildlife conservation efforts. The development of mitigation strategies in addressing such conflicts will therefore involve understanding residents' levels of awareness and attitudes.

Negative impacts on wildlife result with the retaliatory killing of problem wild animals, such as African elephants, that raid crop farms and large carnivores that kill livestock (Balme et al, 2010; Green et al, 2018). Residents directly hunt problem animals with spears, arrows, guns and sometimes poison. Poisoning is the most serious and devastating approach, as it results in the mass killing of both targeted and untargeted animals, such as vultures (Nattrass and Conradie, 2018). Pastoralists leave poison in the carcasses of killed livestock with the aim of killing large carnivores that they suspect, but this act can end up killing vultures and other carnivores in large numbers (Masenga et al, 2013; Ogada, 2014). Indirectly, human activities, such as hunting (both legal and illegal), noise from vehicles and other forms of human disturbances, affect the behaviour of wild animals. Wild animals exposed to high levels of human disturbance become more nervous, for instance. Elephants in areas characterised by high poaching rates are dangerous, as they are more likely to attack people than those in low areas with less human disturbance (Hunninck et al, 2017). In high human disturbance areas wild animals also choose to spend most of their time hiding in dense valley habitats and sometimes become inactive during the day (Kyando et al, 2017). Animals in turn become more vigilant and devote less time to feeding and breeding, resulting in population decline (Tingvold et al, 2013). Human activities occurring around PAs with negative impacts on wild animals include the extraction of timber and wild animal hunting for bushmeat and valuable parts, such as ivory, hide, skin, nails, hooves, among others.

Timber extraction is a common phenomenon in most rural communities positioned close to PAs in sub-Saharan Africa, including those in Tanzania (Mohammed et al, 2015). People enter PAs to extract timber, as this resource is greatly depleted in human settlements. Approximately 80% of the human population in Tanzania resides in rural areas and much of this population depends on natural forests for poles and timber for the construction of houses and for firewood as an energy source for domestic cooking (Mohammed et al, 2015). However, natural forests are almost absent outside of Pas and mainly due to the increased demands of rapidly growing populations. Tanzania's human population increased from approximately 7 million in 1961 to approximately more than 52 million in 2018 (URT, 2013;

URT, 2016). With an annual growth rate of 3.1%, Tanzania's population is projected to reach 69.1 and 129.1 million in 2025 and 2050, respectively (PRB, 2018). This rapidly growing human population concurrent with increased deforestation activities will lead to the fragmentation and loss of habitats, which will in turn lead to the local extinction of wildlife species.

Communities positioned adjacent to PAs depend on these areas for bushmeat as a source of protein or income (Knapp, 2012; Kideghesho, 2016). Naturally, dependence on bushmeat is higher among relatively poor households than among wealthier ones. Rural dwellers lacking alternative sources of income resort to bushmeat as an important source of protein, as it is relatively cheaper relative to alternative sources (Ndibalema and Songorwa, 2007; Mfunda and Røskaft, 2010). In addition to socio-economic factors, cultural norms have an influence on bushmeat consumption. However, most hunting tools used by bushmeat hunters, such as wire snares and pit traps, kill both targeted and untargeted wild animals, including endangered species, such as the wild dog (*Lycaon pictus*) and cheetah (*Acinonyx jubatus*).

Hunting activities with commercial motives target wild animals such as elephants for their ivory; leopards for their hide; and lions for their hide, nails and teeth. Legally, this can be conducted under professional monitoring and supervision in the case of the trophy hunting business, for which a specific quota is predetermined from an animal census. However, animals illegally hunted and sold on the black market are killed using varied and unauthorised hunting methods such as poisoning and wire snaring. Whether hunting is performed legally or not, the behaviours of wild animals are affected negatively. In many wild populations, rates of hunting-induced mortality are often substantially higher than natural mortality rates for adult animals (Allendorf and Hard, 2009; Rodríguez-Muñoz et al, 2015). Trophy hunting selection and harvesting consequently have considerable effects on the evolution of adult characteristics and particularly of the characteristics of prime-aged adults (Whitman et al, 2004; Milner et al, 2007; Rodríguez-Muñoz et al, 2015). Phenotypic characteristics, such as those of body size and colour and horn and antler structures, are used as selective elements of animals for hunting practices (Festa-Bianchet and Apollonio, 2003; Loveridge et al, 2007; Milner et al, 2007; Bateman and Fleming, 2014; Rodríguez-Muñoz et al, 2015). Under such scenarios, hunting can lead to unintended selection by reducing the frequency of phenotypes favoured by females for mate selection (Heffelfinger, 2018). More direct and serious effect, however, can involve altered age structures and sex ratios and reduced population sizes resulting from poorly regulated hunting practices (Tuomainen and Candolin, 2010; Rodríguez-Muñoz et al, 2015).

Dependence on PA grazing areas for the livestock of adjacent villages is becoming more prominent in most regions of Tanzania, which is partly a result of the depletion of grazing land in communities in which most areas are being converted into other forms of land use, such as settlement land and cultivated cropland, rendering PAs a destination for livestock incursion. This has mainly occurred due to an increase in livestock volumes, as according to a 2014/15 annual agricultural sample survey Tanzania included 25,812,203 cattle, followed by 19,020,060 goats and 5,533,360 sheep (URT, 2016). A lack of land use planning results in a failure to allocate enough grazing land in communities, causing pastoralists to illegally move their livestock into PAs, negatively impacting both wild animals and livestock as a result. Livestock are often affected by diseases such as malignant catarrhal fever (MCF), which kills a large number of cattle (*Bos taurus*) when pasture is contaminated with *Alcelaphine herpes* virus-1 (AHV-1) during the wildebeest (*Connochaetes taurinus*) calving period. Domestic dogs (*Canis lupus*) can also transmit rabies to wild dogs and to other wild carnivores (Mangesho et al, 2017). Apart from disease transmission habitat alteration can also occur, as continuous livestock grazing can change vegetation types and structures, leading to the local extinction of wild animals as a result of their emigration to other areas.

Alleviating wildlife damage to property and the conflicts that arise will involve balancing the needs of humans and wildlife and wildlife damage managers using their knowledge to identify integrated means to reduce damage to tolerable levels (Karanth and Kudalkar, 2017). The science of wildlife damage management has not yet identified a proverbial silver bullet or panacea for mitigating human wildlife conflicts (Blackwell et al, 2016). Several approaches to mitigating property damage caused by wildlife have been developed, including compensation policies compensating those affected for property damaged by problem wild animals (Johnson et al, 2018). However, there has been must debate on the extent to which governments and conservation institutions can implement compensation schemes as mitigation methods mainly due to inadequate financial resources (Ravenelle and Nyhus, 2017). The application of fencing as a control measure has been argued to constitute an effective means of controlling crop damage caused by problem animals but not at broader scales (Osipova et al, 2018). It is important that measures are applied in a manner that is humane, environmentally benign and socially acceptable. For instance, farmers in South

Africa have initiated the lethal control of predators by using tools such as gin traps (leg-hold traps), gun traps, poison and hunting with and without hounds to eradicate carnivores and other problem animals (McManus et al, 2015). Measures such as incentives and awareness and training programs can help mitigate conflicts between farmers and problem wild animals and support the construction of strong enclosures (Bauer et al, 2010; Sarker et al, 2015).

In Tanzania, most related studies have focused on the Serengeti (Holmern, 2010; Lyamuya et al, 2014; Setsaas et al, 2018), Katavi-Rukwa (Mgawe et al, 2012; Martin and Caro, 2013), and Tarangire ecosystems (Hariohay and Røskaft, 2015; Kiffner et al, 2015); on areas surrounding the Udzungwa Mountains (Nielsen, 2006; Nielsen et al, 2013) and on the southern side of Ruaha National Park (Dickman et al, 2014). Negative impacts of human wildlife interactions, such as crop damage, livestock depredation, effects on animal behaviour due to legal and illegal trophy and bushmeat hunting, and illegal timber extraction, are not limited to these ecosystems and likely commonly occur in other areas as well. The Rungwa-Ruaha Ecosystem (RRE) constitutes another region of Tanzania in which these challenges are rampant. These challenges have prompted the need for an analysis of crop losses due to crop raiding wild animals, livestock losses to large carnivores and factors that contribute to such negative interactions between wildlife and humans in the area. Furthermore, there is need to assess the attitudes of residents towards wildlife conservation in the area. Finally, it is necessary to explore the negative impacts of human activities on wild animals in the area and driving forces causing people to enter PAs and to engage in activities deemed illegal according to the Tanzania Wildlife Conservation Act No. 5 of 2009. Knowledge of human-wildlife interactions and especially of impacts on both entities (i.e., humans and wildlife) can reveal more pragmatic ways of addressing such challenges and the management and conservation of wildlife.

Aim

This thesis evaluates challenges of wildlife conservation resulting from interactions between people and wildlife in the RRE of Central Tanzania as a case study. Interactions between people and wildlife have different impacts on both wildlife and residents (Dejene et al, 2017). Multiple factors reported since 2014 (Dickman et al, 2014) have shown that more than 98% of pastoralists and agro-pastoralists living around the RRE experience problems with wildlife. To address this issue, the first part of this thesis (paper I-III) focuses on crop damage, livestock depredation and attitudes towards wildlife conservation in the area with the following questions. Which wild animals are responsible for crop damage? Which wild animals are largely responsible for livestock depredation? Do crop damage and livestock depredation increase with decreased distance from PA boundaries? What attitudes do people hold towards wildlife conservation in the area? The second part of this thesis (Papers IV and V) focuses on the impacts of human activities on wildlife, such as the effects of trophy hunting (legal) and poaching (illegal) on wild mammal species in the RRE, using the following questions. How does trophy hunting affect the behaviours of wild mammals? What drives people to become conservation criminals? What are the demographic characteristics of those arrested as suspected conservation criminals?

1. We assessed the economic loss inflicted by wildlife species to local communities located in the Rungwa-Katavi wildlife corridor, which connects the Rungwa Game Reserve to Katavi National Park. We investigated the costs of livestock and crop damage caused by wildlife and the relationship between crop and livestock damage and distance from protected areas (Paper I).
2. We examined distribution patterns of impacts of African elephants on crop farms in areas adjacent to the Rungwa, Kizigo, and Muhesi Game Reserves, Tanzania. The seasonal variation (the rain and dry seasons) and spatial (< 1 km, 1-5 km and > 5 km) distribution patterns of crop damage caused by African elephants were analysed (Paper II).
3. We assessed local awareness and attitudes toward wildlife in the Katavi-Rungwa wildlife corridor. We examined levels of awareness in relation to socio-demographic factors and factors that influence positive and negative attitudes towards wildlife (Paper III).
4. We examined the effects of trophy hunting on two common species, the impala (*Aepyceros melampus*) and greater kudu (*Tragelaphus strepsiceros*). For both antelope species, we assessed flight initiation distance (FID), sex ratios, recruitment rates, group sizes and different behaviours in relation to protected area types. We also tested sex ratios, group sizes, vigilance and feeding behaviours, and FID in relation to habitat type (Paper IV).
5. We assessed socio-demographic characteristics of those arrested as suspected conservation criminals and drivers of different forms of conservation crime committed in the RKM GRs (Paper V).

General methods

Study areas

The study areas are situated in Central Tanzania (i.e., the Rungwa, Kizigo, and Muhesi Game Reserves) and in Ruaha National Park in Southcentral Tanzania (Figure 1). Ruaha National Park together with the surrounding game reserves (the Rungwa, Kizigo, and Muhesi RKM GRs) form the single continuous RRE that covers an area of roughly 45,000 square kilometres. Ruaha National Park (RNP), which was established in 1964, is currently the largest national park in Tanzania and East Africa. Its covers an area of approximately 20226 square kilometres (Nahonyo, 2005; MNRT, 2011). Its name is derived from the Great Ruaha River flowing along its southeastern margins and it serves as a stronghold for elephant populations of more than 15,000 individuals (TAWIRI, 2015). The RKM GRs are mostly located in Manyoni of the Singida Region (98%) in Central Tanzania, and 2% of this area is situated within the Chunya District of the Mbeya Region (MNRT, 2011). These three reserves are managed as one entity with headquarters based in the village of Rungwa in the Manyoni District. The reserves also border the Sikonge District (Tabora region), Iringa Eural District (Iringa region) and Chamwino District (Dodoma region) (MNRT, 2011). The three reserves cover an area of 17,340 km² (the Rungwa Game Reserve (RGR) covers 8,818 km², the Kizigo Game Reserve (KGR) covers 5,379 km² and the Muhesi Game Reserve (MGR) covers 3,143 km²) (MNRT, 2011) (Figure 1). Elevation levels range from 800 m asl at the Kizigo/Mzombe River and confluence to 1800 m asl on the Ikili Hill (MNRT, 2011).

The area experiences a long dry season from June–November and a single rainy season running from November–April. The area receives an average amount of annual rainfall of 873 mm with a single wet season occurring from November to May and with the highest rainfall levels recorded in December and January. Temperature range from an average of 21.5°C from June-July to 26.5°C from August-October (Marttila, 2011). The area is located at the interface of Zambezian Miombo woodlands and Somalia-Masai Acacia-Commiphora deciduous bushland and thickets dominated by Miombo woodland, which offer habitats for several wildlife species (Lobora et al, 2017). Among others, wildlife species present in the area include lions (*Panthera leo*), leopards (*Panthera pardus*), spotted hyenas (*Crocuta crocuta*), black backed jackals (*Canis mesomelas*), Cape buffalos (*Syncerus caffer*), greater kudus (*Tragelaphus strepsiceros*), African elephants, plain zebras (*Equus burchellii*), hippopotamuses (*Hippopotamus amphibius*), bush pigs (*Potamochoerus larvatus*), warthogs

(*Phacochoerus africanus),* olive baboons (*Papio anubis*), Vervet monkeys (*Chlorocebus pygerythrus*), and Nile crocodiles (*Crocodylus niloticus*). The area is also home to various species of antelope, such as impalas (*Aepyceros melampus*) and duikers (*Cephalophinae* spp.). Finally, the ecosystem hosts large concentrations of birds (MNRT, 2011; Nahonyo, 2005).

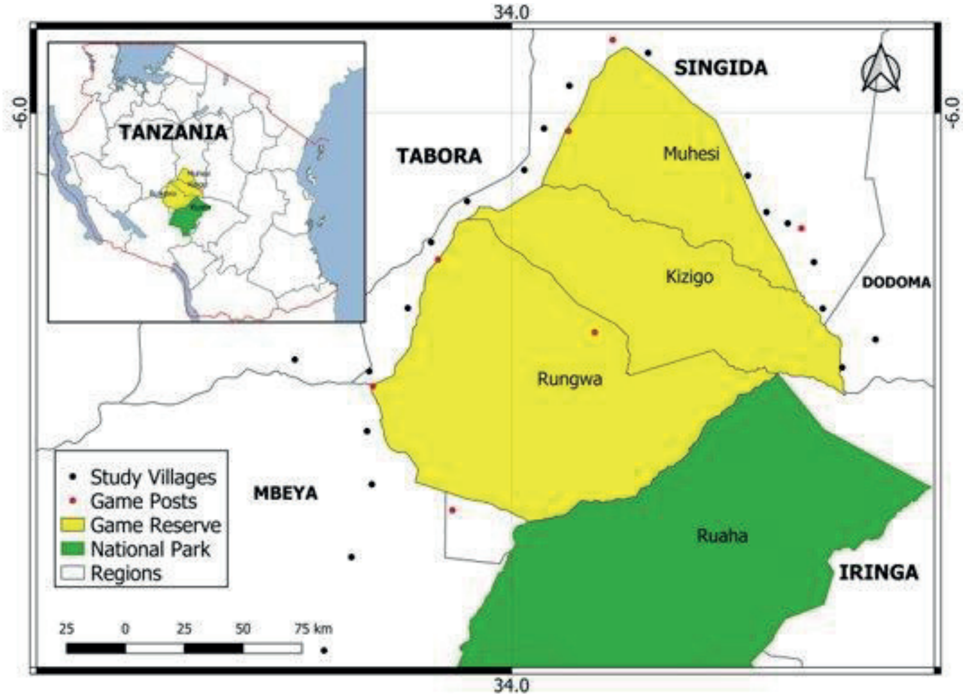

Figure 1: Map showing the location of the Rungwa, Kizigo, and Muhesi Game Reserves and Ruaha National Park in Central Tanzania. Black dots indicate villages in which questionnaire surveys were conducted, and red dots indicate ranger/game posts.

Respondent demographics

Most residents in the study area are poor, owning no/or little land and livestock. A total of 1082 respondents were interviewed (Papers I and III: 240 respondents, Paper II: 210 respondents and Paper V: 631 respondents). The main ethnic groups in the study area include the Nyakyusa, Kimbu, Taturu, Nyaturu, Gogo, Safwa, Sangu, Kinga, Nyiramba, Ngoni and Sukuma. Their main social economic activities are dependent on crop cultivation (> 60%) and livestock (33%), while beekeeping and formal employment activities are in the minority (7%). A large proportion of immigrants live in and farm crops close to the game reserve boundaries. Firewood collected from the protected area serves as the main fuel source used for cooking and is considered a potential source of income for daily subsistence purposes. Adult men and women acting as heads of household or as household members were recruited as reliable interviewees.

Data collection and analyses

Fieldwork was conducted from April 2014 to September 2017. The study areas were classified by degrees of protection: national parks in which only photographic tourism is permitted (i.e., RNP) and game reserves allowing for trophy hunting as the main tourism activity (i.e., the RKM GRs).

For each of the study sites, socio-economic and demographic information was collected through semi-structured interviews and the GPS position of each household was recorded. With the help of the heads of household we estimated the distance between each farm and each interviewed household (Paper II). We then grouped these into three distance categories (< 1 km, 1-5 km, and >5 km) during our analysis. After interviews were conducted, semi-structured questionnaires were administered to 631 respondents including 316 arrested wildlife criminals and 315 adult men and women randomly selected from the study sites as a control group (Paper V). We also interviewed farmers whose crop farms had been damaged by elephants and other wildlife (Papers I, II and III). The questionnaire included questions on socio-economic and demographic variables and a set of statements to test the respondents' attitudes regarding the conservation of protected areas and African elephants, human-elephant interactions and farmers' views of African elephants as pests. Information was gathered on the perceived benefits and problems associated with protected areas and we recorded the names of major wildlife species causing crop damage (except for damage caused by rodents, domestic animals and insect species), seasons with a high prevalence of crop damage, and actions taken by farmers to control crop damage. The names of farm crops damaged by elephants and volumes of crops lost from elephants were also recorded (in kg in Paper I and in Ha in Paper II).

Data collection for Paper IV was conducted by establishing a total of 10 transects, with nine covering a length of 50 km and one covering a length of 15 km. To do thus we drove a Land Rover pick-up truck at a speed of 10–20 km/h with two observers and one recorder participating in road scanning along major roads within RNP and the RGR. When a group of antelope or single antelope (impala or kudu) was sighted, the car was immediately stopped. The GPS positioning of the car was recorded; the distance to the animal(s) was measured with a LEICA LRF 900 SCAN laser rangefinder (LEITZ, Wetzlar, Germany) for distance estimation; and we then recorded the total number of individuals along with their sex, age, behaviours and finally took a photo. The fieldwork period lasted for 28 days of each year, resulting in a total study period of 56 days running from April 2014 to September 2017.

Data were analysed using SPSS v. 21(IBM Corp, 2012) (paper I-IV) whereas data for Paper V were also analysed using R software (R Core Team, 2016). The differences between variables were explored via χ^2 (Chi-squared) tests of independence and using a generalized linear regression model. Regression analyses were conducted to examine relationships between multiple variables. Further information on the methods and data analysis employed are elaborated on in the respective papers (Appendixes I - V).

Study species

African elephant

The African elephant is the largest terrestrial animal and currently resides in 37 sub-Saharan countries. There are two sub species of the African elephant: the African savannah elephant (*Loxodonta africana africana*) (photo 1) and forest elephant (*Loxodonta africana cyclotis*). The species was red listed by the IUCN in 2004 and given a vulnerable conservation status (Blanc, 2008). African elephants are found in different zones from tropical through sub-tropical to temperate zones. The home range of African elephants may vary based on habitat conditions. In high-quality habitats (e.g., Lake Manyara, Tanzania) the African elephant is known to occupy areas of 15 to 52 km². However, in desert areas (e.g., West Namibia) they can occupy areas of more than 18,000 km² (Parker et al, 2007). African elephants are normally characterized by migration behaviour in searching of food, water, space and other resources based on their ability to travel longer distances along their varying routes (Gereta and Røskaft, 2010, p 186 - 210). In addition to this, the elephants need roughly 160 litres of water and a diet of varied vegetation amounting to at least 5% of their body weight or 100 to 300 kg of food per day, which can sometimes result in the elephants raiding crops, creating conflicts with humans (photo 2). African elephants also prefer areas characterized by fertile soil and enough water (Parker et al, 2007). The gestation period for these elephants is roughly 22 months.

Photo 1: African savannah elephants in the Rungwa Game Reserve (Photo: by Kwaslema Malle Hariohay, 2015).

Crop farms near the boundaries of PAs have been frequently damaged. Photo 2 of a farm in the study area damaged by African elephants was taken during data collection.

Photo 2: A farm in the village of Rungwa damaged by the African elephant (Photo: by Kwaslema Malle Hariohay, 2015)

Impala

Impala are medium-sized African antelope with individuals ranging between 120-160 cm in length (photo 3) (Averbeck, 2002). Impala are sexually dimorphic antelopes where only males are horned and are noticeably larger than females (Lunde et al, 2016; Setsaas et al, 2018). Males stand approximately 75-92 cm tall and weigh 53-76 kg, while females weigh 40-53 kg (Averbeck, 2002; Averbeck et al, 2009). Impala inhabit savannah grasslands and woodlands positioned close to water sources. They are mixed foragers of grasses, forbs, monocots, dicots and foliage (Wronski, 2002; Marshal et al, 2012). Impala travel between habitats between seasons due to variability in food availability (Wronski, 2002; Marshal et al, 2012). They live in three distinct social groups: 1) female herds with a territorial male, 2) bachelor herds (males of different ages) and 3) single territorial males. Their gestation period is six to seven months.

Photo 3: Impala in Ruaha National Park (Photo: by Kwaslema Malle Hariohay, September 2017)

Greater kudu

Greater kudu males are considerably larger than females and have spiralled horns (photo 4). Males are approximately 185-245 cm long (Hoffmann, 2016). Greater kudus are found in woodlands, as they are browsers that eat leaves and shoots. In the dry season, they eat wild watermelons and other fruits for their liquid content and for the natural sugars that they provide (de Garine-Wichatitsky et al, 2004). While male kudus can be found in bachelor groups, they are more likely to be solitary (Kie, 1999; Hoffmann, 2016). Their dominance displays tend not to last long and they are generally peaceful with males making themselves appear larger by making their hair stand on end. Males are seen with females only during the mating season when they form groups of 5–15 kudus, including offspring (Hoffmann, 2016). Calves grow quickly and are independent of their mothers from six months of age. Kudu are also dimorphic with males that have horns, while females are polled like the impala.

Photo 4: Greater kudu in the Rungwa Game Reserve (Photo: by Kwaslema Malle Hariohay, September 2017)

Main results

The following papers (I-III) focus on the negative impacts of wild animals on humans and on local residents' views of wildlife conservation in the area whereas Papers IV and V focus on negative impacts of human activities on wild animals.

Paper I: Negative impacts of problem wild animals on humans

Livestock depredation

Of the 240 respondents studied only 32.1% (n = 240) owned livestock and more than half (59.7%, n = 77) of those who owned livestock had experienced livestock depredation. Livestock most frequently killed were cattle (58.8%), followed by goats (25.6%), sheep (11.6%), and donkeys (7%). A total of 83 livestock were recorded to have been killed, including 39 cattle, 26 goats, 14 sheep, and 4 donkeys, resulting in respective economic losses of US $9750, US $780, US $420 and US $240 per year to households reporting depredation incidences. Total economic losses caused by livestock depredation in the study area are valued at roughly US $11,190.00, representing an average of US $243.26 per year per household. Throughout the study, in the local markets cattle were sold at an average price of US $250/animal, goats and sheep were sold at an average price of US $30/animal and donkeys were sold at an average price of US $60/animal. The majority 53.5% (n = 46) of depredation incidences were caused by spotted hyenas, followed by lions (25.6%) and leopards (20.9%). All lion attacks were on cattle (100%, N = 16), while spotted hyenas mostly attacked cattle (44.4%, N = 18), goats (38.9%, N = 18) and donkeys (16.7%, N = 18); and leopards attacked goats (44.4%, N = 9) and sheep (55.6%, N = 9) ($\chi^2 = 40.68$, df = 6, $P < 0.001$). A binary logistic regression was conducted using livestock loss (yes/no) as a dependent variable and the distance to a PA, gender, marital status, age, residency (immigrant or not), education level, the number of dependants and the number of killed livestock animals as independent factors. Distance from a PA was found to be the only statistically significant factor, explaining 53.1% of the variation in livestock depredation incidences (Wald = 9.47, df = 1, P = 0.002). The other independent variables were not found to be significant.

Crop damage

Most respondents (92.5%, n = 240) in the area were peasant farmers. Nearly half of the farmers (45.9%, n = 222) had experienced crop damage due to problem wild animals. Crops cultivated included maize (60.4%) and all other crops combined (39.6%). Maize crops accounted for 97% of crops lost to problem animals whereby farmers estimated average losses of 417 kg of maize, equivalent to US $125 per year per household, while other crops combined accounted for an average loss of 13 kg per year per household, equivalent to US $16.90 per year per household. The African elephant had caused most of the crop damage, causing over 96% of crop losses, while the remaining damage had been caused by warthogs (2.9%) and greater kudu (1%). We used a binary logistic regression analysis with crop damage incidences used as the dependent variable and using the same independent variables as those employed for livestock depredation. The 33.1% variation in crop damage observed is best explained by the distance from a PA (Wald = 36.01, df = 1, $P \leq 0.001$) and gender (Wald = 11.17, df = 1, $P \leq 0.001$). Other variables including education, tribe, age, marital status, and crop type were not found to be important in explaining variation in crop damage.

Paper II: Distribution patterns of crop damage caused by the African elephant

Crop damage incidents varied statistically significantly with distance between a farm and a reserve boundary (χ^2 = 53.96, df = 2, $P < 0.001$). Most of the respondents residing within a distance of < 1 km (81.0%, n = 79) reported crop damage caused by African elephants as a major problem, followed by respondents with farms at a distance of 1-5 km (65.9%, n = 41), while very few respondents with farms at a distance of > 5 km reported this as a major problem (20.0%, n = 90). The estimated number of losses attributable to elephants is equivalent to 437.5 hectares of crop farms or to an average of 4.0 (±SD 4.6) ha per affected household per year in the study area. Estimated losses varied with farm distance to the RKMGR, as those positioned less than 1 km away reported a higher average crop loss, followed by those of the distance 1-5 km category. Farms positioned > 5 km away presented the lowest estimates of crop damage.

We observed a statistically significant difference between seasons of the year and reported crop damage (yes/no). Most respondents reported the first half of the year (61.7%, n = 141) as the main season for crop damage caused by African elephants, followed by the second half of the year (35.8%, n = 272 53), while a few reported incurring damage throughout the year (18.8%, n = 16) (χ^2 = 22.79, df = 2, $P < 0.001$). Greater average losses were incurred in the first half of the year (4.6 ±SD 4.8 ha) with few losses occurring in the second half of the year (1.1 ±SD 1.9 ha) and with very few average losses occurring throughout the year (0.7 ±SD 0.4 ha) (χ^2 = 4.85, df = 2, $P < 0.010$).

Mitigation measures used by farmers included noise making, lighting fires at night and launching stones with hand-held catapults. Other methods reported include employing someone to guard crop fields; planting unfavourable crops, such as chilli (*Capsicum* spp.), around farms; and soliciting help from wildlife rangers who perform disturbance shooting, place honeybee (*Apis mellifera*) beehives around crop fields and smear dirty oils on ropes with pieces of cloth around farm fields.

Paper III: Awareness of and attitudes towards wildlife conservation in the area.

Most of the respondents (89%, n = 240) were aware of wildlife conservation activities in their area. A binary logistic regression analysis was conducted with awareness/no awareness used as a dependent variable and with age, gender, education level, immigration status, and the distance from PA boundaries used as predictors. The most important independent variables that explained 15% of the variance in awareness of wildlife conservation are the following: education level (Wald = 8.51, $p = 0.004$), age (Wald = 7.12, $p = 0.008$), immigration status (Wald = 5.42, $p = 0.020$), and distance to a PA (Wald = 6.74, $p = 0.009$); gender was not found to be a significant factor.

Residents with formal education had positive views of wildlife ($\beta = 1.79$, Wald = 53.79, $P < 0.001$). Distances to PAs significantly influenced attitudes, as those who lived far from a PA expressed positive views of wildlife ($\beta = 0.66$, Wald = 24.31, $P < 0.001$). Those not employed held more negative views ($\beta = -1.99$, Wald = 5.18, $P = 0.023$) of wildlife than those who depended on maintaining livestock or farming or who were employed as their source of income. The immigration status of the respondents was the last factor to shape attitudes towards wildlife, as Indigenous populations held more positive views ($\beta = 0.90$, Wald = 6.93, $P < 0.008$). Crop damage and livestock depredation negatively influenced attitudes, as those who had incurred crop losses held negative attitudes ($\beta = -1.25$, Wald = 14.30, $P < 0.001$) and those who had incurred livestock losses due to wild animals also held negative attitudes ($\beta = -1.21$, Wald = 16.25, $P < 0.001$).

Paper IV: Effect of human activities (trophy hunting) on animal behaviour

Impala group sizes present a greater mean value in RNP than in the RGR. Management regimes of a protected area influence impala group sizes and protected area status ($t = 5.48$, $P < 0.001$) as the only significant contributor to the observed 11.3% variation, while the year (t

= 1.89, P = 0.060) and habitat type (t = -0.74, P = 0.459) do not add significance in explaining the variation in impala group size. Similarly, greater kudu aggregate in larger mean groups in RNP than in the RGR. Protected area status (t = 4.42, P < 0.001) was found to be significant contributor to the observed 18.4% variation in greater kudu group size. Impala and greater kudu calf recruitment rates differed significantly across protected areas with a much lower mean number of calves per adult females observed in the RGR than in RNP. Both impala and greater kudu were found to be more vigilant and to present large flight initiation distance as antipredator behaviours in the RGR than RNP.

Paper V: Factors that drive individuals to commit conservation crimes and their impacts on wildlife conservation in the area.

Multiple drivers behind each type of conservation crime were found. First, bushmeat poaching was mostly done by people who did not own land (coefficient estimate = 2.05, Z = 2.78, P = 0.005) and by immigrants (coefficient estimate = 2.31, Z = 3.09, P = 0.002), while older people (coefficient estimate = -0.56, Z = -2.09, P = 0.036) and the employed (coefficient estimate = -4.51, Z = -5.72, P < 0.001) were less likely to do so. Second, the arrested timber loggers were unemployed, as employed people are less likely to be timber loggers (coefficient estimate = -4.35, Z = -7.40, P < 0.001), and they did not own land (coefficient estimate = 1.42, Z = 3.84, P < 0.001) and/or livestock (coefficient estimate = 1.73, Z = 4.18, P < 0.001) and were young immigrants (coefficient estimate = 1.96, Z = 4.97, P < 0.001). Third, elephant poachers did not own land (coefficient estimate = 2.76, Z = 2.18, P = 0.029) and were unemployed as people who are employed are less likely to be elephant poachers (coefficient estimate = -5.06, Z = 0.96, P < 0.001). Fourth, livestock grazing in the RKM GRs was mostly done by immigrants (coefficient estimate = 2.42, Z = 3.42, P < 0.001) who owned livestock but who did not own land (coefficient estimate = 1.99, Z = 3.57, P < 0.001). Finally, illegal mining was mainly done by the unemployed, as employed people are less likely to engage in this activity (coefficient estimate = -3.97, Z = -3.03, P = 0.002), and these individuals were immigrants (coefficient estimate = 4.27, Z = 3.24, P < 0.001) who did not own livestock (coefficient estimate = 2.78, Z = 2.09, P < 0.036).

General discussion

Crop and livestock losses due to problem wild animals

In Paper I we quantified economic losses to farmer and livestock owners caused by wildlife in terms of crop damage and the depredation of livestock. Depredation incidents were influenced by the distances between households and reserve boundaries, as livestock owners who lived in the closest villages experienced more incidents of livestock depredation than those who lived in distant villages. The influence of distance on livestock depredation in villages close to PAs has also been reported for the western Serengeti wildlife corridor (Nyahongo, 2010; Mwakatobe et al, 2013). More depredation incidents were reported by male respondents than by females, more immigrant tribes reported depredation than indigenous tribes, and respondents with no education reported more depredation incidents than those with a formal education (Paper I). The frequency of depredation reports was found to be correlated with livestock ownership in the area, in which most livestock owners belonged to immigrant tribes and were older in age. Depredated livestock included cattle, goats, sheep, and donkeys. Cattle were the most heavily depredated livestock, representing more than 55% of cases. The spotted hyena caused most incidents of depredation, being responsible for more than 65% of cases. For the western Serengeti, Mwakatobe et al (2013) and Nyahongo (2010) reported similar trends, where spotted hyena was found to be the large carnivore most responsible for livestock depredation, possibly because spotted hyena can hide in small areas of community land and attack livestock at night and can travel large distances of approximately 70 kilometres in a single night.

The results of Paper I show that more than 45% of the crop farmers had incurred crop losses to different types of wildlife. The African elephant was ranked the most responsible for crop damages with others including the warthog and greater kudu. Maize was identified as the most frequently damaged crop with an estimated average loss of 417 kg per year per household. Types of crops damaged included maize, sunflower, groundnut, bean, sesame , and tobacco crops, possibly because maize is the main food crop grown in the area and because its high sugar content attracts wild animal species, such as the African elephant.

Spatial and seasonal distribution of crop damage caused by African elephants

Distribution patterns of crop damage caused by the African elephant are important in devising effective mitigation measures to reduce crop losses. In Paper II we analysed the seasonal and spatial distribution of crop damage incidences, and it was revealed that most crop damage incidents had occurred in the first season of the year (January-June). This time of the year represents the rain season when crop cultivation takes place, thus attracting African elephants. Rainfall promotes crop cultivation and at mature stages, crops such as maize attract elephants (Barnes et al., 2007; Gubbi, 2012). Mean crop damage losses (in ha) and the frequency of reported crop damage were found to be the highest for farms close to the RKMGR. Distances to reserve boundaries affected the crop farms most, as farms close to the RKMGR experienced more frequent crop damage associated with foraging elephants than farms located farther away. Other studies show that farmers residing close to reserves experience more crop damage than those positioned farther away (Sarker et al, 2015; Blair and Meredith, 2017). Crop damage caused by elephants was thus found to be associated with farm distances to game reserve boundaries, and farms positioned at a distance of < 1 km recorded greater mean losses.

Awareness of and attitudes towards wildlife conservation in the area

Levels of awareness and attitudes of local residents are central to the success of local wildlife conservation efforts (Paper III). Most residents (89%) in the study area reported being aware of wildlife conservation activities. Awareness was found to be higher for the middle aged group, among those with a formal education and for those living close to PA boundaries than older groups, those with no education and those living farther away from PA boundaries. Similarly, Carter et al (2014) found age to influence respondent awareness and attitudes in Nepal’s Chitwan National Park, and Lyamuya et al (2016) found that awareness of wild animal species varies with education level and age among those living around Serengeti National Park. Bitanyi et al (2012) also reported Indigenous tribes residing close to PAs to exhibit a stronger awareness of wildlife. Factors that influenced attitudes toward wildlife included age, education, distances to PAs, the depredation of livestock by large carnivores and previous crop farm damage caused by African elephants or other wild animals (Paper III). Positive attitudes decreased with the age, as people above 55 years of age were less positive, and this was found to be correlated with livestock and land ownership, as many older residents owned livestock and land in the area. Livestock and crop farmers who had encountered incidents of livestock depredation by carnivores or crop farm damage caused by wild animals held negative attitudes towards wildlife conservation in the area. Similarly, Shibia (2010) reported that people above 54 years of age owned more livestock and did not support wildlife conservation in their area, and Mir et al (2015) and Lyamuya et al (2016) found that respondents with a formal education held more positive views of wildlife conservation.

Impacts of human activities on wildlife

Different forms of anthropogenic disturbances negatively affect wild animal behaviours. In Paper IV, the effects of trophy hunting on impala and greater kudu behaviours were examined. The hunted population in the Rungwa Game Reserve (RGR) was characterized by smaller group sizes, low calf recruitment levels, more vigilance, and larger flight initiation distances (FIDs) than the population in the non-hunting area of Ruaha National Park (RNP). Selective removal through trophy hunting likely affects mammals' fitness by lowering the recruitment rate via either higher calf mortality or lower fecundity, when the proportion of males falls below a tolerable threshold in the hunted population. On the other hand, trophy hunting disturbances limit feeding opportunities and increase stress levels (Benhaiem et al, 2008). Such disturbances can compromise body conditions that result in reduced breeding efforts, lowering calf survival (Milner et al, 2007). The majority of impala and greater kudu groups were found to be more vigilant and to flee longer distances in the RGR. Animals were more relaxed in RNP, for which we found feeding behaviours, followed by resting to be the dominant behaviours in impala groups. By contrast, the dominant behaviours observed in the RGR were running, followed by feeding, most likely due to differences in the disturbance levels, which caused the studied RGR animals to devote less time to feeding in a highly disturbed area. A French study found that roe deer (*Capreolus capreolus*) trade off risk avoidance for food availability and spend more time being vigilant during the hunting season (Benhaiem et al, 2008). The observed antipredator behaviours of RGR impala and greater kudu may have been shaped by game hunting, as we observed larger mean FID values in the RGR than in RNP. Hunninck et al (2017) found that elephants are more stressed outside of national parks than those within the Etosha National Park in Namibia, and Holmern et al (2016) found the same difference between elephants located within and outside of Serengeti National Park.

Humans also cause disturbances to wild animals by hunting illegally to obtain bushmeat, ivory, skin, hide, and so on. Other disturbances result from grazing livestock in the PA, mining and timber extraction. In Paper V we examined the factors that drive people to commit these conservation criminalities in the Rungwa-Kizigo-Muhesi Game Reserves (RKMGRs) based on the socio-demographic characteristics of arrested suspects. The illegal harvesting of wildlife and forest resources from RKM GRs is linked to unemployment and a lack of asset ownership (livestock and land). Like businessmen keeping money in a bank, livestock owners regard their livestock as banks on hooves. Participation in wildlife crimes was influenced by a lack of livestock and land ownership, as most illegal mining, timber logging, elephant poaching and bushmeat poaching were practiced by those who did not own land or livestock. A similar trend was observed in villages surrounding Serengeti National Park, in which those who participated in bushmeat poaching were not livestock owners (Loibooki et al, 2002). Employment status was found to be another main driver of those involved in illegal bushmeat hunting, timber logging, elephant poaching, and illegal mining in the RKM GRs. Similar findings have been reported by researchers such as Knappa et al (2017) and Rogana et al (2017), who show that a lack of income constitutes one of the main driving forces behind poaching. Therefore, our finding that most arrested suspects were unemployed might indicate that residents of the study area practice the illegal harvesting of natural resources as a means to cope with unemployment. The link between conservation crimes and lacking employment has been reported in other parts of Tanzania (Loibooki et al, 2002; Holmern, 2010; Kideghesho, 2015). Most people committing conservation crimes are between 18 and 36 years of age. Loibooki et al (2002) also reported that males of 15-35 years of age are more likely to be involved in hunting for bushmeat in the western Serengeti. Age was found to be an important driver of bushmeat hunting and timber extraction whereby older individuals were less likely to be involved in these illegal conservation crimes, which might be the case because such activities demand energy and are thus riskier for older people to engage in. Thus, young people are more likely to be involved in conservation criminality as also observed in Nigeria (Friant et al, 2015).

Mitigation measures

Many livestock owners depend on the use of dogs to guard livestock whereas others employ night watchmen to guard their livestock premises as reported by Lyamuya et al (2016). Crop farmers reported applying traditional methods using simple and affordable technologies such as noise making techniques (hitting objects, such as tins and drums; yelling; and sometimes whistling) to direct problem elephants away from farm fields (Khumalo and Yung, 2015). Other methods cited included the use of disturbance shooting, planting chilli crops and introducing African honeybees. Disturbance shooting and the destruction of problem African elephants have been used by wildlife authorities close to protected areas in Kenya to deter elephants from farm fields (Hoare, 2015). Chilli peppers are recognized as cash crops of high economic value that can also serve as mitigation measures to prevent elephants from damaging crop farms and as an alternative crop for communities that share land with crop-damaging animals (Khumalo and Yung, 2015). Noise from African honeybees is known to deter African elephants, which upon hearing the sound of disturbed honeybees make alarm calls that cause all members in the group run from the sound (King et al, 2010). While beehive fences are the most effective, their use may be limited by a lack of funds. Additionally, animals overtime learn when bees are inactive, such as during nighttime hours.

Conclusion and recommendations

Negative impacts of wildlife on human beings are prevalent in the study area, while human activities such as hunting influence wild animal populations and behaviour. Livestock owners and crop farmers residing close to PA boundaries were found to be the most heavily affected by wild animals. Losses incurred due to crop damage and livestock depredation had significant economic impacts, as most residents in the area were unemployed and thus mostly depended on livestock and crops to secure daily household needs. Generally speaking, the majority of people living in the study area hold positive views of wildlife conservation. However, those who had incurred crop or livestock losses due to wild animals exhibited negative attitudes towards wildlife conservation in the area, and thus, measures to mitigate damage caused by wild animals must receive public support. Human activities such as hunting have negative effects on animal behaviour whereby important behaviours such as mating can be compromised in favour of anti-predator behaviour (vigilance and running), ultimately resulting in low calf recruitment levels which in the future can lead to animal population decline in the hunted population or to the formation of sinks while Ruaha NP supplies source populations. Being unemployed and lacking assets (livestock and land) were found to be the most prevalent drivers behind bushmeat poaching, African elephant poaching for ivory, timber extraction, and illegal mining in PAs whereas a lack of grazing land in villages was found to motivate livestock owners to graze livestock within PAs.

Based on our findings that communities surrounding the RRE have faced property damage caused by wild animals and that human activities in the area have also negatively affected wild behaviour, the following on the conservation and management of wildlife in the RRE are presented.

i. Conservation education must be given on control measures for preventing problem wild animals, such as elephants, from destroying crop farms to reduce economic losses incurred. The introduction of conservation education to primary schools and encouraging parents to bring their children to these schools is critical. Pupils receiving conservation education at a young age may become ambassadors of wildlife conservation in their home villages and introduce such concepts to their parents.

ii. We recommend that farmers residing around the RRE avoid growing crops close to protected areas, as incidences of crop raiding by wild animals and livestock depredation increase close to protected area boundaries.

iii. The construction of strong enclosures ("**bomas**") and the use of herding practices is recommended to reduce livestock depredation levels. For example, Bauer et al (2010) found that by improving enclosures and changing herding methods (e.g., herding livestock with more than one herder or constructing strong bomas for livestock to use at night), cases of livestock depredation can be decreased.

iv. Farmers who have lost crops to elephants must be compensated more than what is currently offered to affected communities.

v. The results of Paper IV indicate that in hunted populations, animals show clear signs of disturbance, as they are found in smaller groups, present lower calf recruitment rates and are more nervous than conspecifics in the absence of trophy hunting in RNP. This may indicate that the RGR is dependent on RNP for recruitment or that we may expect a dramatic decline in hunted populations in RGR. However, this conclusion requires further testing and long-term monitoring. Studies like ours may prove useful in assessing how activities associated with different types of protected areas may influence animal stress levels, behaviours and key demographic parameters. Furthermore, such effects serve as important considerations for managers setting hunting quotas.

vi. Finally, raising employment levels in the area through the delivery of micro-credit loans and providing entrepreneurship education to youth will help indirectly reduce participation in bushmeat poaching, timber extraction and other conservation criminalities. Raising employment levels should be done with care to ensure that benefits accrued from alternative income generation activities are more substantial than what could be earned from illegal activities. People in most cases weigh benefits against costs, those who are employed are less likely engage in illegal activities.

Future research prospects

The current rate of human population growth threatens the survival of wildlife due to habitat fragmentation, habitat loss and overutilization from increasing per capita demand. In the study area (the RRE) these forms of interactions are prevalent, and hence further research must be conducted in this area to explore more realities on effects of human activities on wildlife populations. The populations of hunted wild animals must be monitored to understand how habitat destruction and hunting activities affect calf recruitment and sex ratio in order to project future populations of the species in question and come up with appropriate management interventions. The RRE is a single continuous ecosystem that supports two main tourism activities (trophy hunting and ecotourism), thus allowing animals to travel from one side to another. The use of camera traps and GPS collaring may help identify specific areas used by wild animals as they migrate or disperse, in turn enabling wildlife managers to zone and dedicate their conservation efforts to such areas.

References

Allendorf, F.W., & Hard, J.J., 2009. Human-induced evolution caused by unnatural selection through harvest of wild animals. *Proc. Natl. Acad. Sci. U. S. A, 106*, 9987-9994. http://dx.doi.org/10.1073/pnas.0901069106

Averbeck, C., (2002). *Population ecology of impala (Aepyceros melampus) and community-based wildlife conservation in Uganda.* Technische Universität München. Retrieved from http://tumb1.biblio.tumuenchen.de/publ/diss/ww/2002/averbeck.html

Averbeck, C., Apio, A., Plath, M., & Wronski, T., 2009. Hunting differentially affects mixed-sex and bachelorherds in a gregarious ungulate, the impala (*Aepyceros melampus*). *Afr. J. Ecol, 48*, 255-264. http://dx.doi.org/10.1111/j.1365-2028.2009.01118.x

Balakrishnan, M., & Belay, G., 2017. Human–wildlife conflict and attitude of local people towards conservation of wildlife in Chebera Churchura National Park, Ethiopia AU - Megaze, Aberham. *Afr. Zool, 52*(1), 1-8. http://www.doi.org/10.1080/15627020.2016.1254063

Balme, G.A., Slotow, R., & Hunter, L.T.B., 2010. Edge effects and the impact of non-protected areas in carnivore conservation: leopards in the Phinda–Mkhuze Complex, South Africa. *Anim. conserv, 13*(3), 315-323. http://www.doi.org/10.1111/j.1469-1795.2009.00342.x

Bateman, P.W., & Fleming, P.A., 2014. Living on the edge: effects of body size, group density and microhabitat selection on escape behaviour of southern leopard frogs Lithobates sphenocephalus. *Curr. Zool, 60*(6), 712-718. http://dx.doi.org/10.1093/czoolo/60.6.712

Bauer, H., de Iongh, H., & Sogbohossou, E. 2010. Assessment and mitigation of human-lion conflict in West and Central Africa *Mammalia* (Vol. 74, pp. 363).

Benhaiem, S., Delon, M., Lourtet, B., Cargnelutti, B., Aulagnier, S., Hewison, A.J.M., . . . Verheyden, H., 2008. Hunting increases vigilance levels in roe deer and modifies feeding site selection. *Anim. Behav, 76*(3), 611-618. http://dx.doi.org/10.1016/j.anbehav.2008.03.012

Bitanyi, S., Nesje, M., Kusiluka, L.J.M., Chenyambuga, S.W., & Kaltenborn, B.P., 2012. Awareness and perceptions of local people about wildlife hunting in western Serengeti communities. *Trop. Conserv. Sci, 5*(2), 208-224. http://www.doi.org/10.1177/194008291200500209

Blackwell, B.F., DeVault, T.L., Fernández-Juricic, E., Gese, E.M., Gilbert-Norton, L., & Breck, S.W., 2016. No single solution: application of behavioural principles in mitigating human–wildlife conflict. *Animal Behaviour, 120*, 245-254. https://doi.org/10.1016/j.anbehav.2016.07.013

Blair, A., & Meredith, T., 2017. Community perception of the real impacts of human-wildlife conflict in Laikipia, Kenya:Capturing the relative significance of high-frequency, low-severity events. *Oryx, 2*, 1-11. http://dx.doi.org/10.1017/s0030605316001216

Buxton, R.T., Lendrum, P.E., Crooks, K.R., & Wittemyer, G., 2018. Pairing camera traps and acoustic recorders to monitor the ecological impact of human disturbance. *Glob. Ecol. Conserv, 16*, e00493. https://doi.org/10.1016/j.gecco.2018.e00493

Carter, N.H., Riley, S.J., Shortridge, A., Shrestha, B.K., & Liu, J.G., 2014. Spatial assessment of attitudes toward tigers in Nepal. *Ambio, 43*(2), 125-137. http://www.doi.org/10.1007/s13280-013-0421-7

de Garine-Wichatitsky, M., Fritz, H., Gordon, I.J., & Illius, A.W., 2004. Bush selection along foraging pathways by sympatric impala and greater kudu. *Oecologia, 141*(1), 66-75. http://dx.doi.org/10.1007/s00442-004-1630-3

Dejene, S.W., Heitkönig, I.M.A., Prins, H.H.T., Lemma, F.A., Mekonnen, D.A., Alemu, Z.E., . . . de Boer, W.F., 2017. Correction: Risk Factors for Bovine Tuberculosis (bTB) in Cattle in Ethiopia. *Plos One, 12*(4), e0176654-e0176654. http://www.doi.org/10.1371/journal.pone.0176654

Dickman, A.J., Hazzah, L., Carbone, C., & Durant, S.M., 2014. Carnivores, culture and 'contagious conflict': Multiple factors influence perceived problems with carnivores in Tanzania's Ruaha landscape. *Biol. Conserv, 178*, 19-27. https://doi.org/10.1016/j.biocon.2014.07.011

Festa-Bianchet, M., & Apollonio, M., 2003. Exploitative wildlife management as a selective pressure for life-history evolution of large mammals *Animal behavior and wildlife conservation* (pp. 191-207). Washington, Covelo, London: Island Press.

Friant, S., Paige, S., B, & Goldberg, T., L. 2015. Drivers of bushmeat hunting and perceptions of zoonoses in Nigerian hunting communities. *PLoS. Neglect. Trop. D, 9*(5), 1-16. https://doi.org/10.1371/journal.pntd.0003792

Gereta, E.J., & Røskaft, E., 2010. *Conservation of Natural Resources: Some African & Asian Examples*: Tapir academic press.

Green, D.S., Johnson-Ulrich, L., Couraud, H.E., & Holekamp, K.E., 2018. Anthropogenic disturbance induces opposing population trends in spotted hyenas and African lions. *Biodivers. Conserv, 27*(4), 871-889. http://www.doi.org/10.1007/s10531-017-1469-7

Hariohay, K.M., & Røskaft, E., 2015. Wildlife induced damage to crops and livestock loss and how they affect human attitudes in the kwakuchinja wildlife corridor in northern Tanzania. *Environ. Nat. Resour. J, 5*(3). http://dx.doi.org/10.5539/enrr.v5n3pxx

Hazzah, L., Mulder, M.B., & Frank, L., 2009. Lions and warriors: Social factors underlying declining African lion populations and the effect of incentive-based management in Kenya. *Biol. Cons, 142*(11), 2428-2437. https://doi.org/10.1016/j.biocon.2009.06.006

Heffelfinger, J.R., 2018. Inefficiency of evolutionarily relevant selection in ungulate trophy hunting. *J. Wildlife Manage, 82*(1), 57-66. http://www.doi.org/10.1002/jwmg.21337

Hoare, R., 2015. Lessons from 20 years of human-elephant conflict mitigation in Africa: Perspective on human-wildlife conflict. *Hum Dimens Wildl, 20*(4), 289-295. http://dx.doi.org/10.1080/10871209.2015.1005855

Hoffmann, M., 2016. IUCN SSC Antelope Specialist Group: Assessment of *Tragelaphus strepsiceros*, greater kudu. Retrieved 20th December, 2017 from http://www.iucnredlist.org

Holmern, T., 2010. Bushmeat hunting in Western Serengeti: Implications for community-based conservation. In Gereta, E. & Røskaft, E. (Eds.), *Conservation of natural* *reources; Some African & Asian examples* (pp. 211-236). Trondheim: Tapir academic press.

Holmern, T., Nyahongo, J.W., & Røskaft, E., 2007. Livestock loss caused by predators outside the Serengeti National Park, Tanzania. *Biol. Cons, 135*(4), 534-542. http://www.doi.org/10.1016/j.biocon.2006.10.049

Holmern, T., Setsaas, T.H., Melis, C., Tufto, J., & Røskaft, E., 2016. Effects of experimental human approaches on escape behavior in Thomson's gazelle (Eudorcas thomsonii). *Behav. Ecol, 27*(5), 1432-1440. http://dx.doi.org/10.1093/beheco/arw052

Hunninck, L., Ringstad, I.H., Jackson, C.R., May, R., Fossøy, F., Uiseb, K., . . . Røskaft, E., 2017. Being stressed outside the park—conservation of African elephants (Loxodonta africana) in Namibia. *Conserv. Physiol, 5*(2017), 11. http://dx.doi.org/10.1093/conphys/cox067

Johnson, M.F., Karanth, K.K., & Weinthal, E., 2018. Compensation as a Policy for Mitigating Human-wildlife Conflict Around Four Protected Areas in Rajasthan, India. *Conserv. Soc., 16*(3), 305-319. http://www.doi.org/10.4103/cs.cs_17_1

Karanth, K.K., & Kudalkar, S., 2017. History, Location, and Species Matter: Insights for Human–Wildlife Conflict Mitigation From India. *Hum Dimens Wildl, 22*(4), 331-346. http://www.doi.org/10.1080/10871209.2017.1334106

Khumalo, K.E., & Yung, L.A., 2015. Women, Human-Wildlife Conflict, and CBNRM: Hidden impacts and vulnerabilities in Kwandu Conservancy, Namibia. *Conserv. Soc., 13*(3), 232-243. http://dx.doi.org/10.4103/0972-4923.170395

Kideghesho, J.R., 2015. Realities on deforestation in Tanzania: trends, drivers, implications and the way forward. *Precious Forests-Precious Earth, 2017*(21.12). http://dx.doi.org/10.5772/61002

Kideghesho, J.R., 2016. Reversing the trend of wildlife crime in Tanzania: challenges and opportunities *Biodivers. Conserv, 25*(3), 427-449. http://dx.doi.org/10.1177/194008291600900120

Kideghesho, J.R., Røskaft, E., & Kaltenborn, B.P., 2007. Factors influencing conservation attitudes of local people in Western Serengeti, Tanzania. *Biodiversity and Conservation, 16*(7), 2213-2230. http://www.doi.org/10,1007/s10531-006-9132-8

Kie, J.G., 1999. Optimal foraging and risk of predation: Effects on behavior and social structure in ungulates *J. Mammal, 80*(4), 1114-1129. http://dx.doi.org/10.2307/1383163

Kiffner, C., Peters, L., Stroming, A., & Kioko, J., 2015. Bushmeat Consumption in the Tarangire-Manyara Ecosystem, Tanzania. *Trop. Conserv. Sci, 8*(2), 318-332. http://dx.doi.org/10.1177/194008291500800204

King, L.E., Soltis, J., Douglas-Hamilton, I., Savage, A., & Vollrath, F., 2010. Bee threat elicits alarm call in African elephants. *Plos One, 5*(4). http://dx.doi.org/10.1371/journal.pone.0010346

Knapp, E.J., 2012. Why poaching pays: a summary of risks and benefits illegal hunters face in Western Serengeti, Tanzania. *Trop. Conserv. Sci, 5*(4), 434-445. http://dx.doi.org/10.1177/194008291200500403

Knappa, E.J., Peaceb, N., & Bechtelb, L., 2017. Poachers and poverty: Assessing objective and subjective measures of poverty among illegal hunters outside Ruaha National Park, Tanzania. *Conserv. Soc, 15*(1), 24-32. http://dx.doi.org/10.4103/0972-4923.201393

Kutal, M., Váňa, M., Suchomel, J., Chapron, G., & José Vicente, L.-B., 2016. Trans-Boundary Edge Effects in the Western Carpathians: The Influence of Hunting on Large Carnivore Occupancy. *Plos One, 11*(12). http://dx.doi.org/10.1371/journal.pone.0168292

Kyando, M., Ikanda, D., & Røskaft, E., 2017. Hotspot elephant-poaching areas in the Eastern Selous Game Reserve, Tanzania. *Afr. J. Ecol, 55*(3), 365-371. http://dx.doi.org/10.1111/aje.12363

Lobora, A.L., Nahonyo, C.L., Munishi, L.K., Caro, T., Foley, C., & Beale, C.M., 2017. Modelling habitat conversion in miombo woodlands: insights from Tanzania. *Journal* *of Land Use Science, 12*(5), 391-403. http://www.doi.org/10.1080/1747423X.2017.1331271

Loibooki, M., Hofer, H., Campbell, K.L.I., & East, M.L., 2002. Bushmeat hunting by communities adjacent to the Serengeti National Park, Tanzania: the importance of livestock ownership and alternative sources of protein and income. *Environ. Conserv, 29*(3), 391-398. http://dx.doi.org/10.1017/S0376892902000279

Loveridge, A.J., Searle, A.W., Murindagomo, F., & MacDonald, D.W., 2007. The impact of sport-hunting on the population dynamics of an African lion population in a protected area. *Biol. Cons.* Retrieved 11th January, 2018 from http://www.sciencedirect.com/science/journal/00063207

Lunde, E.T., Bech, C., Fyumagwa, R.D., Jackson, C., & Røskaft, E., 2016. Assessing the effect of roads on impala (Aepyceros melampus) stress levels using faecal glucocorticoid metabolites. *Afr. J. Ecol, 54*(4), 434-441. http://dx.doi.org/10.1111/aje.12302

Lyamuya, R.D., Masenga, E.H., Mbise, F., Fyumagwa, R.D., Mwita, M., & Røskaft, E., 2014. Human-carnivore conflict over livestock in the eastern part of the Serengeti ecosystem, with a particular focus on the African wild dog *Lycaon pictus*. *Oryx, 48*(3), 378-384. http://www.doi.org/10.1017/S0030605312001706

Lyamuya, R.D., Straube, A.C.S., Guttu, A.M., Masenga, E.H., Mbise, F.P., Fyumagwa, R.D., . . . Røskaft, E., 2016. Can Enhanced Awareness Change Local School Children's Knowledge of Carnivores in Northern Tanzania? *Hum. Dimens. Wildl, 21*(5), 403-413. http://www.doi.org/10.1080/10871209.2016.1180566

Mangesho, P.E., Neselle, M.O., Karimuribo, E.D., Mlangwa, J.E., Queenan, K., Mboera, L.E.G., . . . Rweyemamu, M., 2017. Exploring local knowledge and perceptions on zoonoses among pastoralists in northern and eastern Tanzania. *PLoS. Negl. Trop. Dis, 11*(2), e0005345. http://www.doi.org/10.1371/journal.pntd.0005345

Marshal, J.P., Grange, S., & Marneweck, D., 2012. Seasonal variation in body condition of impala at Manyeleti Game Reserve, South Africa. *S. Afr. j. wildl. res, 42*(2), 128-137. http://dx.doi.org/10.3957/056.042.0212

Martin, A., & Caro, T., 2013. Illegal hunting in the Katavi-Rukwa ecosystem. *Afr. J. Ecol, 51*(1), 172-175. http://dx.doi.org/10.1111/aje.12000

Marttila, O., 2011. *The great savanna, the national parks of Tanzania and other key conservation areas*. Rauha, Finland: Auris Publishers.

Masenga, E.H., Lyamuya, R.D., Nyaki, A., Kuya, S., Jaco, A., Kohi, E., . . . Røskaft, E., 2013. Strychnine poisoning in African wild dogs (*Lycaon pictus*) in the Loliondo game controlled area, Tanzania. *Int. J. Biodivers. Conserv, 5*(6), 367-370. http://www.doi.org/10.5897/IJBC12.100

McManus, J.S., Dickman, A.J., Gaynor, D., Smuts, B.H., & Macdonald, D.W., 2015. Dead or alive? Comparing costs and benefits of lethal and non-lethal human–wildlife conflict mitigation on livestock farms. *Oryx, 49*(4), 687-695. http://www.doi.org/10.1017/S0030605313001610

Mfunda, I.M., & Røskaft, E., 2010. Bushmeat hunting in Serengeti, Tanzania: An important economic activity to local people. *Int. J. Biodivers. Conserv, 2*(9), 263-272. http://dx.doi.org/10.5897/IJBC2010.16541

Mgawe, P., Mulder, M.B., Caro, T., Martin, A., & Kiffner, C., 2012. Factors affecting bushmeat consumption in the Katavi-Rukwa ecosystem of Tanzania. *Trop. Conserv. Sci, 5*(4), 446-462. http://dx.doi.org/10.1177/194008291200500404

Milner, J.M., Nilsen, E.B., & Andreassen, H.P., 2007. Demographic side effects of selective hunting in ungulates and carnivores. *Conserv. Biol, 21*(1), 36-47. http://dx.doi.org/10.1111/j.1523-1739.2006.00591.x

Mir, Z.R., Noor, A., Habib, B., & Veeraswami, G.G., 2015. Attitudes of local people toward wildlife conservation: A case study from the Kashmir Valley. *Mt. Res. Dev, 35*(4), 392-400. http://www.doi.org/10.1659/MRD-JOURNAL-D-15-00030.1

MNRT. 2011. *Rungwa-Kizigo-Muhesi Game Reserves general management plan*. Dar es Salaam: Government printers.

Mohammed, Y.S., Bashir, N., & Mustafa, M.W., 2015. Overuse of wood-based bioenergy in selected sub-Saharan Africa countries: review of unconstructive challenges and suggestions. *J Clean Prod, 96*, 501-519. https://doi.org/10.1016/j.jclepro.2014.04.014

Mwakatobe, A., Nyahongo, J.W., & Røskaft, E., 2013. Livestock depredation by carnivores in the Serengeti Ecosystem, Tanzania. *Environ. Nat. Resour. J, 3*(4), 46-57. http://www.doi.org/10.5539/enrr.v3n4p

Nahonyo, C.L., 2005. Assessment of anti-poaching effort in Ruaha national park, Tanzania. *Tanz. J. Sci, 31*(2), 13-22. http://dx.doi.org/10.4314tjs.v31i2.18416

Nattrass, N., & Conradie, B., 2018. Predators, livestock losses and poison in the South African Karoo. *J Clean Prod, 194*, 777-785. https://doi.org/10.1016/j.jclepro.2018.05.169

Ndibalema, V.G., & Songorwa, A.N., 2007. Illegal meat hunting in Serengeti: dynamics in consumption and preferences. *Afr. J. Ecol, 46*(3), 311-319. http://dx.doi.org/10.1177/194008291100400407

Nielsen, M.R., 2006. Importance, cause and effect of bushmeat hunting in the Udzungwa mountains, Tanzania: Implications for community-based wildlife management. *Biol. Cons, 128*(4), 509-516. http://dx.doi.org/10.1016/j.biocon.2005.10.017

Nielsen, M.R., Jacobsen, J.B., & Thorsen, B.J., 2013. Factors determining the choice of hunting and trading bushmeat in the Kilombero valley, Tanzania. *Conserv. Biol*. http://dx.doi.org/10.1111/cobi.12197

Nyahongo, J.W., 2010. Depredation of livestock by wild carnivores and illegal utilisation of natural resources by humans in western Serengeti, Tanzania. In Gereta, E. & Røskaft, E. (Eds.), *Conservation of natural resources; Some African & Asian examples* (pp. 255-269). Trondheim: Tapir academic press.

Ogada, D.L., 2014. The power of poison: pesticide poisoning of Africa's wildlife. *Ann. N.Y. Acad. Sci, 1322*(1), 1-20. http://www.doi.org/10.1111/nyas.12405

Ontiri, E.M., Odino, M., Kasanga, A., Kahumbu, P., Robinson, L.W., Currie, T., & Hodgson, D.J., 2019. Maasai pastoralists kill lions in retaliation for depredation of livestock by lions. *People and Nature, 1*(1), 59-69. http://www.doi.org/10.1002/pan3.10

Osipova, L., Okello, M.M., Njumbi, S.J., Ngene, S., Western, D., Hayward, M.W., & Balkenhol, N., 2018. Fencing solves human-wildlife conflict locally but shifts problems elsewhere: A case study using functional connectivity modelling of the African elephant. *J. Appl. Ecol, 55*(6), 2673-2684. http://www.doi.org/10.1111/1365-2664.13246

Parker, G., Osborn, F., Hoare, R., & Niskanen, L., 2007. Human-Elephant Conflict Mitigation. *A training course for Community-based Approaches in Africa. Participant's manual elephant pepper development Trust, Livingstone, Zambia*

PRB. 2018. 2018 World Population Data Sheet With Focus on Changing Age Structures. Retrieved 12th January, 2019 from https://www.prb.org/2018-world-population-data-sheet-with-focus-on-changing-age-structures/

R Core Team. 2016. R: A Language and Environment for Statistical Computing. Retrieved 10th September, 2018 from http://www.R-project.org/

Ravenelle, J., & Nyhus, P.J., 2017. Global patterns and trends in human–wildlife conflict compensation. *Cons.Biol, 31*(6), 1247-1256. http://www.doi.org/10.1111/cobi.12948

Rodríguez-Muñoz, R., del Valle, C.R., Bañuelos, M.J., & Mirol, P., 2015. Revealing the consequences of male-biased trophy hunting on the maintenance of genetic variation. *Conserv. Genet, 16*(6), 1375-1394. http://www.doi.org/10.1007/s10592-015-0747-8

Rogana, M.S., Lindsey, P.A., Tamblinge, C.J., Golabeka, K.A., Chaseh, M.J., Collinsd, K., & McNutta, J.W., 2017. Illegal bushmeat hunters compete with predators and threaten wild herbivore populations in a global tourism hotspot. *Biol. Cons, 210*(2017), 233-242. http://dx.doi.org/10.1016/j.biocon.2017.04.020

Sarker, A.H.M.R., Hossen, A., & Røskaft, E., 2015. Fatal elephant cncounters on humans in Bangladesh: Context and incidences. *Environ. Nat. Resour. J, 5*(2), 99-108. http://dx.doi.org/10.5539/enrr.v5n2pxx

Setsaas, T., Hunninck, L., Jackson, C.R., May, R., & Røskaft, E., 2018. The impacts of human disturbances on the behaviour and population structure of impala (Aepyceros melampus) in the Serengeti ecosystem, Tanzania. *Glob. Ecol. Conserv, 16*, e00467. https://doi.org/10.1016/j.gecco.2018.e00467

Shibia, M.G., 2010. Determinants of Attitudes and Perceptions on Resource Use and Management of Marsabit National Reserve, Kenya. *Hum. Ecol, 30*(1), 55-62. http://www.doi.org10.1080/09709274.2010.11906272

TAWIRI. 2015. Aerial census of large animals in the Ruaha-Rungwa ecosystem, dry season, Population status of African elephant. Ausha: Tanzania Wildlife Research Institute: Conservation Information and Monitoring Unit.

Tingvold, H.G., Fyumagwa, R., Baardsen, L.F., Rosenlund, H., Bech, C., & Røskaft, E., 2013. Determining adrenocortical activity as a measure of stress in African elephants (*Loxodonta africana*) in relation to human activities in Serengeti ecosystem. *Afr. J. Ecol, 51*, 580-589. http://dx.doi.org/10.1111/aje,12069

Tuomainen, U., & Candolin, U., 2010. Behavioural responses to human-induced environmental change. *Biol. Rev, 86*(3), 640-657. http://dx.doi.org/10.1111/j.1469-185X.2010.00164.x

URT. 2013. Population and housing census counts 2012. Retrieved 7th February, 2018 from http://www.nbs.go.tz/projections/dodoma_projections.pdf

URT. 2016. Annual agricultural sample survey. Retrieved 8th February, 2018 from http://www.nbs.go.tz/nbs/takwimu/Agriculture/2014_15_AASS_%20report_with_Livestock_module.pdf

Veldhuis, M.P., Ritchie, M.E., Ogutu, J.O., Morrison, T.A., Beale, C.M., Estes, A.B., . . . Olff, H., 2019. Cross-boundary human impacts compromise the Serengeti-Mara ecosystem. *Science, 363*(6434), 1424-1428. http://www.doi.org/10.1126/science.aav0564

Watson, F.G.R., Becker, M.S., Milanzi, J., & Nyirenda, M.J., 2015. Human encroachment into protected area networks in Zambia: implications for large carnivore conservation.

Reg. Environ. Change, 15(2), 415-429. http://www.doi.org/10.1007/s10113-014-0629-5

Whitman, K., Starfield, A.M., Quadling, H.S., & Packer, C., 2004. Sustainable trophy hunting of African lions. *Nature, 428*(6979), 175-178. http://dx.doi.org/10.1038/nature02395

Woodroffe, R., 2000. Predators and people: using human densities to interpret declines of large carnivores *Anim. conserv, 3*, 165-173. http://www.doi.org/10.1017/S136794300000086X

Woodroffe, R., 2011. Ranging behaviour of African wild dog packs in a human-dominated landscape. *J. Zool, 283*(2), 88-97. http://www.doi.org/10.1111/j.1469-7998.2010.00747.x

Wronski, T., 2002. Feeding ecology and foraging behaviour of impala (*Aepyceros melampus)* in lake Mburo National Park, Uganda. *Afr. J. Ecol, 40*(3), 205-211. http://dx.doi.org/10.1046/j.1365-2028.2002.00348.x

Paper I

academicJournals

Vol. 9(8), pp. 273-283, August 2017
DOI: 10.5897/IJBC2017.1116
Article Number: B7547DA65669
ISSN 2141-243X

http://www.academicjournals.org/IJBC

International Journal of Biodiversity and Conservation

Full Length Research Paper

Assessing crop and livestock losses along the Rungwa-Katavi Wildlife Corridor, South-Western Tanzania

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Received 23 May, 2017; Accepted 8 August, 2017

Humans and wildlife interact negatively, especially when humans transform natural wildlife habitats by establishing settlements and crop fields. Encroachment and habitat fragmentations caused by human activities decrease habitat size and quality for wildlife and reduce connectivity among protected areas. The major objective was to quantify economic loss inflicted by wildlife species to local communities in terms of crop and livestock losses. The influence of distance from the boundary of the protected area was also assessed. 240 copies of open and closed ended questionnaire were randomly administered in five selected villages in the Rungwa-Katavi Corridor between the Rungwa Game Reserve and Katavi National Park. The average loss to wildlife per household was 430 kg of crops, equivalent to US $126.23, as well as livestock, including cattle (0.9), goats (0.6), sheep (0.3), and donkeys (0.09) equivalent to US $260.23 per household per year. The reported incidences of crop damage and livestock attack varied among different age groups and between genders. The depredation and crop raiding incidences increased with proximity to the protected areas as contact with predators and vermin animals was higher closer to the protected areas. Implementing proper land use planning for livestock keepers, crop production and conservation land is recommended as an effective strategy to safeguard protected areas and minimize human-wildlife conflict.

Key words: Human-wildlife conflict, crop damage, livestock depredation, Rungwa Game Reserve, wildlife corridor.

INTRODUCTION

Transformation of wildlife habitats into croplands, settlements and grazing lands for livestock increasingly threatens the future survival of wild animals in areas surrounding protected areas in Tanzania and the rest of

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the world; protected areas are becoming islands (Akenden, 2015; Woodroffe, 2000). According to the United Nations list of world protected areas, protected areas covered a total area of 32,868,673 km^2 worldwide in 2014, which accounts for 14% of the terrestrial world land area and 3.4% of the marine protected area network (Deguignet et al., 2014). Approximately, 65% of the global protected area network sites are in Europe. However, they account for only 12% of the total area covered by protected areas worldwide. Africa has fewer sites of protected areas, but these sites account for 13.8% of the total area covered by the global protected area's network (Juffe-Bignoli et al., 2015). The largest terrestrial protected area in the world is found in Greenland. The Republic of Tanzania is well known for setting aside approximately 45% of its land as protected areas under different categories such as National Parks, Game Reserves, Forest Reserves, Wildlife Management Areas, and Game Controlled Areas (IUCN, 2017; TNRF, 2008).

The fragmentation and loss of habitat facing many protected areas is exacerbated by the rapidly growing human population. Tanzania's human population has increased from approximately 7 million in 1961 to approximately 45 million in 2012 (URT, 2013). With an annual growth rate of 3.1%, Tanzania's population is projected to reach 69.1 and 129.1 million in 2025 and 2050, respectively (PRB, 2013). More than 80% of the country's population depend on small scale agriculture and livestock as their major livelihood strategies. According to the population census of 2012, more than 75% of the Tanzanian human population are young, below the age of 35 years; most are unemployed and reside in areas that are also wildlife habitats or corridors, thus blocking wildlife movements from one protected area to another (Caro et al., 2009; Hariohay and Røskaft, 2015).

Humans and wildlife interact adversely when wildlife disperses from core protected areas (PAs) through the premises of local communities. In such cases they destroy crops, depredate on livestock and pose a threat to human security. Such interactions cause negative attitudes towards wild animals and their conservation (Nyahongo, 2007). Other negative impacts are the increase in time spent in guarding farms and livestock and other infrastructures such as water sources (Shemweta and Kideghesho, 2000).

Areas currently used by humans were historically used by wild animals as habitats, especially when they are moved from one protected area to another (Caroet al., 2009). The negative human-wildlife interactions were minimal because the human population was low; consequently, demand for settlements, agricultural and grazing lands was low. Over the last several decades, human population growth has led to increased encroachment on dispersal areas and wildlife corridors, causing small, non-continuous patches of habitats. Opening of new agricultural fields and nomadic pastor.

Nomadic pastoralism are traditional farming methods used by local communities in the villages surrounding most protected areas in Tanzania and are detrimental to future existence of these protected areas (Kideghesho, 2015). The impact of human beings on wildlife is not well understood, but the disturbance to wild animals creates stress, which might affect their ability to reproduce (Tingvold et al., 2013).

Among the dominant livestock owners in Tanzania are the people of the Sukuma tribe. Increasing conversion of land to settlements and croplands and impacts of climate change have forced movement of these people further South to Rungwa-Katavi from Shinyanga, Tabora, Simiyu, and Mwanza regions (Figure 1). This movement has subjected the area to rapid human population increase and therefore anthropogenic activities such as land clearing to open up fields, charcoal burning, timber, settlements and overgrazing leading to habitat deterioration (Caro et al., 2009; Hassan, 2003; Kideghesho et al., 2006). These activities have adversely affected the Rungwa-Katavi Wildlife Corridor, which is ecologically important for large mammals including African elephants (*Loxodonta africana*), African wild dogs (*Lycaon pictus*), hartebeests (*Alcelaphus buselaphus)*, impala (*Aepyceros melampus),* greater kudus (*Tragelaphus strepsiceros*) and lesser kudu (*Tragelaphus imberbis*). As in other areas of Tanzania, the pressure to degazette the protected areas to allow other human uses has increased in Rungwa-Katavi in recent years. However, the question is: what will occur if such areas do not exist? Some have argued that this would provide suitable grazing land for livestock keepers. Establishing and implementing proper land use and management strategies at the village level will avoid unnecessary conflicts between livestock owners and protected area management and enhance sustainable conservation of wildlife resources.

Objectives

The main aim of this study was to assess the economic loss inflicted by wildlife species to local communities living in the Rungwa-Katavi wildlife corridor, connecting the Rungwa Game Reserve and the Katavi National Park.

The specific objectives were: (1) to identify the cost of livestock and crop damage by wildlife in the study area; (2) to assess the relationship between crop and livestock damage to distance from protected area.

Two hypotheses were tested: first, there is no significant loss caused by wildlife to crop and livestock in the study area and secondly, there is no significant difference between livestock depredations and crop damage with the distance to the protected area.

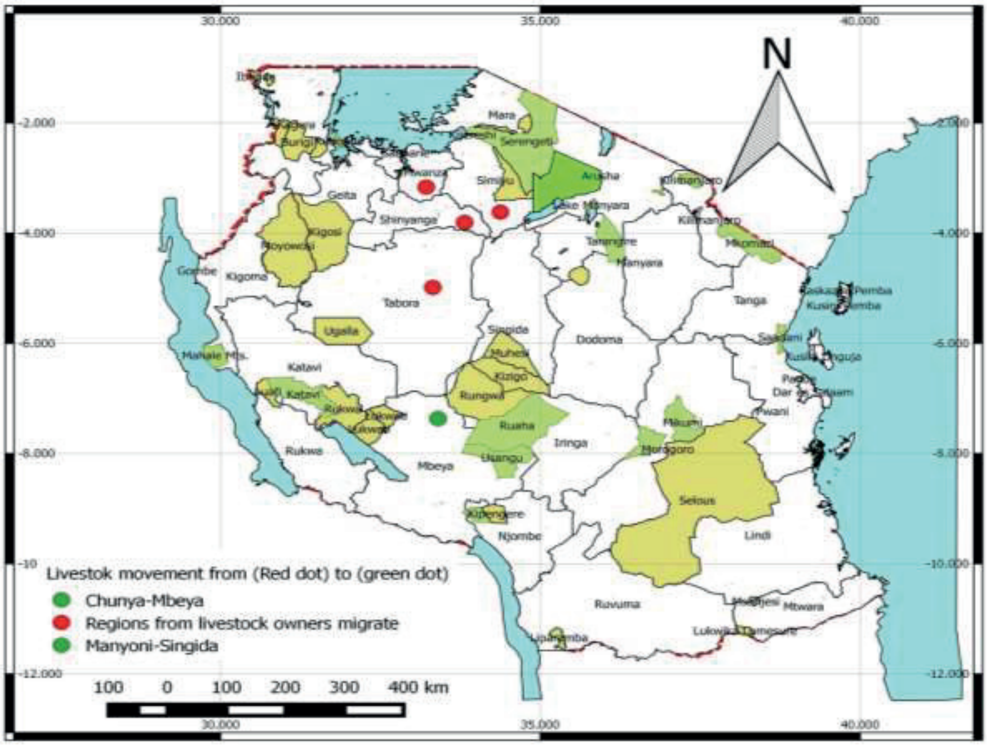

Figure 1. The regions where livestock keepers migrate from (red dots) and the regions they go to (green dot).

MATERIALS AND METHODS

Study area

The Rungwa-Katavi Wildlife Corridor connects the Rungwa/Kizigo/ Muhesi Game Reserves in the east and on the western side of Katavi National Park with the Lukwati/Piti and Rukwa/Lwafi Game Reserves (Figure 1). The Rungwa-Ruaha Ecosystem is the second stronghold, after the Selous-Mikumi Ecosystem, for a large population of African elephants (TAWIRI, 2014). The corridor covers an area of 9,378.58 km^2 located in the east between S 6.97421, E 33.51251 and S 7.80476, E 33.83169 and in the west between S 7.71328, E 33.50591 and S 7.16871, E 32.70056. The corridor comprises the area between the Matandala and Mbanga Mountains, which is a water catchment that supplies the Lukwati Game Reserve and the Mwipa and Mwise Rivers feeding into the Rungwa River. From the west, elephants move from the top of the Lake Rukwa Escarpment, along the Lukwati River, and then on to the Mwipa and Mwise Rivers and northwards to the Piti and Rungwa Rivers during the dry season. Similarly, elephant movements occur from Ruaha National Park and Rungwa Game Reserve to the east towards the Mwaliji/Lueja Rivers during the dry season (Jones et al., 2012).

People residing in this area are agro-pastoralist reliant on farming and beekeeping as their major social economic activities. Tobacco, sesame and sunflower are cultivated as cash crops, whereas maize, beans and millet are major food crops. Most of the immigrants practice both crop cultivation and livestock keeping, while the residents mostly depend on crop cultivation and few depend on beekeeping and selling bee honey as source of household income. The main ethnic groups include Kimbu, Nyamwezi, Sukuma, Fipa, Nyakyusa, Safwa, Gogo, Sangu, Nyaturu, and Taturu. The others, such as Kurya and Haya, are in minority.

Experimental

'A total of 240 respondents was randomly selected and interviewed from five villages. Villages were grouped into two categories: (1), those in proximity to the boundary of the Game Reserve (Kanoge and Kambikatoto) and (2) the villages further away from the Game Reserve (Isangawana, Kipembawe and Mafyeko) (Figure 2). In each village, 48 copies of the questionnaire were randomly administered to respondents, aged 18 years and above. The researcher worked from the village centres, where he randomly stopped people for interview. The researcher then moved to the next centre with a high concentration of people. Several questions were asked aimed at gathering information about their interactions with wildlife, as well as the demography and socio-economic activities of the respondents. The other part of the questionnaire contained questions on crop damage incidences, types of wildlife

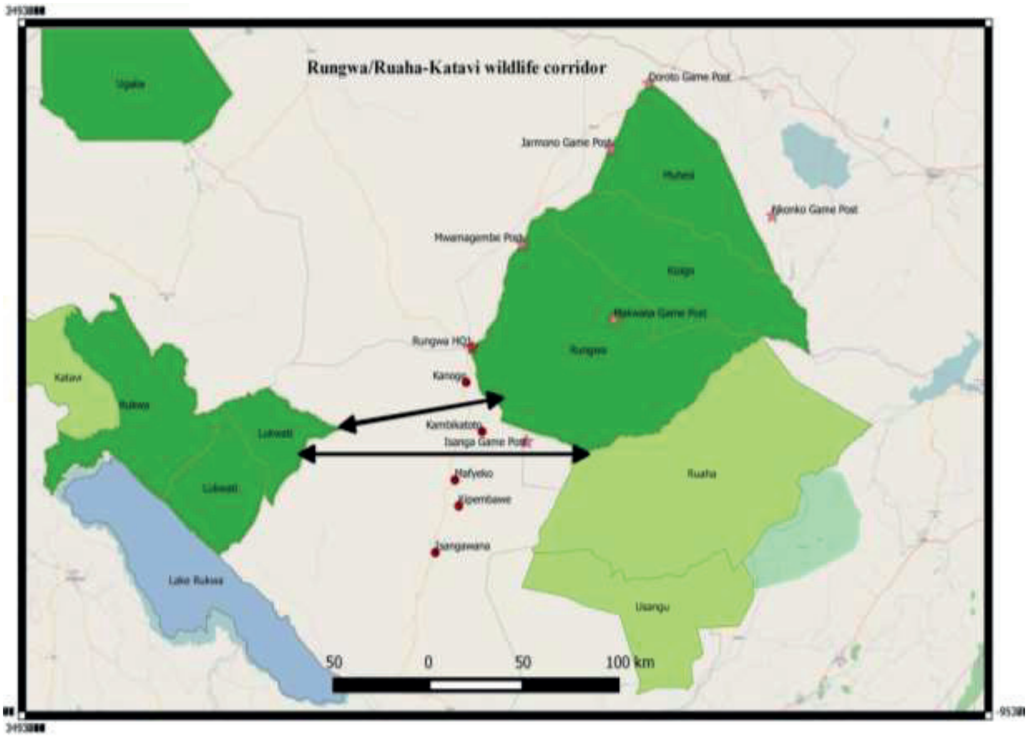

Figure 2. Rungwa– Katavi wildlife corridors represented by arrows and study villages by red dots.

responsible, livestock depredations incidences, type of predators responsible and mitigation measures used.

Statistical analyses

Quantitative data were processed and analysed using Statistical Package of Social Science (SPSS) version 19.0. Descriptive statistics were used to generate means and percentages, which are important for comparison purposes. Chi-square tests were used to determine the significant differences among the research results. Non-parametric statistics were mostly used when data were not normally distributed. The significance level was set at $p < 0.05$. Finally, linear regression or logistic regression analyses was used to test the most influential factors.

RESULTS

Social-demographic variables of the respondents

The 240 respondents included both males (68.8%) and females (31.2%). The majority of respondents were in the 37 to 55 years age group (48.3%), followed by 18 to 36 years (32.5%) and above 55 years (19.2%). 61.2% of the respondents had attended primary school, while less than 1.3% had been to secondary school and 37.5% were illiterate. Two-thirds (66.7%) of the respondents were indigenous and 33.3% were immigrants. The main socioeconomic sources of income were crop cultivation (64.6%), followed by livestock keeping (31.2%) and employment/business (4.2%). A majority of the respondents (60%) came from distant villages, and only 40% lived close to the protected area. 12.9% of respondents had no dependants, while 6.7% had >10 dependants, 27.5% had 5 to 10 dependants, and 52.9% had <5 dependants.

Livestock ownership

Out of 240 respondents, only 32.1% owned livestock. Most of the livestock owners owned 62 cattle (80.5%), while a minority owned 8 goats (10.4%), 4 sheep (5.2%) and 3 donkeys (3.9%). There was a significant increase in livestock ownership with age, as the majority of livestock owners were in the >55 years age category, followed by those in the 37 to 55 age category, with the

Table 1. Livestock ownership versus age, gender, tribe (Sukuma vs. others combined), marital status, dependants and education in the Rungwa-Katavi Wildlife corridor (N = 240).

Variable	Description	Livestock ownership			χ^2	df	P
		Yes (%)	No (%)	Number			
Age (years)	18-36	19.2	80.8	78	41.78	2	<0.0001
	35-55	25.0	75.0	116			
	>55	71.7	28.3	46			
Gender	Male	38.2	61.8	165	9.02	1	<0.003
	Female	18.7	81.3	75			
Tribe	Indigenous	2.5	97.5	160	192.8	1	<0.0001
	Immigrants	91.2	8.8	80			
Marital status	Married	37.9	62.1	195	17.72	3	<0.001
	Not married	0.0	100.0	23			
	Divorced	20.0	80.0	10			
	Widowed	8.3	91.7	12			
Numbers of dependants	0	0.0	100.0	31	68.94	3	<0.0001
	<5	19.7	80.3	127			
	5-10	56.1	43.9	66			
	>10	93.8	6.2	16			
Education level	Not been to school	81.1	18.9	90	158.9	1	<0.0001
	Been to school	2.7	97.3	150			

least livestock owners in the 18 to 36 age category (Table 1). Most of the livestock owners were immigrants; very few were from the indigenous group (Table 1).

The majority of the respondents who had not been to school owned livestock, while very few of who had been to school owned livestock, with a statistically significant difference (Table 1). There was a significant difference between married and unmarried respondents in terms of livestock ownership, as most of those who owned livestock were married and only a few who were not married owned livestock (Table 1).

Livestock ownership significantly varied with the number of dependants, as those respondents with no dependants did not own livestock. Livestock ownership increased with the number of dependants respondents had: respondents with <5 dependants owned few livestock, followed by respondents with 5 to 10 dependants; more than 90% of respondents with >10 dependants owned a large quantity of livestock (Table 1).

Livestock depredation

More than half of the livestock owners (54.5%, N = 77) had experienced livestock depredations. Depredation incidences varied with distance from the PA, as most respondents close to the PA (81.5%) experienced depredation, while 40.0%, of the respondents from distant villages reported fewer depredation cases; this difference was statistically significant (Table 2). Livestock depredation varied significantly between male and female respondents, as more males reported more depredation incidences than females (Table 2). Depredations reports varied with tribe, as the Sukuma tribe reported a higher livestock depredation incidence than all of the other tribes combined (Table 2).

Additionally, depredation incidences varied with education level, as more of those who had not attended formal education reported depredation incidences than those who had attained formal education (Table 2). However, depredation incidences did not differ between any of the groups, including age and marital status (Table 2).

Livestock killed and economic loss

Respondents estimated the average loss of killed

Table 2. Livestock depredation (among livestock owners) versus gender, age and distance to PA, residency, marital status and education level of respondents.

Variable	Description	Livestock depredation			χ^2	df	P
		Yes (%)	No (%)	Number			
Gender	Male	67.3	32.7	55	4.54	1	0.03
	Female	40.9	59.1	22			
Age (years)	18-36	60.0	40.0	15	0.50	2	0.77
	37-55	58.6	41.4	29			
	>55	60.6	39.4	33			
Villages	Close	81.5	18.5	27	12.17	1	0.0001
	Far	40.0	60.0	50			
Tribe	Indigenous	0.0	100.0	4	5.06	1	0.02
	Immigrants	57.5	42.5	73			
Marital status	Married	60.8	39.2	74	3.25	2	0.196
	Not married	0.0	0.0	0			
	Divorced	0.0	100.0	2			
	Widowed	100.0	0.0	1			
Education	Not been to school	57.5	42.5	73	5.06	1	0.02
	Been to school	0.0	100	4			

Percentages are respondents who replied yes and no to livestock depredation in the Rungwa-Katavi wildlife corridor.

livestock per person per year to be 1.9 animals (N = 43). Cattle were most often reported as killed by depredation (55.8%). Other livestock killed included goat (25.6%), sheep (11.6%), and donkey (7%). In the local markets where this study was conducted, cattle are sold at an average price of US $250/animal: goats and sheep are sold at an average price of US $30/animal and donkeys were sold at an average price of US $60/animal.

A total of 83 livestock were recorded killed, which included 39 cattle, 26 goats, 14 sheep, and 4 donkeys, equivalent to an average of 0.9, 0.6, 0.3, and 0.09 animals killed, respectively, per year per household. In monetary terms, cattle contributed greatest the economic loss (US $226.74), followed by goats (US $18.14), sheep (US $9.77) and donkey (US $5.58) per year to the households that reported depredation incidences. The total economic loss caused by livestock depredation in this study is about US $11,190.00, which is an average of US $260.23 per year per household.

Type of predator

Spotted hyenas was the most common predator, reported to cause 53.5% (N = 23) of the depredation incidences, followed by lions (25.6%, N = 11) and leopards (20.9%, N = 9). The frequency of type of predator and livestock killed varied statistically significantly; lions attacked only cattle (100.0%, N = 16), while hyenas attacked mostly cattle (44.4%, N = 18), followed by goats (38.9%, N = 18) and donkeys (16.7%, N = 18); finally, leopards attacked goats (44.4%, N = 9) and sheep (55.6%, N = 9) (χ^2 = 40.68, df = 6, P < 0.0001).

A binary logistic regression using livestock loss (yes/no) as a dependent variable and the distance to PA, gender, marital status, age, residency (immigrant or not), education level, number of dependants, and number of livestock killed as independent factors. Distance from PA was the only statistically significant factor and explained the 53.1% variation in livestock depredation incidences (Table 3). The other independent variables did not explain any of the variation (Table 3).

Crop damage

The majority (92.5%) of the respondents owned a piece of land and were peasants (Table 4). The most common crop grown was maize (60.4%); the other types (39.6% combined) included sunflower, beans, sesame, groundnut and tobacco. Land ownership variation was statistically significant with age; respondents 18 to 36 years owned

Table 3. Binary regression analysis with depredation cases of livestock as the dependent variables versus independent variables (age, distance, dependants, sex, marital status, residency, education and socio-economic activities and livestock type).

Dependent variable	Independent variable: Livestock depredation		
	Wald	df	P
Distance	9.471	1	0.002
Gender	2.615	1	0.106
Dependants	2.702	1	0.100
Marital status	0.551	1	0.458
Immigration status	0.0001	1	0.999
Age	2.861	1	0.091
Education	0.000	1	0.999
Income	0.0001	1	0.999
Constant	0.0001	1	1.000

Percentage are respondents who replied yes and no to livestock depredation in the Rungwa-Katavi wildlife corridor.

Table 4. Land ownership versus age, gender, tribe (Sukuma vs. others combined), marital status, dependants and education in the Rungwa-Katavi Wildlife corridor (N = 240).

Variable	Description	Land ownership			χ^2	df	P
		Yes (%)	No (%)	Number			
Age (years)	18-36	76.9	23.1	78	40.41	2	≤0.0001
	35-55	100.0	0.0	116			
	>55	100.0	0.0	46			
Gender	Male	91.5	8.5	165	0.73	1	≤0.39
	Female	94.7	5.3	75			
Tribe	Indigenous	89.4	10.6	160	6.76	1	≤0.009
	Immigrants	98.8	1.2	80			
Marital status	Married	97.9	2.1	195	104.9	3	≤0.0001
	Not married	39.1	60.9	23			
	Divorced	100.0	0.0	10			
	Widowed	100.0	0.0	12			
Numbers of dependants	0	54.8	45.2	31	73.49	3	≤0.0001
	1-4	96.9	3.1	127			
	5-10	100.0	0.0	66			
	>10	100.0	0.0	16			
Education level	Not been to school	96.7	3.3	93	8.05	1	≤0.02
	Been to school	89.8	10.2	150			

less, while all respondents in the 37 to 55 age group and the above 55 years group owned land (Table 4).

Approximately 45.9% of the peasants experienced crop damage (Table 5). There was a significant difference between close and distant villages, as respondents close to the PA experienced more damage than those far away (Table 5). Reported crop damage incidences varied with the age of the respondents (Table 5). Respondents in the 37 to 55 years age category reported the most crop damage incidences, followed by the >55 years age group; the 18 to 36 years' age group reported less crop damage incidences (Table 5). The gender of respondents

Table 5. Crop damage (among farmers) versus gender, age and distance to PA, residency, marital status and education level of respondents.

Variable	Description	Crop damage			χ^2	df	P
		Yes (%)	No (%)	Number			
Gender	Male	60.9	39.1	151	6.80	1	≤0.009
	Female	42.3	57.7	71			
Age (years)	18-36 years	41.7	58.3	60	8.39	2	≤0.010
	37-55 years	63.8	36.2	116			
	>55 years	50.0	50.0	46			
Villages	Close	80.9	19.1	89	40.3	1	≤0.0001
	Far	37.6	62.4	133			
Tribe	Indigenous	52.4	47.6	143	1.02	1	≤0.312
	Immigrants	59.5	40.5	79			
Marital status	Married	56.0	44.0	191	2.00	3	≤0.570
	Not married	33.3	66.7	9			
	Divorced	60.0	40.0	10			
	Widowed	50.0	50.0	12			
Education	Not been to school	58.0	42	88	0.53	1	≤0.467
	Been to school	53.0	47	134			

Percentage are respondents who replied yes and no to crop damage in the Rungwa-Katavi wildlife corridor.

varied significantly in terms of reporting crop damage; more males reported crop damage incidences than female respondents (Table 5). Reported crop damage incidences did not differ significantly between any of the other groups, including education, tribe and marital status (Table 5).

Crop damaged and economic loss

The most commonly damaged crop was maize (97%). The average loss included 417 kg of maize, which is equivalent to US $125 per year per household. Other crops accounted for an average loss of 13 kg per year per household, which is equivalent to a loss of US $1.30 per year per household. Respondents ranked the problem animals causing crop damage. Elephant was the most problematic animal (96.1%) followed by warthog (2.9%) and greater kudu (1%).

Measures to control problem animals

More than three-quarters of the respondents (76.7%) reported controlling problem animals by guarding (25.8%) and scaring by lighting fires and making noises (57.5%). Other strategies cited by 16.7% of the respondents included farming away from the borders of the PAs, growing crops such as pepper that are undesirable to wild animals, or smearing dirty oil on raised poles along the borders of the field.

A binary logistic regression analysis was performed with crop damage incidences as the dependent variable and with the same independent variables as for livestock depredation. The 33.1% variation in crop damage was best explained by distance from the PA and gender (Table 6). Other variables including education, tribe, age, marital status, and crop type were not important variables in explaining the variation in crop damage (Table 6).

DISCUSSION

Connectivity between Wildlife Protected Areas has been an important topic for discussion for many scholars to maintain genetic flow and biodiversity stability (Weldon, 2006). Considering that many protected areas cannot accommodate populations of mega wildlife such as the African elephant and African wild dogs with large home ranges, wildlife corridors are important for facilitating species movement from one protected area to another. Today, many human-wildlife conflicts are caused by

Table 6. Binary regression analysis with crop damage as the dependent variables versus independent variables (age, distance, dependants, sex, marital status, residency, education and socio-economic activities and livestock type).

Dependent variable	Independent variable (Crop damage)		
	Wald	df	P
Distance	36.010	1	≤0.0001
Gender	11.170	1	≤0.001
Dependants	1.929	1	≤0.165
Marital status	1.227	1	≤0.268
Immigration status	0.235	1	≤0.628
Age	0.131	1	≤0.717
Education	0.024	1	≤0.877
Income	0.006	1	≤0.941
Constant	4.180	1	≤0.041

people who are encroaching on these corridors, which had previously been used by wild animals as habitats or stepping stones. Blockage of corridors and dispersal areas for wild animals caused by a rapid human population increase has resulted in the transformation of more wildlife habitats to croplands (Kideghesho et al., 2013, Watkins et al., 2003).

In this study, most of the respondents were males, which are attributed to the fact that males were more free and ready to talk to the researcher than females. All age groups were well represented. However, over 48% were between 37 and 55 years old. This age group owned livestock and agricultural land. Most of the respondents were growing crops for food and keeping livestock as their major source of income. Other sources of income included beekeeping and formal employment in tourist companies operating in the nearby protected areas. Kideghesho (2015) and Kideghesho et al. (2013) reported that dependency on small-scale farming and livestock keeping as major sources of income is common among the villages in areas bordering the protected areas in Tanzania. Researchers were interested mostly in the farmers and livestock keepers, as these groups are the ones incurring the costs of wildlife conservation from livestock depredation and crop damage.

Livestock depredation

Most livestock owners had experienced losses by various predators such as lions, hyenas and leopards as predicted in the first hypothesis. The edge effect theory can best explain why most of the large predators such as lions and hyenas require large home ranges; therefore, encroachment into wildlife habitats created small patches of habitats that increased the chances of predators attacking livestock (Nyahongo, 2007). More than 50% of the respondents mentioned spotted hyena as the leading predator, followed by lions and leopards. This might be explained by the fact that the Ruaha-Rungwa ecosystem has large populations of large carnivores and by the occurrence of encroachment of the livestock keepers and settlements near the borders of these protected areas. For example, a study by Kideghesho (2010) in the western Serengeti corridor indicated that spotted hyena was the most problematic predator, responsible for approximately 98% losses of livestock near the national park boundary. Additionally, spotted hyena can walk long distances, up to 20 km, in a single night and hide in small patches of forest in the village around the human settlement. Similar to our findings, Mwakatobe et al. (2013), reported the spotted hyena as the major livestock-killing predator in the western Serengeti ecosystem.

Reported depredation incidences varied with the distance from the protected area, with more reports from respondents living close to the PA, thus supporting our first hypothesis that impact varies with distance. The findings around Tarangire National Park by Hariohay and Røskaft (2015) and in the Serengeti by Mwakatobe et al. (2013) support our results, as they reported more livestock depredations near the PA than in distant villages. These results therefore support our first hypothesis. Mostly males complained about livestock depredation, which is attributed to the fact that men are responsible for herding cattle in African pastoralist societies such as the Sukuma. Therefore, they experienced more incidences of livestock attacks than females, corroborating the results of Treves and Karanth (2003).

According to respondents, the amount of losses incurred in terms of the number of livestock lost and the price in the local market was economically significant; this supported our second hypothesis: we expected crop and livestock losses in the study area. Economic loss of livestock was estimated to be US $260.23 per year per household in the five villages in and around the corridor.

The reported incidences of livestock depredation by hyenas and lions occurred mostly at night and are attributed to poorly built livestock “bomas” using tree poles. Most of the respondents justified their choice of not building strong and permanent buildings to keep their livestock in overnight by reasoning that they do not expect to live there for many years. The majority of the livestock owners in the area (Sukuma) had the habit of moving from one locality to another when the area becomes unsuitable for crop cultivation and the quality and quantity of pasture for their livestock decline. Generally, no proper protection measures have been taken by the livestock owners; most of the time, young boys (under 16 years old) had been looking after large herds of cattle during the day with temporary buildings for livestock during the night. Many of them depended on dogs; others employed a night watchman to guard their livestock premises, similar to what was reported by Lyamuya et al. (2016).

Crop damage

Most of the peasants in the area were victims of wild animals, as their crops had been destroyed by problem animals. More crop damage occurred in the villages close to PA. This is because villages close to the boundary of the wildlife protected areas face the most contact with wildlife such as elephants and other vermin species. Mwakatobe et al. (2014) had similar findings in the western Serengeti, as the crop damage happened at farms closest to the protected area. Most of the crop fields bordered the Rungwa Game Reserve. Crop damage took the form of trampling by elephants. Mfunda and Røskaft (2011) reported crop damage by problem animals in the western Serengeti and their findings support our results in that elephants caused more damage to crops such as maize, sunflower and groundnuts than other animals.

Respondents ranked elephants as the primary problem animal, causing over 90% of the crop damage. The damage occurs mostly during the night. Other animals such as the greater kudu caused crop damage at early stages of plant growth (tender) and destroyed crops mostly during the day; thus, the farmers could guard their crop fields, unlike during the night. An average of 430 kg of various crops was lost per household, which accounts for a significant amount of household income in the villages studied. The estimated amount was from the 222 households who had farmed in the study year. However, the most frequently lost crop type was maize, up to 417 kg; this was attributed to the fact that it was the most commonly cultivated crop. Research in the western Serengeti corridor by Kideghesho (2010) indicated crop losses to have accounted for about US $516 per household higher than our result of US $126.23 per household per year. The difference might be due to the difference in time when the two studies were conducted and fact that majority of communities living adjacent to the western Serengeti corridor are agro-pastoralist and wildlife migrate in that area. The crop losses caused by elephants and other wild animals are among the reasons for poverty among local people and exacerbate unsustainable wildlife conservation in the wildlife corridor. Kideghesho et al. (2007) and Adams et al. (2004) discussed the importance of biodiversity conservation benefiting local communities for the success of sustainable conservation of wildlife, and Bandara (2005) noted that habitat fragmentation is the primary source of conflict between elephants and human beings. Both our first and second hypotheses were supported: first that people faced negative impacts in terms of crop damage in the corridor and second that the crop damage incidences varied with the distance from the Rungwa Game Reserve.

CONCLUSION AND RECOMMENDATIONS

Crop raids and livestock depredation were directly influenced by the distance from the game reserve boundary. The findings supported our hypotheses: first, the negative interactions in terms of crop and livestock losses in the study area and second, that livestock depredation and crop damage occurred more often in villages close to the protected areas. Important factors that influenced crop damage incidences among respondents included age, gender and distance from the PA. Important factors that influenced reporting livestock depredations included gender, education, immigration status and distance from the protected area. It was found that among the immigrants, the Sukuma tribe (91.3%) reported the most livestock depredations.

It was found that livestock keepers lost an average of 1.9 animals to predators per household per year in the study area. The majority of livestock lost were cattle, followed by goat, sheep and donkey. The study recorded farmers to have incurred significant losses of crops, mainly maize (417 kg). Most livestock losses were incurred by the immigrants, but immigrants and residents incurred crop losses equally. This supported our first hypothesis that wildlife had caused significant livestock and crop losses in the study area.

It was recommended that the responsible wildlife authorities should provide education on control measures to prevent problem wild animals such as elephants from destroying their crop farms to reduce the economic losses incurred. Construction of strong bomas and herding practices are recommended to reduce the levels of livestock depredation. Also, it was recommend that communities around the Rungwa Game Reserve should avoid growing crops close to protected areas, as incidences of crop raiding by wild animals and livestock depredation increase towards the protected area boundary. The legislation should recognize wildlife corridors to increase their conservation status; Ministry of Natural Resources and Tourism (MNRT) should identify all remaining corridors that can be given conservation status and restrict anthropogenic activities that are ecologically destructive.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Adams WM, Aveling R, Brockington D, Dickson B, Elliott J, Hutton J, Roe D, Vira B, Wolmer W (2004). Biodiversity conservation and the eradication of poverty. Science 306:1146-1149.

Akenden Z (2015). Human- wildlife conflict; The case of elephant at Mole National Park Trondheim: NTNU.

Bandara R (2005). The economics of human-elephant conflict. (unpublished manuscript).

Caro T, Jones T, Davenport TRB (2009). Realities of documenting wildlife corridors in tropical countries. Biol Conserv. 142:2807-2811.

Deguignet M, Juffe-Bignoli D, Harrison J, MacSharry B, Burgess ND, Kingston N (2014). United nations list of protected areas. Cambridge, UK.

Hariohay KM, Røskaft E (2015). Wildlife induced damage to crops and livestock loss and how they affect human attitudes in the Kwakuchinja Wildlife Corridor in northern Tanzania. Environ. Nat. Resour. Res. 5:56-63.

Hassan SN (2003). Impacts of space use by humans on the large mammal species diversity in the Kwakuchinja - Mbungwe wildlife corridor, northern Tanzania. Tanz. J. For. Nat. Conserv. 76:134-143.

Jones T, Bamford AJ, Ferrol-Schulte D, Hieronimo P, McWilliam N, Rovero F (2012). Vanishing wildlife corridors and options for restoration: a case study from Tanzania. Trop. Conserv. Sci. 5:463-474.

Juffe-Bignoli D, MacSharry B, Bingham H, Deguignet M, Kingston N (2015). World database on protected areas user manual. Cambridge, UK.

Kideghesho JR (2010). Wildlife conservation and local land-use conflicts in the western Serengeti corridor, Tanzania. In: Conservation of natural resources; Some African & Asian examples. Trondeim: Tapir academic press. pp. 130-154.

Kideghesho JR (2015). Realities on deforestation in Tanzania: trends, drivers, implications and the way forward http://dx.doi.org/10.5772/61002. In: Precious Forests - Precious Earth. Web of science: INTECH Open Science/Open minds

Kideghesho JR, Nyahongo JW, Hassan SN, Thadeo C, Mbije NE (2006). Factors and ecological impacts of wildlife habitat destruction in the Serengeti ecosystem in northern Tanzania. Afr. J. Environ. Assess. Manag. 11:17-32.

Kideghesho JR, Rija AA, Mwamende KA, Selemani IS (2013). Emerging issues and challenges in conservation of biodiversity in the rangelands of Tanzania. Nat. Conserv. 6:1.

Kideghesho JR, Røskaft E, Kaltenborn BP (2007). Factors influencing conservation attitudes of local people in Western Serengeti, Tanzania. Biodivers. Conserv. 16:2213-2230.

Lyamuya RD, Masenga EH, Fyumagwa RD, Mwita MN, Røskaft E (2016). Pastoralist herding efficiency in dealing with carnivore-livestock conflicts in the eastern Serengeti, Tanzania. Intl. J. Biodivers. Sci. Ecosyst. Serv. Manag.12:202-211.

Mfunda IM, Røskaft E (2011). Wildlife or crop production: the dilemma of conservation and human livelihoods in Serengeti, Tanzania. Intl. J. Biodivers. Sci. Ecosyst. Serv. Manag. 7:39-49.

Mwakatobe A, Nyahongo JW, Ntalwila J, Røskaft E (2014). The impact of crop raiding by wild animals in communities surrounding the Serengeti National Park, Tanzania. Intl. J. Biodivers. Conserv. 6:637-646.

Mwakatobe A, Nyahongo JW, Røskaft E (2013). Livestock depredation by carnivores in the Serengeti Ecosystem, Tanzania. Environ. Nat. Resour. Res. 3:46-57.

Nyahongo JW (2007). Depredation of livestock by wild carnivores and illegal utilization of natural resources by humans in the Western Serengeti [PhD]. Trondheim, Norway: Norwegian University of Science and Technology. World Population Sheet. Washington, DC, 2013; www.prb.org

Shemweta DTK, Kideghesho JR (2000). Human-wildlife conflicts in Tanzania. Proceedings of the 1st University Wide Conference 5th - 7th April 2000, Tanzania.

TAWIRI (2014). Aerial census of large animals in the Selous - Mikumi Ecosystem, Dry season, 2013, population status of African elephant. Arusha, Tanzania.

Tingvold HG, Fyumagwa R, Baardsen LF, Rosenlund H, Bech C, Røskaft E (2013). Determining adrenocortical activity as a measure of stress in African elephants (*Loxodonta africana*) in relation to human activities in Serengeti ecosystem. Afr. J. Ecol. 51:580-589.

Treves A, Karanth KU (2003). Human-carnivore conflict and perspectives on Carnivore management worldwide. Conserv. Biol.17:1491-1499.

URT (2013). Population and housing census counts 2012. Dar es Salaam.

Watkins RZ, Chen J, Pickens J, Brosofske KD (2003). Effects of forest roads on understory plants in a managed hardwood landscape. Conserv. Biol. 17:411-419.

Weldon AJ (2006). How corridors reduce Indigo bunting nest success. Conserv. Biol. 20:1300-1305.

Woodroffe R (2000). Predators and people: using human densities to interpret declines of large carnivores. Anim. Conserv.3:165-173.

Paper II

This paper is awaiting publication and is not included in NTNU Open

Paper III

Human Dimensions of Wildlife

An International Journal

ISSN: 1087-1209 (Print) 1533-158X (Online) Journal homepage: https://www.tandfonline.com/loi/uhdw20

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HUMAN DIMENSIONS OF WILDLIFE
2018, VOL. 23, NO. 6, 503–514
https://doi.org/10.1080/10871209.2018.1494866

Awareness and attitudes of local people toward wildlife conservation in the Rungwa Game Reserve in Central Tanzania

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ABSTRACT

Studies have demonstrated that wildlife conservation success depends on local people's attitudes toward wildlife. We conducted semi-structured interviews with 240 respondents living in five villages outside the south-western Rungwa Game Reserve (RGR). Results revealed 89% of the respondents were aware of wildlife conservation, and their awareness varied with age, education, immigration status, and distance to the protected area (PA). Factors influencing the attitude of local people toward wildlife in the area included age, distance to the PA, education level, and sources of income. Depredation and crop damage negatively influenced people's attitudes toward problem animals. For effective conservation, the attitudes of local people toward wildlife need to be considered. This conservation will be achieved through timely compensation schemes, the involvement of the local people in conservation planning, and the provision of education programs about sustainable conservation.

KEYWORDS

Attitudes; awareness; knowledge; Rungwa Game Reserve (RGR); wildlife corridor

Introduction

Tanzania is among the countries with mega-biodiversity and has set aside more than 38% of her terrestrial land as protected area (PA) (Masalu, 2008). Most PAs in Tanzania and in other countries were established by evicting local communities who legally occupied the land (Adams & Hutton, 2007; Kideghesho, Røskaft, & Kaltenborn, 2007; Kideghesho, Røskaft, Kaltenborn, & Tarimo, 2005; Lyamuya et al., 2014). Eviction was forcefully conducted, but people were not ready to lose their ancestral land. The government's good intention of setting aside these areas for the conservation of wildlife was not accepted by people because these people were neither compensated for their lost land nor given prior information on the government actions (Kideghesho et al., 2005).

Studies on attitudes toward conservation are important for public understanding, acceptance, and the impact of conservation interventions (Barlow & Jung, 2012; Holmes, 2003; Røskaft, Händel, Bjerke, & Kaltenborn, 2007). The human attitude encompasses both feelings and beliefs that predict human behavior toward the presence of wildlife in their vicinity (Ajzen & Fishbein, 1980; Lyamuya et al., 2014). Understanding local peoples' attitudes toward conservation is, thus, a prerequisite for improving people–PAs relationship (Ciocănea, Sorescu, Ianoşi, &

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Bagrinovschi, 2016; Mir, Noor, Habib, & Veeraswami, 2015; Shrestha & Alavalapati, 2006; Vodouhê, Coulibaly, Adégbidi, & Sinsin, 2010) and shaping the future of wildlife conservation (Adams & Hutton, 2007; Barua, Bhagwat, & Jadhav, 2013; Lyamuya et al., 2014; Røskaft et al., 2007). Understanding such attitudes helps in making correct choice of a strategy for effective involvement of local communities in conservation of PAs. Perceptions and beliefs are imperative since most of the threats to biodiversity and, subsequently, significant decline of wildlife populations and natural habitats come from activities of local communities through deforestation, hunting, and agricultural practices (Bitanyi, Nesje, Kusiluka, Chenyambuga, & Kaltenborn, 2012; Caro, Jones, & Davenport, 2009; Mmassy & Røskaft, 2013).

Negative attitudes can be a strong influence on human behavior and lead to the destruction of natural resources. For example, people with negative feelings toward wild animals may use measures such as poisoning to eliminate them. Likewise, when people realize benefits from conservation and see no risk of being killed, injured or loss of property due to wildlife, they will be more positive to conservation initiatives and supportive to PAs (Tessema, Ashenafi, Lilieholm, & Leader-Williams, 2010).

Little is known about the perceptions and beliefs of local residents adjacent to Rungwa Game Reserve (RGR) and Ruaha National Park also known as the Ruaha-Rungwa Ecosystem (RRE). RRE is one of the most biologically diverse ecosystems in Tanzania. This ecosystem is among the strongholds for large mammal species, such as African elephants (*Loxodonta africana)*. At the same time, the annual human population growth rate is 4.3% (URT, 2013) outside the game reserve, which has increased the pressure on its natural resources (Hariohay, Fyumagwa, Kideghesho, & Røskaft, 2017; MNRT, 2011). The management of RGR conducts environmental education and conservation awareness, despite limited financial resources and manpower available to initiate development activities in the ecosystem. Management success of the area largely relies on cooperation with local communities and management of the RGR (Hampson et al., 2015; Hariohay et al., 2017). Finding ways to improve and strengthen the relationships between local residents and management of the reserve is critical for future sustainable conservation.

Because awareness and attitudes toward wildlife play a substantial role in shaping human behavior and, thereby, interaction with such natural resources, we thus aim to assess people's awareness and attitudes toward wildlife in the Katavi-Rungwa wildlife corridor. This article advances three hypotheses: (a) the awareness of the local people on wildlife conservation varies with age, gender, education levels, immigration status, and the distance from the PA; (b) factors such as age, education level, distance to the PA, sources of income, and immigration status positively influence local people's attitudes toward wildlife conservation; and (c) crop damage and livestock depredation incidents negatively influence people's attitudes toward wildlife conservation. Finally, the article offers recommendations for creating conservation awareness and improving the attitudes of local people toward wildlife conservation.

Methods

Study area

The five villages studied border the RGR and Ruaha National Park located in the central-western part of Tanzania (Figure 1) and covered an area of 9,378.58 km^2. RGR was created

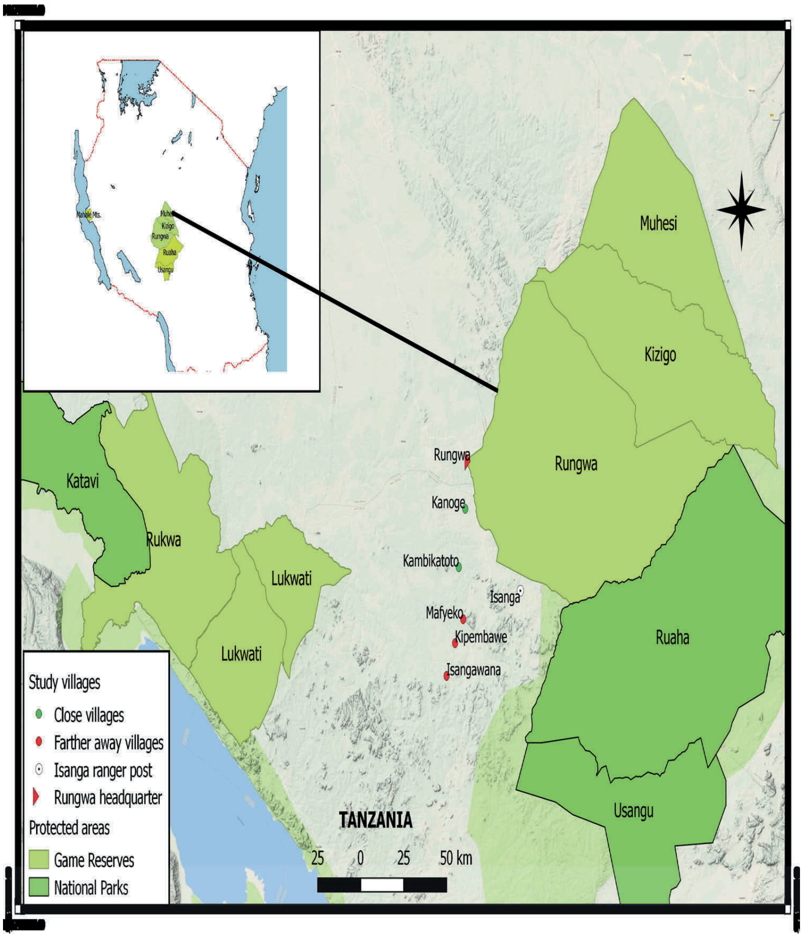

Figure 1. The study villages: green dots (close villages) and red dots (farther away villages) located in the Katavi-Rungwa wildlife corridor.

in 1951, and the Ruaha National Park was created in 1964. RGR and Ruaha National Park are part of the RRE, which includes protected and unprotected areas (Itigi thickets, MBOMIPA Wildlife Management Area) and was previously known as the Lunda Game Controlled Area, with a total area of 45,000 km^2. The RRE is connected by the Katavi-Rungwa wildlife corridor which is a significant conservation area for African elephants (Hariohay et al., 2017). A wildlife corridor is an open area with no management regulations or laws neither at a national or local level. Such corridors are allowed to be invaded by human immigrants from other districts and regions looking for areas to establish crop farms, grazing land for livestock, and settlements. The Katavi-Rungwa wildlife corridor is currently used by African elephants to move from RGR to Katavi National Park (Caro et al., 2009; Hariohay et al., 2017). RGR is under the management of the Tanzania Wildlife Management Authority (TAWA) at the national level. This corridor is also important for water catchment that supplies Lukwati Game Reserve, Mwipa and Mwise rivers feeding into the Rungwa river (Caro et al., 2009; Hariohay et al., 2017).

The area is dominated by miombo woodlands, which offer habitats for a number of wildlife species, such as lions (*Panthera leo*), leopards (*Panthera pardus*), spotted hyenas (*Crocuta crocuta*), black backed jackals (*Canis mesomelas*), Cape buffalos (*Syncerus caffer*), greater kudus (*Tragelaphus strepsiceros*), African elephants, plain zebras (*Equus burchelli*), hippopotamuses (*Hippopotamus amphibius*), bush pigs (*Potamochoerus larvatus*), warthogs (*Phacochoerus africanus*), baboons (*Papio anubis*), vervet monkeys (*Chlorocebus pygerythrus*), and crocodiles (*Crocodylus niloticus*). The area is also home to various species of antelope, such as impalas (*Aepyceros melampus*) and duikers (*Cephalophinae* spp.). Finally, this ecosystem hosts large concentrations of birds (MNRT, 2011; Nahonyo, 2005). The area experiences a long dry season from June–November, and a single rainy season from November–April. The amount of rainfall ranges from 500–700 mm, and the mean annual temperature is 28°C (Nahonyo, 2005). The main ethnic groups in the study area include Nyakyusa, Kimbu, Taturu, Nyaturu, Gogo, Safwa, Sangu, and Sukuma. Their main social economic activities are dependent on crop cultivation (> 60%) and livestock (33%), while beekeeping and some formal employment are in the minority (7%).

Data collection

Data for this article were collected using semi-structured interview questionnaire, which involved a total of 240 respondents. In each village, we randomly chose 48 respondents, interviewing them one at a time. To ensure anonymity, respondent's names were not connected to the questionnaire; instead, each questionnaire was assigned a number. The researcher ensured that there was no repetition of the interviewed respondents by asking their names, which were cross-checked before proceeding with questions. Questionnaires were prepared in the Swahili language, which all our respondents understood, and therefore, there was no need for a language translator. The population size of each village was as follows: Kambikatoto (1,300), Kanoge (750), Kipembawe (800), Mafyeko (1,500), and Isangawana (1,000), for a total population of 5,350 people (URT, 2013).

The 240 respondents constituted 5% of the total population. Villages were grouped into two categories: those that were close to the game reserve boundary and those that were farther away. The close villages were less than 10 km from the boundary and included Kanoge (3 km) and Kambikatoto (9 km). Those that were farther away from the game reserve included Isangawana (51 km), Kipembawe (45 km), and Mafyeko (49 km).

We ensured that the respondent was a resident of the respective village. Those who were born or lived in the village before 1974 were termed indigenous (nonimmigrants), because 1974 is the year in which many villages were formed in Tanzania. Those respondents that moved to the respective village after 1974 were termed immigrants in this study. The respondents were 18 years of age or older. The interviews were conducted in the village centers. Within each village, the researcher moved from one sub-village center to another sub-village center. People from the periphery to the centers were assumed to be coming to the village centers to purchase goods for household needs and therefore, respondents were representative of the whole village.

The questions assessed the awareness and attitudes of people regarding wildlife and wildlife conservation. The questions also assessed people's awareness that this area is a wildlife corridor. For attitudes of wildlife in the area, we examined: (a) perceptions to share land with wildlife and human beings; (b) benefits of wildlife; (c) benefits of the RGR to communities; and (d) conservation education to wildlife conservation. These four statements formed an attitude index of "wildlife in the area". We also assessed the attitude toward eliminating predators and problem animals using two items: (a) respondent's perceptions toward eliminating predators; and (b) killing problem animals will be the best solution to control the depredation of livestock and crop damage. Responses were: (a) strongly agreed (b) agree (c) no opinion (d) disagree and (e) strongly disagree. Demographic and socioeconomic data of the respondents were recorded. We also asked respondents how long they have lived in the area, whether they were indigenous or immigrants, and wildlife-related crop damage and livestock depredation.

Descriptive statistics were used to generate means and percentages. Chi-square tests were used to identify significant differences at $p < .05$. Finally, we used generalized linear regression or binary logistic regression analyses to identify the best predictors.

Results

Demographic and socioeconomic characteristics of respondents

Of the 240 respondents, 69% ($n = 165$) were male and 31% ($n = 75$) were female. Nearly half were between 37 and 55 years in age (48%, $n = 116$), while the remaining belonged to the age groups of 18–36 years (33%, $n = 78$) and > 55 years (19%, $n = 46$). Sixty percent of respondents ($n = 144$) lived farther away from the PA, while 40% ($n = 96$) lived close to the PA. Nearly two-thirds (63%, $n = 240$) had attained formal education while 37% had not. The majority of respondents (54%, $n = 150$) with formal education belonged to the age group 37–55 years, followed by age group 18–36 years (39%, $n = 150$), while the age group > 55 years (7%, $n = 150$) having lowest level of formal education. The respondents were immigrants (47%, $n = 113$) and indigenous (53%, $n = 127$). The major social economic activities of the respondents included farming/crop cultivation (65%, $n = 155$), livestock keeping (31%, $n = 75$) and business/employment (4%, $n = 10$).

Awareness of local people toward wildlife conservation

Eighty-nine percent ($n = 214$) were aware of the wildlife conservation measures in their area. A binary logistic regression analysis was conducted with awareness/no awareness as a dependent variable and age, gender, education level, immigration status, and the distance from the boundary of PA as the predictors. The most important independent variables that explained 15% of the variance in people's awareness of wildlife conservation included education level (Wald = 8.51, $p = .004$), age (Wald = 7.12, $p = .008$), immigration status (Wald = 5.42, $p = .020$), and distance to the PA (Wald = 6.74, $p = .009$); gender was not a significant factor.

Factors influencing local people's attitude toward wildlife in the area

We used a generalized linear regression model to test the attitude index of "wildlife in the area" as the dependent variable, with distance, age, gender, education, sources of income, and immigration status as the independent variables. Factors that significantly explained the variation in this attitude were ages between 18 and 36 years and ages between 37 and 55 years, which positively influenced their attitude (Table 1). People with formal education had a positive attitude toward wildlife (Table 1). The distance to the PA significantly influenced the people's attitude, as those who lived far from the PA had a positive attitude toward wildlife (Table 1). People with no employment were less positive to wildlife than those who depended on livestock as their source of income, while people who depended on crop cultivation as their source of income did not contribute significant in explaining the model (Table 1). Immigration status of the respondents was finally an important factor in determining their attitude to wildlife, as the indigenous were more positive (Table 1), while gender was nonsignificant (Table 1).

Factors influencing local people's attitude toward problem animals

Sixty-four percent of the livestock owners (64%, n = 49) and 58% of the farmers (n = 129) would kill or trap wildlife that prey on their livestock or damage their crops. We used a linear regression to examine the "attitude toward eliminating predators and problem animals" as the dependent variable, with distance, age, gender, education, immigration status, depredation, and crop damage incidents as the independent variables. Only two variables significantly explained the variation in the attitude score: livestock depredation

Table 1. A generalized linear model with attitude index toward wildlife as the response variable and age, gender, distance to the protected area (PA), education, immigration status, and sources of income as explanatory variables.

			Statistical tests	
Independent variables	*B*	*SE*	Wald Chi-square	*p-value*
(Intercept)	10.04	.55	339.41	.001
[age = 1] 18–36 years	0.74	.21	12.49	.001
[age = 2] 37–55 years	0.50	.19	6.78	.009
[age = 3] > 55 years	0[a]	.	.	.
[Distance = 1] close	0[a]	.	.	.
[Distance = 2] far	0.66	.13	24.31	.001
[Gender = 1] male	−0.06	.14	0.19	.658
[Gender = 2] female	0[a]	.	.	.
[Income = 1] not employed	−1.99	.87	5.18	.023
[Income = 2] livestock keeping	0.99	.34	8.21	.004
[Income = 3] farming	−0.25	.53	0.23	.629
[Income = 4] employed	0[a]	.	.	.
[Education = 1] been to school	1.79	.24	53.79	.001
[Education = 2] not been to school	0[a]	.	.	.
[status = 2] indigenous	0.90	.34	6.93	.008
[Immigration status = 4] immigrants	0[a]	.	.	.
(Scale)	1[b]			

"a" Set as zero because this parameter is redundant.
"b" Fixed at the displayed value.
"B" the negative value of beta indicates the negative influence on the attitude, while the positive value indicates the positive influence of the attitude.

and crop damage incidences. Those who experienced depredation or loss were more negative (Table 2). All other variables were nonsignificant (Table 2).

Discussion

Awareness of local people toward wildlife conservation

Our findings indicated that the majority of local people were aware of wildlife conservation in their area. This awareness was influenced by age, level of education, immigration status, and distance to the PA. Middle-aged people (37–55 years) indicated more awareness of wildlife conservations in the area. This age group is old enough to know the dynamic history of the area, the wildlife species found in their area, and they have more formal education than the other age groups. The low awareness level shown by the age group above 55 years might have been caused by a lower education level as more than three quarters had not attained formal education. Similarly, Carter, Riley, Shortridge, Shrestha, and Liu (2014) noted that age influenced respondents' awareness and attitudes in Nepal's Chitwan National Park. Mmassy and Røskaft (2013) and Lyamuya et al. (2016) found that knowledge varied with age among people around Serengeti National Park. Older people's awareness mostly depended on their experience gained from living in the area and coexistence for long time with wildlife (Barlow & Jung, 2012; Mmassy & Røskaft, 2013; Tessema et al., 2010). However, our findings indicated lower awareness of the older people toward wildlife conservations in our study area.

Table 2. A generalized linear model with attitude index of eliminating problem animals as the response variable and age, gender, distance to the PA, education, and immigration status, sources of income, depredation, and crop damage as explanatory variables.

			Statistical tests	
Independent variables	B	*SE*	Wald Chi-square	*p-value*
(Intercept)	7.29	.83	77.90	.001
[age = 1] 18–36 years	0.08	.34	0.07	.792
[age = 2] 37–55 years	−0.10	.27	0.14	.705
[age = 3] > 55 years	0[a]	.	.	.
[Distance = 1] close	0.05	.33	0.03	.875
[Distance = 2] far	0[a]	.	.	.
[Gender = 1] male	−0.26	.34	0.59	.440
[Gender = 2] female	0[a]	.	.	.
[Income = 1] not employed	−1.13	1.03	1.21	.272
[Income = 2] livestock keeping	0.33	1.12	0.09	.767
[Income = 3] farming	0[a]	.	.	.
[Education = 1] been to school	0.50	.86	0.34	.560
[Education = 2] not been to school	0[a]	.	.	.
[Immigration status = 2] indigenous	−1.13	.90	1.57	.210
[Immigration status = 4] immigrants	0[a]	.	.	.
[Crop damage = 1] yes	−1.25	.33	14.30	.001
[crop damage = 2] no	0[a]	.	.	.
[Livestock depredation = 1] yes	−1.21	.29	16.25	.001
[Livestock depredation = 2] no	0[a]	.	.	.
(Scale)	1[b]			

"a" Set as zero because this parameter is redundant.
"b" Fixed at the displayed value.
"B" the negative value of beta indicates the negative influence on the attitude, while the positive value indicates the positive influence of the attitude.

Education also influenced awareness toward wildlife conservation, as those who had formal education were more aware. Those with formal education had courses related to wildlife, and their ability to read various magazines and books might have created the difference in awareness. The indigenous respondents were more aware of wildlife conservations because people who had lived there and depended on wildlife resources for a long time had more experience than those who had just immigrated to the area. People residing close to the PA had more awareness than those from farther away villages, which might be caused by their frequent contact with wildlife. Bitanyi et al. (2012) reported similar findings; indigenous tribes that lived close to the PA had a greater awareness of wildlife. Our first hypothesis was supported by these results.

Factors influencing local people's attitude toward wildlife in the area

Age, education, distance to the PA, immigration status, and sources of income influenced local people's attitudes toward wildlife conservation in their area. This supports our second hypothesis. People aged between 37 and 55 years were most positive toward wildlife conservation in their area, and more than those aged over 55 years. The decrease in positive attitudes with an increase in age of respondents might have been that the people aged more than 55 years owned livestock, which also incurred more losses to depredation by predators. Similarly, Shibia (2010) and Mir et al. (2015) reported that people above 54 years owned more livestock and did not support wildlife conservation in their area. In African societies people aged above 55 years are mostly livestock and crop farm owners (Hariohay & Røskaft, 2015; Shibia, 2010).

Education positively influenced the attitude of local people toward wildlife conservation (Lyamuya et al., 2016; Mir et al., 2015). Respondents with formal education were more positive toward wildlife conservation (Kideghesho et al., 2007; Lyamuya et al., 2016; Røskaft et al., 2007; Vodouhê et al., 2010). Most respondents with no formal education did not support the conservation of wildlife (Dalum, 2013; Lyamuya et al., 2016; Shibia, 2010).

People who lived far away from the PA expressed a more positive attitude because they experience less costs from wildlife conservation. Hariohay and Røskaft (2015), Carter et al. (2014), and Shibia (2010) reported similar findings. In areas of the western Serengeti, and in the South Rift Valley of southern Kenya have also reported similar results by Barua et al. (2013), Kideghesho et al. (2007), and Barlow and Jung (2012). These people might benefit from the RGR in the form of money provided to villages in building classrooms, dispensaries, and providing employment opportunities. However, the attitudes of individual people might not have been changed by the benefits, because benefits mostly targeted the community and not individuals. For the sustainable conservation of wildlife, it is important for individuals to get tangible benefits from conservation – for example, most local people depend on natural resources in the form of firewood collection, timber and construction poles, as well as bush-meat as a source of protein and income. Tessema et al. (2010) and Mamo (2015) indicated the importance of benefits due to access to firewood and construction poles to local communities surrounding PAs to create positive attitudes toward wildlife conservation.

The immigration status of the respondents also influenced attitudes positively as indigenous people were more positive than the immigrants. This may have occurred because immigrants owned more livestock (Hariohay et al., 2017). Indigenous people were more positive to wildlife conservation because they may have experienced less damage from predators. Kideghesho et al. (2007) reported a similar trend in the western Serengeti wildlife corridor where indigenous people were more positive toward wildlife conservation.

Income positively influenced the attitude of local people toward wildlife conservation, as people who had employment, and keeping livestock expressed a more positive attitude compared to the people who had no employment. Similarly, other studies reported that people with employment held more positive toward wildlife conservation (Ciocănea et al., 2016; Infield, 1988; Tomićević, Shannon, & Milovanović, 2010). People who were not employed depended more on natural resources from the PA as their alternative source of income.

Factors influencing local people's attitude toward problem animals

Results indicated that people who incurred losses from depredation and crop damage by wild animals expressed a more negative attitude toward wildlife conservation in their area. These individuals supported killing or trapping wildlife that either preyed upon their livestock or caused crop damage. Results here support findings by Nyahongo and Røskaft (2011), Bandara and Tisdell (2003), Treves and Karanth (2003), Kideghesho (2010) and Holmern and Røskaft (2014), who noted that conflict between wildlife and humans can shape people's attitudes toward wildlife. According to Hampson et al. (2015), local people who face conflict due to depredation or crop damage are more willing to retaliate against a predator or problem animal. Losses of cattle to large predators such as lions and spotted hyena and crop damage by African elephants have been reported in the area (Hariohay et al., 2017). Most people supported removing or eliminating problem animals from the areas. Similarly Rust and Marker (2013) reported that those people who lost their cattle to large predators performed negative attitude to such predators in Namibia. This result supports our third hypothesis that people who experienced crop damage and livestock depredation would show a negative attitude toward wildlife.

Conclusion and recommendations

Local people were aware of wildlife conservation in their area. Age, education level, distance to the PA, and sources of income positively influenced attitude of local people toward wildlife conservations. Livestock depredation and crop damage incidents negatively influenced the attitude of local people toward wildlife conservation. We recommend that conservation education programs be developed in local communities that share immediate borders with PAs. The introduction of conservation education in primary schools and encouraging parents to bring their children to those schools are important. Pupils that receive conservation education at a young age may become ambassadors of wildlife conservation back in their home villages and to their parents. Since attitudes are affected by the negative impacts from wildlife, we advise implementing various measures, such as education on how to control crop damage and depredation by wild animals to reduce negative impacts, including crop damage, livestock depredation and human injuries.

Acknowledgments

We are thankful for the Norwegian government and the EU Horizon-2020 financed project under GA 641918 (*AfricanBioServices*) for funding the write-up of this research. Furthermore, we extend our gratitude to the Tanzania Wildlife Management Authority (TAWA) and the Tanzania Wildlife Research Institute (TAWIRI) for granting us the access to conduct this research study. We would also like to extend our thanks to Patrice Richard for his help in the field during data collection, two anonymous referees, and the assistant editor for commends improving this article.

References

Adams, W. M., & Hutton, J. (2007). People, parks and poverty: Political ecology and biodiversity conservation. *Conservation and Society*, *5*(2), 147–183.

Ajzen, A., & Fishbein, M. (1980). *Understanding attitudes and predicting social behavior*. Englewood Cliffs, New York, USA: Prentic Hall, Inc.

Bandara, R., & Tisdell, C. (2003). Comparison of rural and urban attitudes to the conservation of Asian elephants in Sri Lanka: Empirical evidence. *Biological Conservation*, *110*(3), 327–342. doi:10.1016/S0006-3207(02)00241-0

Barlow, M., & Jung, J. (2012). *Rural and urban attitudes towards wildlife - a comparison within Kenya and with Sweden*. Bachelor Ethology and Animal Welfare Programme. Swedish University of Agricultural Sciences. Retrieved from http://urn.kb:se/resolve?

Barua, M., Bhagwat, S. A., & Jadhav, S. (2013). The hidden dimensions of human-wildlife conflict: Health impacts, opportunity and transaction costs. *Biological Conservation*, *157*, 309–316. doi:10.1016/j.biocon.2012.07.014

Bitanyi, S., Nesje, M., Kusiluka, L. J. M., Chenyambuga, S. W., & Kaltenborn, B. P. (2012). Awareness and perceptions of local people about wildlife hunting in western Serengeti communities. *Tropical Conservation Science*, *5*(2), 208–224. doi:10.1177/194008291200500209

Caro, T., Jones, T., & Davenport, T. R. B. (2009). Realities of documenting wildlife corridors in tropical countries. *Biological Conservation*, *142*(11), 2807–2811. doi:10.1016/j.biocon.2009.06.011

Carter, N. H., Riley, S. J., Shortridge, A., Shrestha, B. K., & Liu, J. G. (2014). Spatial assessment of attitudes toward tigers in Nepal. *Ambio*, *43*(2), 125–137. doi:10.1007/s13280-013-0421-7

Ciocănea, C. M., Sorescu, C., Ianoşi, M., & Bagrinovschi, V. (2016). Assessing public perception on protected areas in Iron Gates Natural Park. *Procedia Environmental Sciences*, *32*, 70–79. doi:10.1016/j.proenv.2016.03.013

Dalum, M. V. (2013). *Attitude change towards wildlife conservation and the role of environmental education* (MSc). Utrecht University, Utrecht, Netherlands. Retrieved from https://dspace.library.uu.nl

Hampson, K. J., McCabe, T., Estes, A., Ogutu, J. O., Rentsch, D., Craft, M., … Cleaveland, S. (2015). Human- wildlife conflict and coexistence. In T. Sinclair (Ed.), *Living in the greater Serengeti ecosystem* (Vol. iv, pp. 606–649). University of Chicago Press, Chicago, IL

Hariohay, K. M., Fyumagwa, R. D., Kideghesho, J. R., & Røskaft, E. (2017). Assessing crop and livestock losses along the Rungwa-Katavi wildlife corridor, South-Western Tanzania. *International Journal of Biodiversity and Conservation*, *9*(8), 273–283. doi:10.5897/IJBC2017.1116

Hariohay, K. M., & Røskaft, E. (2015). Wildlife induced damage to crops and livestock loss and how they affect human attitudes in the Kwakuchinja wildlife corridor in northern Tanzania. *Environment and Natural Resources Research*, *5*(3). doi:10.5539/enrr.v5n3pxx

Holmern, T., & Røskaft, E. (2014). The poultry thief: Subsistence farmers' perceptions of depredation outside the Serengeti National Park, Tanzania. *African Journal of Ecology*, *52*(3), 334–342. doi:10.1111/aje.12124

Holmes, C. M. (2003). The influence of protected area outreach on conservation attitudes and resource use patterns: A case study from western Tanzania. *Oryx*, *37*(03), 305–315. doi:10.1017/S0030605303000565

Infield, M. (1988). Attitudes of a rural community towards conservation and a local conservation area in Natal, South Africa. *Biological Conservation*, *45*(1), 21–46. doi:10.1016/0006-3207(88)90050-X

Kideghesho, J. R. (2010). Wildlife conservation and local land-use conflicts in the western Serengeti corridor, Tanzania. In E. Gereta & E. Røskaft (Eds.), *Conservation of natural resources; some African & Asian examples* (pp. 130–154). Trondheim, Norway: Tapir academic press.

Kideghesho, J. R., Røskaft, E., & Kaltenborn, B. P. (2007). Factors influencing conservation attitudes of local people in Western Serengeti, Tanzania. *Biodiversity and Conservation*, *16*(7), 2213–2230. doi:10.1007/s10531-006-9132-8

Kideghesho, J. R., Røskaft, E., Kaltenborn, B. P., & Tarimo, T. M. C. (2005). 'Serengeti shall not die': Can the ambition be sustained? *International Journal of Biodiversity Science & Management*, *1*(3), 150–166. doi:10.1080/17451590509618089

Lyamuya, R. D., Masenga, E. H., Mbise, F. P., Fyumagwa, R. D., Mwita, M. N., & Røskaft, E. (2014). Attitudes of Maasai pastoralists toward the conservation of large carnivores in the Loliondo game controlled area of northern Tanzania. *International Journal of Biodiversity and Conservation*, *6*(1), 797–805. doi:10.5897/IJBC2014.0769

Lyamuya, R. D., Straube, A. C. S., Guttu, A. M., Masenga, E. H., Mbise, F. P., Fyumagwa, R. D., . . . Røskaft, E. (2016). Can enhanced awareness change local school children's knowledge of carnivores in Northern Tanzania? *Human Dimensions of Wildlife*, *21*(5), 403–413. doi:10.1080/10871209.2016.1180566

Mamo, Y. (2015). Attitude and perceptions of the local people toward benefits ond conflict they get from conservation of Bale Mountain National Park and Mountain Nyala (*Tragelaphus buxtoni*). *International Journal of Biodiversity and Conservation*, *7*(1), 28–40. doi:10.5897/IJBC2014.0792

Masalu, F. I. (2008). *Impact of refugees on wildlife habitats and populations in burigi and kimisi game* reserves, *Ngara* District, *Tanzania* (MSc). Sokoine University of Agriculture, Morogoro, Tanzania. Retrieved from http://suaire.suanet.ac.tz:8080/xmlui/bitstream/handle/123456789/373/FAUSTINE%20ILOBI%20MASALU%202008.pdf?sequence=1&isAllowed=y

Mir, Z. R., Noor, A., Habib, B., & Veeraswami, G. G. (2015). Attitudes of local people toward wildlife conservation: A case study from the Kashmir valley. *Mountain Research and Development*, *35*(4), 392–400. doi:10.1659/MRD-JOURNAL-D-15-00030.1

Mmassy, E. C., & Røskaft, E. (2013). Knowledge on birds of conservation interest among the people living close to protected areas in Serengeti, Northern Tanzania. *International Journal of Biodiversity Science, Ecosystem Services & Management*, *9*(2), 114–122. doi:10.1080/21513732.2013.788566

MNRT. (2011). *Rungwa-Kizigo-Muhesi Game Reserves general management plan*. Dar es Salaam, Tanzania: Government printers.

Nahonyo, C. L. (2005). Assessment of anti-poaching effort in Ruaha national park, Tanzania. *Tanzania Journal of Science*, *31*(2), 13–22. http://dx.doi.org/10.4314tjs.v31i2.18416

Nyahongo, J. W., & Røskaft, E. (2011). Perception of people towards lions and other wildlife killing humans, around Selous Game Reserve, Tanzania. *International Journal of Biodiversity and Conservation*, *3*(4), 110–115.

Røskaft, E., Händel, B., Bjerke, T., & Kaltenborn, B. P. (2007). Human attitudes towards large carnivores in Norway. *Wildlife Biology*, *13*(2), 172–185. doi:10.2981/0909-6396(2007)13[172:HATLCI]2.0.CO;2

Rust, N. A., & Marker, L. L. (2013). Cost of carnivore coexistence on communal and resettled land in Namibia. *Environmental Conservation*, *41*(1), 45–53. doi:10.1017/S0376892913000180

Shibia, M. G. (2010). Determinants of attitudes and perceptions on resource use and management of Marsabit National Reserve, Kenya. *Human Ecology*, *30*(1), 55–62. doi:10.1080/09709274.2010.11906272

Shrestha, R. K., & Alavalapati, J. R. R. (2006). Linking conservation and development: An analysis of local people's attitude towards Koshi Tappu Wildlife Reserve, Nepal. *Environment, Development and Sustainability*, *8*(1), 69–84. doi:10.1007/s10668-005-0188-5

Tessema, M. E., Ashenafi, Z. T., Lilieholm, R. J., & Leader-Williams, N. (2010). *Community attitudes towards wildlife conservation in Ethiopia* (MSc). University of Kent, Canterbury, U K. Retrieved from http://digitalcommons.library.umaine.edu/mitchellcenter_pubs/94

Tomićević, J., Shannon, M. A., & Milovanović, M. (2010). Socio-economic impacts on the attitudes towards conservation of natural resources: Case study from Serbia. *Forest Policy and Economics*, *12*(3), 157–162. doi:10.1016/j.forpol.2009.09.006

Treves, A., & Karanth, K. U. (2003). Human-carnivore conflict and perspectives on carnivore management worldwide. *Conservation Biology*, *17*(6), 1491–1499. doi:10.1111/j.1523-1739.2003.00059.x

URT. (2013). Population and housing census counts 2012. Retrieved February 7, 2018, from http://www.nbs.go.tz/projections/dodoma_projections.pdf

Vodouhê, F. G., Coulibaly, O., Adégbidi, A., & Sinsin, B. (2010). Community perception of biodiversity conservation within protected areas in Benin. *Forest Policy and Economics*, *12*(7), 505–512. doi:10.1016/j.forpol.2010.06.008

Paper IV

Environment and Natural Resources Research; Vol. 8, No. 2; 2018
ISSN 1927-0488 E-ISSN 1927-0496
Published by Canadian Center of Science and Education

Trophy Hunting Versus Ecotourism as a Conservation Model? Assessing the Impacts on Ungulate Behaviour and Demographics in the Ruaha-Rungwa Ecosystem, Central Tanzania

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Received: March 17, 2018 Accepted: April 10, 2018 Online Published: April 20, 2018

doi:10.5539/enrr.v8n2p33 URL: https://doi.org/10.5539/enrr.v8n2p33

Abstract

Trophy hunting may influence wildlife populations in many ways, but these effects have received little consideration in many of Africa's protected areas. We assessed the effects of trophy hunting on group size, behaviour, flight initiation distance, sex ratio and calf recruitment rate in two model species, impala (*Aepyceros melampus*) and greater kudu (*Tragelaphus strepsiceros*), in Rungwa Game Reserve (RGR), Tanzania. The adjoining Ruaha National Park (RNP) served as a control site, since only ecotourism is permitted. Road transects were driven and data recorded immediately upon sighting animals. Both impala and greater kudu had higher flight initiation distances, smaller group size, lower calf recruitment rates and higher levels of vigilance behaviour in RGR compared to those in RNP. Sex ratios did not differ between the two areas. The observed differences are ascribed to the direct and indirect effects of trophy hunting in RGR. Low calf recruitment rates in RGR are of concern, as this may directly compromise population growth rates. Long-term studies may therefore be required to assess how hunted populations are affected by different hunting intensities and at what point this may threaten population persistence.

Keywords: Calf recruitment, flight initiation distance, group size, sex ratio, trophy hunting

1. Introduction

Anthropogenic disturbances affect wildlife populations in many ways (Christiane Averbeck, Apio, Plath, & Wronski, 2009; Lindsey et al., 2013; Lunde, Bech, Fyumagwa, Jackson, & Røskaft, 2016; Matthias Waltert, Meyer, & Kiffner, 2011; Mathias Waltert et al., 2008). In response, animals may exhibit behavioural changes to minimise potentially negative impacts (Hunninck et al., 2017; Nyahongo, 2008; Tingvold et al., 2013). Vigilance, for example, may increase in response to threatening processes (Nyahongo, 2008; Tingvold et al., 2013; Matthias Waltert et al., 2011) and although this may reduce mortality risk, an increase in vigilance incurs costs as time spent on fitness-increasing behaviours is lost to vigilance (Holmern, Setsaas, Melis, Tufto, & Røskaft, 2016). In this way, behavioural modifications carried out by human activities can have indirect negative population-level effects. Particularly invasive disturbances, however, may lead to direct changes in demographic parameters such as sex ratio and recruitment of young (Christiane Averbeck et al., 2009; Love, Chin, Wynne-Edwards, & Williams, 2005; Lunde et al., 2016; Tuomainen & Candolin, 2010). In combination, such processes have the ability to affect a population's reproductive potential and thereby its probability of persistence.

The rapidly increasing global human population exacerbates the extent and severity of negative anthropogenic effects wildlife populations are exposed to. In response, protected areas are playing an increasingly important role in safeguarding ecosystems and the biodiversity they support. In regions with poor rural communities, however, the natural resources within protected areas represent a valuable source of food (plants and animals), timber for construction, firewood, etc. As a result, human population growth is often particularly rapid in areas immediately alongside protected areas (Kideghesho, 2015; Kideghesho, Nyahongo, Hassan, Thadeo, & Mbije, 2006). Protected areas need to be financially viable and, in this regard, may employ a variety of revenue-generating strategies. Strategies may vary greatly and have equally disparate effects on the ecosystems they ultimately seek to conserve. Two strongly opposing, yet frequently implemented models involve either a "national park" approach, where only non-consumptive ecotourism-type activities are permitted, or a "game reserve" management type that permits trophy hunting of, usually, large mammals. While both have the capacity to generate considerable revenue, their potential effects on wildlife populations differ considerably (Hunninck et al., 2017).

In many wild populations, rates of hunting-induced mortality are often substantially higher than natural mortality rates for adult animals (Allendorf & Hard, 2009). Hunted individuals of any wild mammal will, by definition, have a lower reproductive output. Trophy hunting selection and harvesting consequently have considerable effects on the evolution of adult characteristics, particularly the characteristics of prime-aged adults (Milner, Nilsen, & Andreassen, 2007; Whitman, Starfield, Quadling, & Packer, 2004). Phenotypic characteristics such as body size, colour, horns and antlers are used as selective elements of ungulates during hunting practices (Bateman & Fleming, 2014; Festa-Bianchet & Apollonio, 2003; Loveridge, Searle, Murindagomo, & MacDonald, 2007; Milner et al., 2007). Under such scenarios, hunting can lead to unintended selection by reducing the frequency of phenotypes that are favoured by the females for mate choice (Allendorf & Hard, 2009; Ginsberg & Milner Gulland, 1994; Jarman & Jarman, 1973). A more direct and serious effect, however, can result in altered age structures, sex ratios and reduced population sizes due to poorly regulated hunting practices (Tuomainen & Candolin, 2010). Such variables directly affect a population's reproductive capacity and may therefore influence population trends over time.

Tourist hunting contributes large amounts of money to economies of poor countries such as Tanzania, and it is therefore considered an important industry (Gereta, 2010). A positive effect of tourist hunting is that it contributes to control of wildlife populations, as only animals with large populations are hunted given proper quota allocation and adhered to it (Allendorf & Hard, 2009; Christiane Averbeck et al., 2009). The money accrued from hunters through hunting licenses may be put back into programmes that enhance wildlife and environmental conservation (Allendorf & Hard, 2009; Baldus & Cauldwell, 2004). Thus, if hunting is well regulated, sustainable sport hunting can play an important role in wildlife protection and conservation (Balakrishnan & Ndhlovu, 1992; Caro et al., 1998). Direct conservation benefits, as well as ensuring longer-term population persistence through managing land under a consumptive management regime, frequently remain unclear. Furthermore, the direct effects of consumptive activities on animal populations, in contrast to those of an ecotourism model, remain unclear.

1.1 Objective

The objective of this study was to assess the effect of hunting on two common species in Tanzania's Ruaha-Rungwa ecosystem, the impala (*Aepyceros melampus*) and the greater kudu (*Tragelaphus strepsiceros*). This contiguous ecosystem is managed in two separate parts: Ruaha National Park (RNP), where only non-consumptive ecotourism is permitted, and Rungwa Game Reserve (RGR), which derives most of its income from trophy hunting. For both antelope species, we assessed flight initiation distance (FID), sex ratio, recruitment rate, group size and different behaviours in relation to protected area type. We also tested sex ratio, group size, vigilance and feeding behaviour, as well as FID, in relation to habitat type.

1.2 Hypotheses

We hypothesised that impala and kudu in the RGR would show greater FID, smaller group size, more female-skewed sex ratios, lower recruitment rates and higher vigilance behaviour compared to individuals in RNP. We also hypothesised that habitat type would have no effect on group size, behaviour, sex ratio, recruitment and flight initiation distance.

2. Methods

2.1 Study Areas

This study was conducted in Ruaha National Park (RNP) and Rungwa Game Reserve (RGR) during the 2016 and 2017 hunting seasons, which start in July and end in December each year. The two protected areas (PAs) are located in a single continuous ecological ecosystem (Ruaha-Rungwa), covering more than 43,000 km^2 in Central Tanzania (Figure 1). These PAs fall under different management authorities; RNP falls under Tanzania National Parks (TANAPA), and RGR falls under Tanzania Wildlife Management Authority (TAWA). In RNP, only non-consumptive activities, such as photographic safaris and game viewing, are permitted, while the major tourism activity in RGR is trophy hunting. In both management regimes, there are high densities of animals, as well as a high species richness (biodiversity) (MNRT, 2011). The human population growth rate around RNP is 4% annually (URT, 2013). Villages surrounding such sites are increasingly expanding in response to a demand for land and natural resources to alleviate food shortages, reduce poverty and improve livelihood. Wildlife crimes such as poaching occur at a high degree, particularly in RGR (Hariohay, Fyumagwa, Kideghesho, & Røskaft, 2017).

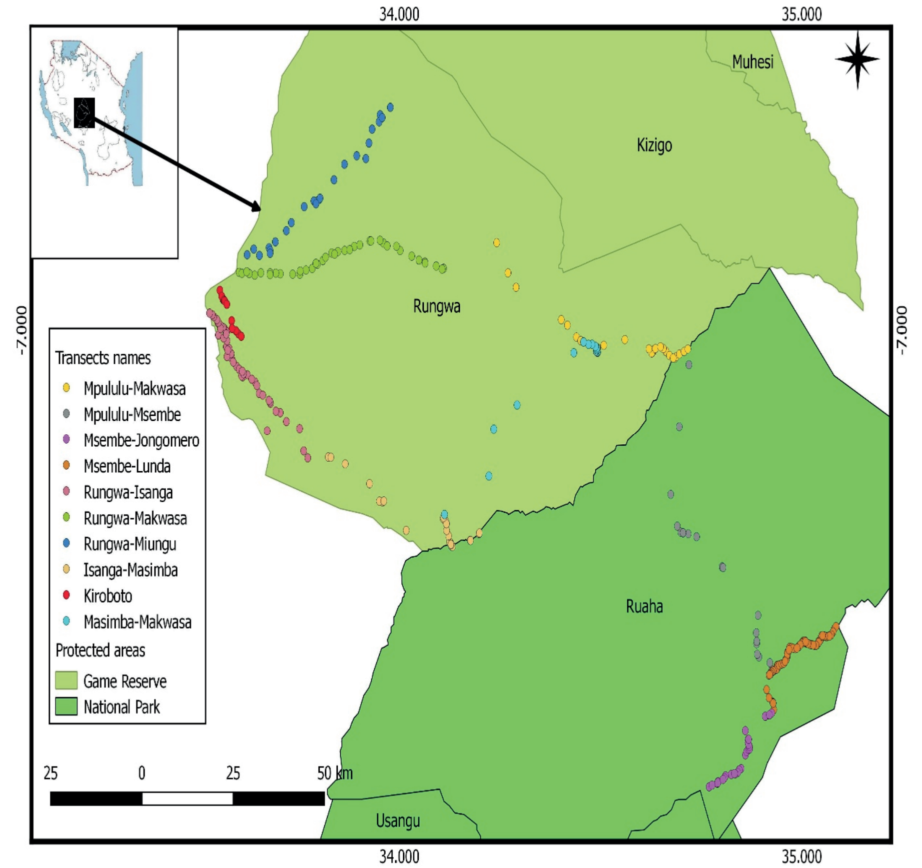

Figure 1. Transects driven in Rungwa Game Reserve and Ruaha National Park

2.3 Study Species

Impala is a medium-sized African antelope, and individuals range between 120-160 cm in length (Averbeck, 2002). Impala are sexually dimorphic antelopes, where only males are horned and are noticeably larger than females (Jarman & Jarman, 1973; Kie, 1999; Lunde et al., 2016). Males stand approximately 75-92 cm tall and weigh 53-76 kg, while females weigh 40-53 kg (C Averbeck, 2002; Christiane Averbeck et al., 2009). Impala inhabit savannah grasslands and woodlands in close proximity to water sources. Impala are mixed foragers of grasses, forbs, monocots, dicots and foliage (Marshal, Grange, & Marneweck, 2012; Wronski, 2002). Impala switch habitats between seasons due to variability of food availability (Marshal et al., 2012; Wronski, 2002). They live in three distinct social groups: 1) female herds with a territorial male, 2) bachelor herds (males in different age groups only) and 3) single territorial males. Their gestation period is six to seven months.

Greater kudu males are considerably larger than females and have spiral horns. Male head-body length is approximately 185-245 cm (Hoffmann, 2016). Greater kudus occur in woodlands, as they are browsers that eat leaves and shoots. In the dry season, they eat wild watermelons and other fruits for their liquid content and the natural sugars that they provide (de Garine-Wichatitsky, Fritz, Gordon, & Illius, 2004). Male kudus can be found in bachelor groups, but they are more likely to be solitary (Hoffmann, 2016; Kie, 1999). Their dominance displays tend not to last long and are generally fairly peaceful, consisting of one male making himself look big by making his hair stand on end. Males are seen with females only in the mating season, when they form groups of 5–15 kudus, including offspring (Hoffmann, 2016). Calves grow quickly and are independent of their mothers starting at six months old.

2.4 Data Collection Techniques

2.4.1 Transects

Fixed transects were established and driven along existing major roads inside RNP and RGR, and off-road driving was done only when it was necessary to come closer to a group of individuals (Okello & Yerian, 2009) (Fig. 1). We used a Land Rover pickup driven at a speed of 10–20 km/h with two observers and one recorder at all times. When a group or single individual (impala, kudu) were sighted, the car was immediately stopped. The GPS position of the car was taken, the distance to the animal(s) was measured with a LEICA LRF 900 SCAN laser rangefinders (LEITZ, Wetzlar, Germany) for distance estimation, and we recorded the total number of individuals, their sexes, ages, initial behaviours (when vehicle stopped), and finally, we took a photo. We established ten road transects, whereby nine of these have a length of 50 km each, and only one road transect had a length of 15 km. In total, we drove 465 km of transects in October 2016 and 465 km in September 2017. The fieldwork lasted for 28 days each year, for a total of 56 days in which we had a total number of observations 283 of impala and 128 observations of greater kudu.

2.4.2 Age and Sex Determination

The ages of individuals were classified into the following classes: 1) calves (10-40% of adult size), 2) young (50-60% of adult size), 3) sub-adults (70-80% of adult size), and 4) adults (90-100% of adult size). In cases of poor visibility, we used a pair of binoculars for classification. In a few cases where we were not able to determine the sex or age of an individual, the variable was recorded as “unknown”. First, we counted all animals, and thereafter, we recorded the sex and age of individuals in a group. During analysis, we determined the sex ratio of the studied species as the ratio of adult and sub-adult females to total numbers of adult and sub-adult individuals of both sexes. Recruitment was estimated as the ratio of calves and young to adult females.

2.4.3 Classification of Group Size

A group was defined as any number (more than one) of individuals that were behaving in a coordinated manner, either moving together in the same direction or engaged in the same activity at any one time and were in close proximity to one another. In each group, individuals were counted, and their initial behaviour (when spotted) was noted (including feeding, vigilance, urine testing, fighting/sparring, resting and moving).

2.4.4 Flight Initiation Distance (FID)

Flight initiation distance (FID) refers to the distance at which an animal reacts by moving or running away from an approaching danger or vehicle, and it is assumed that an animal will make decisions considering both predation risk and potential fitness benefit (Nyahongo, 2008; Setsaas, Holmern, Mwakalebe, Stokke, & Røskaft, 2007). Other researchers define it as an antipredator behaviour and often use FID as a measure of tolerance to different levels of threats in disturbance studies. Thus, a large FID would be expected when the chance of death or serious injury was perceived to be high (Brown et al., 2012). FID is affected by factors such as patch forage quality, reproductive state, risk of capture (e.g., distance from hiding place), speed and direction of the approaching predator, number of predators, individual fitness, group size and starting distance (the distance between predator and prey when approach begins) (Bateman & Fleming, 2014; Holmern et al., 2016). During this study, an individual/group was spotted, and all data were recorded as described, after which we tested FID only when animals did not immediately run away from the car. We used the same method as described by Setsaas et al. (2007); one person walked towards an animal, while another person recorded distances between the person and test animal at the moment of fleeing (Holmern et al., 2016).

2.4.5 Habitat Classification

Habitat was classified into categories of woodland as follows: 1) trees with canopy cover >20% (I = >70%, II = 50-69%, III = 20-49%), 2) bushland (dense woody vegetation <6 m in height), 3) shrubland/bushed grassland (grassland with 2-20% bush canopy), 4) wooded grassland (grassland with 2-20% tree cover), and 5) grassland (grass-dominated).

2.4.6 Behaviour

The following behaviours were recorded: 1) feeding (feeding on vegetation or chewing the cud), 2) walking (slow gait movement from one place to another), 3) vigilance (the time an individual refrained from any other activities, scanning the surrounding environment by standing still, stretching their necks with their heads up), and 4) other behaviours (including resting, urinating, drinking, necking, and mating).

2.5 Statistical Analyses

We performed all statistical data analyses using Statistical Package of Social Science (IBM SPSS statistics for windows, version 19.0, Armonk, NY: IBM Corp) (Alan & Duncan, 2011). We generated ANOVA tests and chi-square tests (χ^2) for comparison of the significance variations in testing the first and second hypotheses (Alan & Duncan, 2011; Bateman & Fleming, 2014). We used chi-square tests to assess the effects of protected area status, year and habitat on the behaviour of impala and greater kudu. We also tested for differences between independent variables (protected area status and habitat types). We performed linear regression analyses to test the interaction effects of different dependent variables, which included group size, sex ratio, recruitment rate of calves, vigilance behaviour and flight initiation distance (FID) on the following independent variables: protected area status (game reserve and national park), year and habitat preference. Statistical significance was set at $P < 0.05$.

3. Results

In total we had 283 observations of impala and 128 greater kudu. Out of 283 observations of impala 37% (n = 105) were from RGR and 63% (n = 178) of impala observation were from RNP. Among the total observation of greater kudu observations 64% (n = 82) came from RGR and 36% (n = 46) grater kudu were observed in RNP.

3.1 Group Size

Group size of the impala did not differ significantly between the first and second year of data collection (Table 1). Impala group size differed significantly between RGR and RNP, with a higher mean group size in RNP and fewer individuals per group in RGR (Table 2). Impala group size varied significantly between different habitats; larger group sizes were observed in grassland, followed by wooded grassland, bushland and shrubland, and the smallest group sizes were found in woodland (Table 3).

We used a linear regression analysis with impala group size as a dependent variable and then included protected area status, year and habitat as independent variables. However, protected area status ($t = 5.48$, $P < 0.001$) was the only significant contributor to the observed 11.3% variation, while year ($t = 1.89$, $P = 0.060$) and habitat type ($t = -0.74$, $P = 0.459$) did not add any significance in explaining the variation in impala group size.

The mean group size of greater kudu herds was significantly larger in the second year than in the first year (Table 1). Furthermore, the mean group size of greater kudu in RGR was significantly smaller than that in RNP (Table 2). Finally, the mean group size of the greater kudu did not vary between different habitats (Table 3). A linear regression analysis was performed with greater kudu group size as a dependent variable and year and protected area status as independent variables. Both protected area status ($t = 4.42$, $P < 0.001$) and year ($t = 2.58$, $P = 0.010$) were significant contributors to the observed 18.4% variation in greater kudu group size.

Table 1. Mean group size, sex ratio, calf-to-female ratio, vigilance behaviour, and flight initiation distance in two different study years of impala and greater kudu in RGR and RNP

Species	Variables	Year 2016		Year 2017		Statistical test		
		Mean±SD	n	Mean±SD	n	F =	df	P
Impala	Group size	9.63±8.29	148	10.73±15.20	135	0.59	1	0.443
	Sex ratio (M/M+F)	0.35±0.38	148	0.39±0.43	135	0.91	1	0.341
	Calves/females	0.17±0.29	115	0.13±0.22	92	1.56	1	0.213
	Vigilant individuals	0.28±0.35	148	0.26±0.41	135	0.35	1	0.557
	Flight distance (m)	45.34±29.39	148	65.16±40.91	135	22.20	1	< 0.001
Greater Kudu	Group size	4.16±2.14	73	5.51±3.43	55	7.40	1	0.007
	Sex ratio (M/M+F)	0.23±0.39	73	0.28±0.33	54	0.616	1	0.433
	Calves/females	0.10±0.21	59	0.20±0.27	46	4.93	1	0.029
	N vigilant/N total	0.48±0.36	73	0.47±0.46	55	0.06	1	0.809
	Flight distance	67.29±32.91	73	76.20±33.41	55	2.27	1	0.134

Table 2. Impala and greater kudu mean differences in group size, sex ratio, calf-to-female ratio, vigilance behaviour, and flight initiation distance in RGR and RNP

Species	Variables	RGR		RNP		Statistical tests		
		Mean±SD	n	Mean±SD	n	F	df	P
Impala	Group size	5.50±4.3	105	12.90±14.20	178	27.15	1	< 0.001
	Sex ratio (M/M+F)	0.35±0.42	105	0.38±0.40	178	0.406	1	0.524
	Calves/females	0.11±0.22	77	0.18±0.27	130	4.46	1	0.036
	N Vigilant/N total	0.48±0.41	105	0.15±0.27	178	60.47	1	< 0.001
	Flight distance (m)	93.09±30.30	105	32.21±14.81	178	512.34	1	< 0.001
Greater Kudu	Group size	3.95±2.18	82	6.15±3.31	46	20.45	1	< 0.001
	Sex ratio (M/M+F)	0.21±0.35	81	0.33±0.38	46	3.28	1	0.073
	Calves/females	0.08±0.19	69	0.26±0.29	36	14.17	1	< 0.001
	N vigilant/N total	0.61±0.38	82	0.24±0.33	46	31.74	1	< 0.001
	Flight distance	84.59±32.33	82	47.11±18.08	46	52.49	1	< 0.001

Table 3. Impala and greater kudu group sizes, sex ratios, calf-to-female ratios, vigilances, and flight initiation distances versus habitat types

Species	Habitat types	WD	WG	G	SH	BU	Statistical tests		
Impala	Variables	Mean±SD n = 59	Mean±SD n = 97	Mean±SD n = 50	Mean±SD n = 55	Mean±SD n = 22	F	df	P
	Group size	7.47±6.30	10.10±15.26	14.80±14.76	9.04±7.50	9.82±7.58	2.76	4	0.028
	Sex ratio (M/M+F)	0.41±0.41	0.38±0.42	0.34±0.41	0.40±0.41	0.18±0.29	1.55	4	0.189
	Calves/females	0.18±0.34	0.14±0.23	0.10±0.20	0.15±0.24	0.23±0.28	0.92	4	0.440
	N vigilant/N total	0.39±0.42	0.25±0.37	0.13±0.28	0.32±0.41	0.24±0.35	3.45	4	0.009
	Flight distance	65.98±41.26	67.63±39.7	33.98±22.38	45.18±27.63	39.55±19.35	11.85	4	< 0.001
Greater kudu	Variables	n = 48 Mean	n = 13 Mean	n = 4 Mean	n = 44 Mean	n = 19 Mean	Statistical test F	df	P
	Group size	4.02±2.31	4.46±2.33	5.50±2.89	5.56±3.39	4.47±2.59	2.14	4	0.079
	Sex ratio	0.29±0.43	0.16±0.29	0.10±0.11	0.23±0.32	0.31±0.40	0.67	4	0.612
	Calves ratio	0.08±0.20	0.10±0.21	0.22±0.31	0.19±0.26	0.21±0.28	1.43	4	0.229
	N vigilant/N total	0.53±0.39	0.54±0.40	0.30±0.24	0.46±0.45	0.38±0.37	0.73	4	0.572
	Flight distance	72.65±30.01	88.46±25.77	43.75±13.77	67.07±34.21	70.53±42.03	1.79	4	0.135

WD (woodland), WG (wooded grassland), G (grassland), SH (shrubland), and BU (bushland).

3.2 Sex Ratio

The impala and greater kudu sex ratios did not vary significantly between different years (Table 1), protected area statuses (Table 2) or between different habitats types (Table 3).

3.3 Calf Recruitment

Impala calf recruitment rates did not vary significantly between different years or habitat types (Tables 1, 3). However, calf recruitment rate differed significantly between protected areas, with much fewer mean calves per adult female in RGR compared to RNP (Table 2).

For greater kudu, the mean number of calves per adult female differed significantly between years, with a higher ratio during the second year (Table 1). Greater kudu calf recruitment ratio also varied between the two protected areas. The calf-to-female ratio in RGR was lower than the recruitment of calves in RNP (Table 2). Mean calf recruitment of greater kudu did not vary significantly between habitat types (Table 3).

A linear regression analysis was completed, with greater kudu calves ratio as a dependent variable and protected area status and year as independent variables. Only protected area ($t = 3.38$, $P < 0.001$) contributed to the observed 14.2% variation, while year ($t = 1.28$, $P = 0.202$) did not add any significance to the observed variation.

3.4 Behaviour

In RGR, out of 105 total observations, 15.2% (n = 16) impala started running immediately once the vehicle was stopped or they heard the sound of the car, while 21.0% (n = 22) were vigilant. In RNP, out of 178 observations, we observed only 2.8% (n = 5) impala running when the car stopped, and 1.1% (n = 2) were vigilant, a significant difference (χ^2 = 59.0, df = 4, P < 0.001). Behaviour did not differ between different habitat types: woodland (10.2% running, n = 6), wooded grassland (8.2% running, n = 8), grassland (6% running, n = 3), shrubland (3.6% running, n = 2) and bushland (9.1% running, n = 2) (χ^2 = 23.4, df = 16, P = 0.103).

The mean numbers of vigilant impala per group did not vary significantly between years (Table 1). A correlation test between the number of vigilant impalas and group size indicated a negative correlation (rho = -0.237, P < 0.001). RGR had a higher number of vigilant individuals per group than did RNP (Table 2). The number of vigilant impala varied significantly between different habitats, with most vigilant individuals found in woodland, followed by wooded grassland, shrubland and bushland, with lowest mean vigilance in grassland (Table 3).

A linear regression analysis with the number of vigilant impala individuals as a dependent variable and group size, protected area status, year and habitat as independent variables indicated that protected area status (t = -6.99, P < 0.001) and group size (t = 2.86, P = 0.005) significantly explained the 22.4% variation in vigilance behaviour of impala, while habitat (t = 1.36, P = 0.214) and year (t = -1.92, P = 0.056) did not add any significance difference to the observed variations.

Greater kudu behaviour differed between RGR and RNP, as slightly more than half of the greater kudu in RNP were feeding (54.3%, n = 25), while only 26.8% (n = 22) were feeding in RGR (χ^2 = 18.1, df = 4, P = 0.001). The behaviour of greater kudu did not vary significantly with any habitat, including woodland (37.5% feeding, n = 18), wooded grassland (38.5% feeding, n = 5), grassland (75% feeding, n = 3), shrubland (27.3% feeding, n = 12) and bushland (42.1% feeing, n = 8) (χ^2 = 2.22, df = 16, P = 0.137).

There was no significant difference in the mean vigilance of greater kudu between years (Table 1). The number of vigilant greater kudu correlated negatively with group size (rho = -0.55, P < 0.001). We recorded a significantly higher number of vigilant individuals in RGR compared to RNP (Table 2). There was no significant difference between mean numbers of vigilant greater kudu in different habitat types (Table 3).

A linear regression analysis with group size, year, protected area status and habitat as independent variables and number of vigilant greater kudus as a dependent variable revealed that group size (t = -5.72, P < 0.001) and protected area status (t = -3.63, P < 0.001) significantly contributed to the observed 16% variation in vigilance behaviour of greater kudu, while habitat (t = -0.04, P = 0.966) and year (t = 1.40, P = 0.163) had no significance.

3.5 Flight Initiation Distance (FID)

The mean distance at which impala ran away from the vehicle was significantly longer in the second year than in the first year (Table 1). The mean FID of impala was significantly longer in RGR compared to RNP (Table 2). The average FID of impala also varied with habitat, as it was significantly longer in wooded grassland, followed by woodland, shrubland and bushland and was lowest in grassland (Table 3).

A linear regression analysis with flight initiation distance as a dependent variable and year and protected area status and habitat as independent variables revealed that year and protected area status significantly contributed to the observed 66% variation in impala FID (protected area status: t = -20.69, P < 0.001; year: t = 2.65, P = 0.009), while habitat (t = 1.28, P = 0.201) did not contribute significantly to the variation.

The mean FID of greater kudu did not differ between years (Table 1). Greater kudu in RNP had significantly lower mean FID than did individuals in RGR (Table 2). The FID of greater kudu did not vary significantly between habitat types (Table 3).

A linear regression revealed that both protected area status and year significantly contributed to the observed 32.4% variation in FID of greater kudu (protected area status: t = -7.53, P < 0.001; year: t = 2.36, P = 0.020).

4. Discussion

4.1 Group Size

The group sizes of both impala and greater kudu were larger in RNP compared to RGR, probably due to the differences in the nature of tourism activities conducted in these two protected areas. Furthermore, Matthias Waltert et al. (2011) reported lower group size of mammals in a hunted area (game reserve) compared to a non-hunted population (national park) in western Tanzania. Similar findings of differences in mean group sizes of impala were found in east Ugalla (less hunting pressure) and west Ugalla (more hunting pressure) in western Tanzania (Wilfred & MacColl, 2016). The smaller group sizes in RGR might be due to the direct effects of trophy hunting, as well as behavioural responses resulting in animals selecting safer habitats further from roads, which are frequently used by hunters. Larger group sizes were observed in the greater kudu populations during the second study year, which might suggest less hunting impact during this period. However, no changes in impala group sizes were recorded between years, and these differences are therefore difficult to interpret.

We found no effect on habitat in greater kudu; however, impala group size was larger in wooded grassland habitats. This difference might have been because impala preferred this habitat for feeding along the rivers where they drink water. Thus, our first hypothesis, that we expect smaller group sizes in RGR than in RNP in both impala and greater kudu, was supported, while our second hypothesis, that there should be no differences between different habitats, was supported by greater kudu observations only. Further testing is necessary to better understand the effect of habitat type on impala group size.

4.2 Sex Ratio

Our results do not support the hypothesis that hunting skews sex ratios towards females. However, unlike our findings the other researchers Marealle, Fossøy, Holmern, Stokke, and Røskaft (2010) reported a female-skewed sex ratio in high poaching risk areas in the Serengeti ecosystem. Furthermore, Milner et al. (2007) reported a female-biased sex ratio in a hunted population. Wilfred and MacColl (2016) found a more pronounced female-skewed sex ratio of mammals in Ugalla Game Reserve (trophy hunting) than in the Katavi National Park (ecotourism). Ndibalema (2009) found a female-biased sex ratio in wildebeest (*Connochaetes taurinus*), and Magige, Holmern, Stokke, Mlingwa, and Røskaft (2009) reported a female-biased sex ratio in ostrich (*Struthio camelus*) in the Serengeti ecosystem. Thus, the Serengeti, an area with high poaching activity, had more female-skewed sex ratios as compared to areas with low poaching activity, which is similar to our results. Our first hypothesis, that we expected a more female-biased sex ratio in RGR than in RNP in both impala and greater kudu, was not supported, while the second hypothesis, that there will be no differences between different habitats, was also supported.

4.3 Calf Recruitment

The recruitment of calves for both impala and greater kudu was lower in RGR than in RNP. Selective removal through trophy hunting probably affects the mammals' fitness by lowering the recruitment rate via either higher calf mortality or lower fecundity, when the proportion of males is below a tolerable threshold in the hunted population (Milner et al., 2007). Selective harvesting by trophy hunters might have negative effects on mammal populations by reducing calf recruitment if the proportion of males harvested goes below the accepted threshold (Milner et al., 2007). However, if hunting is well controlled, there will be less harm to the calves, as in species such as impala, one adult male may be capable of impregnating several adult females (Caro et al., 1998; Milner et al., 2007). On the other hand, trophy hunting disturbances reduce feeding opportunities and increase the level of stress (Benhaiem et al., 2008). Such disturbances may reduce the body conditions that result in reduced breeding efforts, lowering calf survival (Milner et al., 2007). Temporal variation over years was only found in the greater kudu population. We found higher mean recruitment rates in the second year. This might have been because the data in the second year were collected in August and September, whereas data in the first year were collected in October. The difference between years might have been due to the fact that data collection in the second year was closer to the months of March-April, which are the months when most calving occurs in greater kudu, which might have contributed to the observation of more young in the second year compared to the first. We hypothesised that there would be differences in recruitment of calves/young (i.e., a lower calf-to-female ratio in RGR than in RNP). This hypothesis was supported; however, we had also hypothesised that habitat would have no effect on calf recruitment, and our results also supported this idea. Our results might well indicate that Ruaha is an important resource for the Rungwa impala and kudu populations, a hypothesis that needs further testing.

4.4 Behaviour

The majority of impala and greater kudu groups were more vigilant and fleeing at longer distances in RGR. This supports our hypothesis that mammals in the RGR would show more vigilance behaviour than those in RNP. A study in western France found an increased vigilance level in a hunted roe deer (*Capreolus capreolus*) population (Benhaiem et al., 2008). Animals were more relaxed in RNP, where we found feeding behaviour, followed by resting, to be the dominant behaviour in impala groups. In contrast, the dominant behaviour in RGR was running, followed by feeding. This is most likely due to the difference in disturbance levels, resulting in the fact that the studied RGR animals devote less time to feeding in a highly disturbed area. The French study found that roe deer trade off risk avoidance for food availability and spend more time vigilant during hunting season (Benhaiem et al., 2008). Trophy hunting causes more disturbance to wild mammals than does game viewing and photographic tourism activities, which have comparatively less disturbance on wild mammal behaviour and stress level (Allendorf & Hard, 2009; Hunninck et al., 2017; Lunde et al., 2016; Marealle & Røskaft, submitted; Setsaas et al., 2007). We also found support for our hypothesis that there should be no differences in behaviour between habitats.

The flight initiation distance was much higher in the hunting area (RGR). The antipredator behaviour of the RGR impala and greater kudu might have been shaped by game hunting, as we observed larger mean FID there compared to RNP. Hunninck et al. (2017) found that elephants are more stressed outside the national park than those within the Etosha National Park in Namibia and Holmern et al. (2016) in the Serengeti National Park. Findings by Brown et al. (2012) in the Grand Teton National Park in northwestern Wyoming, USA, indicated that elk (*Cervus elaphus*) and pronghorn (*Antilocapra americana*) were responsive towards passing vehicles. Impala FID was much higher in the second year of data collection of our study. The difference between years might have been because when data was collected in the second year, the hunting season was at its peak in RGR, with a subsequent higher level of disturbance. There was no difference between years in the RNP population. Habitat types influenced FID in impala, with higher FID in wooded grassland; this might have been because a greater proportion of impala observations were made in this habitat type, which thereby influenced the observed variations in FID. Thus, our second hypothesis was partly supported, but no differences were observed between habitat types for greater kudu.

5. Conclusion and Recommendations

Data on animal group size, sex ratio, recruitment rate, behaviour and their flight initiation distances are important in determining the impacts of disturbances on animal populations. Our results indicate that in hunted populations, animals showed clear signs of disturbance, as they had smaller group sizes, lower calf recruitment rates and were more nervous than conspecifics in the absence of trophy hunting in RNP. An implication of this might be that RGR is dependent on RNP for recruitment or, alternatively, that we might expect a dramatic decline in hunted populations in Rungwa. However, this conclusion needs further testing and long-term monitoring. Studies similar to ours may be useful to assess how activities associated with different types of protected areas may influence animal stress, behaviour and key demographic parameters. Furthermore, these effects represent important considerations for managers setting hunting quotas.

Acknowledgements

We are thankful to the EU Horizon-2020 financed project under GA 641918 (*AfricanBioServices*) for funding the write up of this research. Furthermore, we extend our gratitude to the Tanzania Wildlife Management Authority (TAWA), Tanzania National Parks (TANAPA), and the Tanzania Wildlife Research Institute (TAWIRI) for granting us the access to conduct this research study. We would also like to extend our thanks to Maulid Mdaki, Onesmo Mwakabejela, Jaredy Makongoro, David Kyangi, Samwel Pere Mollel and Rajabu Kamota for assistance in the field.

References

Alan, B., & Duncan, C. (2011). Quantitative Data Analysis with IBM SPSS 17, 18 and 19: A Guide for Social Scientists. New York: Routledge.

Allendorf, F. W., & Hard, J. J. (2009). Human-induced evolution caused by unnatural selection through harvest of wild animals. *Proceedings of the National Academy of Sciences of the United States of America, 106*, 9987-9994. http://dx.doi.org/10.1073/pnas.0901069106

Averbeck, C. (2002). *Population ecology of impala (Aepyceros melampus) and community-based wildlife conservation in Uganda.* Technische Universität München. Retrieved from http://tumb1.biblio. tumuenchen.de/publ/diss/ww/2002/averbeck.html

Averbeck, C., Apio, A., Plath, M., & Wronski, T. (2009). Hunting differentially affects mixed-sex and bachelorherds in a gregarious ungulate, the impala (*Aepyceros melampus*). *African Journal of Ecology, 48*, 255-264. http://dx.doi.org/10.1111/j.1365-2028.2009.01118.x

Balakrishnan, M., & Ndhlovu, D. (1992). Wildlife utilization and Local people: a case study in upper Lupande Game Management Area, Zambia. *Environmental Conservation, 19*(2), 135-144. http://dx.doi.org/10.1017/ S0376892900030617

Baldus, R. D., & Cauldwell, A. E. (2004). *Tourist hunting and its role in development of wildlife management areas in Tanzania*. Paper presented at the Sixth International Game Ranching Symposium, Paris, France. Retrieved from http://www.wildlife-baldus.com/download/hunting_wma.pdf

Bateman, P. W., & Fleming, P. A. (2014). Living on the edge: effects of body size, group density and microhabitat selection on escape behaviour of southern leopard frogs Lithobates sphenocephalus. *Current Zoology, 60*(6), 712-718. http://dx.doi.org/10.1093/czoolo/60.6.712

Benhaiem, S., Delon, M., Lourtet, B., Cargnelutti, B., Aulagnier, S., Hewison, A. J. M., ... Verheyden, H. (2008). Hunting increases vigilance levels in roe deer and modifies feeding site selection. *Animal Behaviour, 76*(3), 611-618. http://dx.doi.org/10.1016/j.anbehav.2008.03.012

Brown, C. L., Hardy, A. R., Barber, J. R., Fristrup, K. M., Crooks, K. R., & Angeloni, L. M. (2012). The effect of human activities and their associated noise on ungulate behavior. *Plos One, 7*(7). http://dx.doi.org/10.1371/journal.pone.0040505

Caro, T. M., Pelkey, N., Borner, M., Severre, E. L. M., Campbell, K. L. I., Huish, S. A., ... Woodworth, B. L. (1998). The impact of tourist hunting on large mammals in Tanzania: an initial assessment. *African Journal of Ecology, 36*(4), 321-347. http://dx.doi.org/10.1046/j.1365-2028.1998.00146.x

de Garine-Wichatitsky, M., Fritz, H., Gordon, I. J., & Illius, A. W. (2004). Bush selection along foraging pathways by sympatric impala and greater kudu. *Oecologia, 141*(1), 66-75. http://dx.doi.org/10.1007/s00442-004-1630-3

Festa-Bianchet, M., & Apollonio, M. (2003). Exploitative wildlife management as a selective pressure for life-history evolution of large mammals *Animal behavior and wildlife conservation* (pp. 191-207). Washington, Covelo, London: Island Press.

Gereta, E. (2010). The role of biodiversity conservation in development of the tourism industry in Tanzania. In E. E. Gereta, & E. Røskaft (Eds.), *Conservation of natural resources; Some African & Asian examples* (pp. 23-49). Trondheim: Tapir academic press.

Ginsberg, J. R., & Milner Gulland, E. J. (1994). Sex biased harvesting and population dynamics in ungulates: Implications for conservation and sustainable use. *Conservation Biology, 8*(1), 157-166. http://dx.doi.org/10.1046/j.1523-1739.1994.08010157.x

Hariohay, K. M., Fyumagwa, R. D., Kideghesho, J. R., & Røskaft, E. (2017). Assessing crop and livestock losses along the Rungwa-Katavi Wildlife Corridor, South-Western Tanzania. *International Journal of Biodiversity and Conservation, 9*(8), 273-283. http://dx.doi.org/10.5897/IJBC2017.1116

Hoffmann, M. (2016). IUCN SSC Antelope Specialist Group: Assessment of *Tragelaphus strepsiceros*, greater kudu. Retrieved 20.12.2017, 2017, from http://www.iucnredlist.org

Holmern, T., Setsaas, T. H., Melis, C., Tufto, J., & Røskaft, E. (2016). Effects of experimental human approaches on escape behavior in Thomson's gazelle (*Eudorcas thomsonii*). *Behavioral Ecology, 27*(5), 1432-1440. http://dx.doi.org/10.1093/beheco/arw052

Hunninck, L., Ringstad, I. H., Jackson, C. R., May, R., Fossøy, F., Uiseb, K., ... Røskaft, E. (2017). Being stressed outside the park—conservation of African elephants (Loxodonta africana) in Namibia. *Conservation Physiology, 5*(2017), 11. http://dx.doi.org/10.1093/conphys/cox067

Jarman, P. J., & Jarman, M. V. (1973). Social behaviour, population structure and reproductive potential in impala. *East African Wildlife Journal, 11*, 329-338. http://dx.doi.org/10.1111/j.1365-2028.1973.tb00097.x

Kideghesho, J. R. (2015). Realities on deforestation in Tanzania: trends, drivers, implications and the way forward. *Precious Forests-Precious Earth, 2017*(21.12). http://dx.doi.org/10.5772/61002

Kideghesho, J. R., Nyahongo, J. W., Hassan, S. N., Thadeo, C., & Mbije, N. E. (2006). Factors and ecological impacts of wildlife habitat destruction in the Serengeti ecosystem in northern Tanzania. *Ajeam Ragee.* Retrieved 27.08, 2017, from https://pdfs.semanticscholar.org/01a0/e19b0229abe4e8a984f3399d3f3e1e23ae3d.pdf

Kie, J. G. (1999). Optimal foraging and risk of predation: Effects on behavior and social structure in ungulates *Mammalogy, 80*(4), 1114-1129. doi: http://dx.doi.org/10.2307/1383163

Lindsey, P. A., Balme, G. A., Funston, P., Henschel, P., Hunter, L., Madzikanda, H., ... Nyirenda, V. (2013). The trophy hunting of African lions: Scale, current management practices and factors undermining sustainability. *Plos One, 8*(9). http://dx.doi.org/10.1371/journal.pone.0073808

Love, O. P., Chin, E. H., Wynne-Edwards, K. E., & Williams, T. D. (2005). Stress hormones: A link between maternal condition and sex-biased reproductive investment. *American Naturalist, 166*(6), 751-766. http://dx.doi.org/10.1086/497440

Loveridge, A. J., Searle, A. W., Murindagomo, F., & MacDonald, D. W. (2007). The impact of sport-hunting on the population dynamics of an African lion population in a protected area. *Biological Conservation.* Retrieved 11.01, 2018, from http://www.sciencedirect.com/science/journal/00063207

Lunde, E. T., Bech, C., Fyumagwa, R. D., Jackson, C., & Røskaft, E. (2016). Assessing the effect of roads on impala (Aepyceros melampus) stress levels using faecal glucocorticoid metabolites. *African Journal of Ecology, 54*(4), 434-441. http://dx.doi.org/10.1111/aje.12302

Magige, F., Holmern, T., Stokke, S., Mlingwa, C., & Røskaft, E. (2009). Does illegal hunting affect density and behaviour of African grassland birds? A case study on ostrich (*Struthio camelus*). *Biodiversity and Conservation, 18*(5), 1361-1373. http://dx.doi.org/10.1007/s10531-008-9481-6

Marealle, W. N., Fossøy, F., Holmern, T., Stokke, B. G., & Røskaft, E. (2010). Does illegal hunting skew Serengeti wildlife sex ratios? *Wildlife Biology, 16*(4), 419-429. doi: http://dx.doi.org/10.2981/10-035

Marealle, W. N., & Røskaft, E. (submitted). Factors affecting group size and vigilance behaviour of Maasai giraffe (*Giraffa camelopardalis tippelskirchi*) in the Serengeti-Ngorongoro ecosystem, Tanzania. *African Journal of Ecology, submitted*.

Marshal, J. P., Grange, S., & Marneweck, D. (2012). Seasonal variation in body condition of impala at Manyeleti Game Reserve, South Africa. *South African Journal of Wildlife Research, 42*(2), 128-137. http://dx.doi.org/10.3957/056.042.0212

Milner, J. M., Nilsen, E. B., & Andreassen, H. P. (2007). Demographic side effects of selective hunting in ungulates and carnivores. *Conservation Biology, 21*(1), 36-47. http://dx.doi.org/10.1111/j.1523-1739.2006.00591.x

MNRT. (2011). *Rungwa-Kizigo-Muhesi Game Reserves general management plan*. Dar es Salaam: Government printers.

Ndibalema, V. G. (2009). A comparison of sex ratio, birth periods and calf survival among Serengeti wildebeest sub-populations, Tanzania. *African Journal of Ecology, 47*(4), 574-582. http://dx.doi.org/10.1111/j.1365-2028.2008.00994.x

Nyahongo, J. W. (2008). Flight initiation distances of five herbivores to approaches by vehicles in the Serengeti National Park, Tanzania. *African Journal of Ecology, 46*(2), 227-229. http://dx.doi.org/10.1111/j.1365-2028.2007.00818.x

Okello, M. M., & Yerian, S. (2009). Tourist satisfaction in relation to attractions and implications for conservation in the protected areas of the Northern Circuit, Tanzania. *Journal of Sustainable Tourism, 17*(5), 605-625. http://dx.doi.org/10.1080/09669580902928450

Setsaas, T. H., Holmern, T., Mwakalebe, G. G., Stokke, S., & Røskaft, E. (2007). How does human exploitation affect impala populations in protected and partially protected areas? a case study from the Serengeti ecosystem, Tanzania. *Biological Conservation, 136*(4), 563-570. http://dx.doi.org/10.1016/j.biocon.2007.01.001

TAWIRI. (2010). Aerial census in the Serengeti ecosystem (C. I. a. M. Unit, Trans.). Arusha: Tanzania Wildlife Research Institute.

Tingvold, H. G., Fyumagwa, R., Baardsen, L. F., Rosenlund, H., Bech, C., & Røskaft, E. (2013). Determining adrenocortical activity as a measure of stress in African elephants (*Loxodonta africana*) in relation to human activities in Serengeti ecosystem. *African Journal of Ecology, 51*, 580-589. http://dx.doi.org/10.1111/aje,12069

Tuomainen, U., & Candolin, U. (2010). Behavioural responses to human-induced environmental change. *Biological Reviews*. http://dx.doi.org/10.1111/j.1469-185X.2010.00164.x

URT. (2013). Population and housing census counts 2012. Retrieved 7th February, 2018, from http://www.nbs.go.tz/projections/dodoma_projections.pdf

Waltert, M., Meyer, B., & Kiffner, C. (2011). Habitat availability, hunting or poaching: what affects distribution and density of large mammals in western Tanzanian woodlands? *African Journal of Ecology, 47*(4), 737–746. doi: http://dx.doi.org/10.1111/j.1365-2028.2009.01080.x

Waltert, M., Meyer, B., Shanyangi, M. W., balozi, J. J., Kitwara, O., Qolli, S., ... Muhlenberg, M. (2008). Foot surveys of large mammals in woodlands of western Tanzania. *Journal of Wildlife Management, 72*(3), 603–610. doi: http://dx.doi.org/10.2193/2006-456

Whitman, K., Starfield, A. M., Quadling, H. S., & Packer, C. (2004). Sustainable trophy hunting of African lions. *Nature, London, 428*(6979), 175-178. http://dx.doi.org/10.1038/nature02395

Wilfred, P., & MacColl, A. D. C. (2016). Status of wildlife at trophy hunting sites in the Ugalla Game Reserve of Western Tanzania. *Tropical Conservation Science*, 1-10. http://dx.doi.org/10.1177/1940082916667336

Wronski, T. (2002). Feeding ecology and foraging behaviour of impala (*Aepyceros melampus)* in lake Mburo National Park, Uganda. *African Journal of Ecology, 40*(3), 205-211. http://dx.doi.org/10.1046/j.1365-2028.2002.00348.x

Paper V

Global Ecology and Conservation 16 (2018) e00522

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Original Research Article

Drivers of conservation crimes in the Rungwa-Kizigo-Muhesi Game Reserves, Central Tanzania

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ARTICLE INFO

Article history:
Received 4 October 2018
Received in revised form 2 January 2019
Accepted 2 January 2019

Keywords:
Bushmeat poaching
Conservation criminology
Elephant
Illegal timber logging
Wildlife poaching

ABSTRACT

Conservation crimes are posing serious threats to wildlife species and biodiversity of the Rungwa-Kizigo-Muhesi-Game-Reserves. Devising effective strategies to reduce risks to as low as reasonably possible of these crimes, calls for adequate information on factors driving people to commit these crimes. Data for this study were obtained from 315 respondents in 20 villages and 316 people who were arrested for committing different conservation crimes in the Rungwa-Kizigo-Muhesi-Game-Reserves. Our results suggest that arrested respondents were typically young adult males with limited alternative sources of income and owning virtually no livestock or land. There were heterogeneous drivers for each type of conservation crime. To address the challenge of conservation crimes in the Reserve, we recommend, among other strategies, the establishment of effective conservation education programmes, strengthening law enforcements as a deterrence method, and development of entrepreneurship skills to enhance employment.

1. Introduction

Conservation crime is a major challenge facing many game reserve managers in Africa and elsewhere (Gibbs et al., 2010; Essen et al., 2014). The crime is often conducted to cater for commercial and/or subsistence needs. There is no universally accepted definition of the term conservation crime. However, a general consensus suggests that conservation crime impacts negatively on people and survival of fauna and flora (Gore, 2011; Ayling, 2013; Essen et al., 2014; Potter et al., 2016; Rizzolo et al., 2017). Conservation crime, therefore, entails illegal activities such as poaching, capture, collection or processing of animals and plants taken in contravention of national, regional or international laws, and any subsequent trade in such animals and plants, including their derivatives or products (Cooper et al., 2009; Kideghesho, 2016; Potter et al., 2016). For this article, activities such as mining, timber extraction and bushmeat hunting were categorized as local/regional markets, while the other sub-category is poaching for the international market with very high market value products such as African elephant (*Loxodonta africana*) ivory.

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https://doi.org/10.1016/j.gecco.2019.e00522

There are different types of conservation criminals; firstly, those who perform subsistence conservation crimes to meet food needs and or in exchange of food materials such as maize, sugar, salt etc. Such people mostly use less expensive technology such as traps, wire snares but with severe impact on wildlife populations because snares and traps are non-selective (Essen et al., 2014). Illegal logging, illegal bushmeat hunting and illegal mining are often driven by need for sources of cash income and domestic subsistence uses, whereas illegal livestock grazing is driven by the availability of pasture and water resources in protected areas (PAs) due to lack of or deteriorated grazing land outside the PA (Mgawe et al., 2012; Ceppi and Nielsen, 2014; Kiffner et al., 2015; Knappa et al., 2017; Dudley et al., 2018). Naturally, the dependence on natural resources is higher among relatively poor households than wealthier ones, but it does not necessarily translate greater levels of extraction as they use poor technology (Duffy and St John, 2013). Poverty impedes conservation because poaching and environmental degradation is often pursued by the poor in a short-sighted way. Normally, such people will not think of long term consequences of the unsustainable use of natural resources (Loibooki et al., 2002; Duffy and St John, 2013; Essen et al., 2014; Kideghesho, 2016; Knappa et al., 2017). Poverty normally encourage people to poach, but sometimes people poach as part of social resistance, cultural expression, to get cash money, or as a source of food (Duffy and St John, 2013; Knappa et al., 2017; Kyando et al., 2017). Individuals from poor communities would for instance not engage themselves in poaching of commercially valuable species, unless there has been a demand from wealthier communities (Duffy and St John, 2013). Secondly, are the commercial criminals who target commercially valuable species such as black rhinos (*Diceros bicornis*) and African elephants (Ayling, 2013; Duffy and St John, 2013). Thus, there is a need for different approaches for different types of crimes to control such different crimes (Duffy and St John, 2013; Essen et al., 2014). According to Brennan and Kalsi (2015) many seizures have been associated with China, but multiple transit-hub countries (e.g. Hong Kong, Malaysia, Thailand and Japan) are involved in the movement of illegal ivory originated from East Africa.

Conservation crimes threaten earth's natural ecosystems, wildlife species, and people (Gibbs et al., 2010; Essen et al., 2014; Kideghesho, 2016). Overharvesting of mammals such as elephants and habitat loss due to illegal timber logging, and subsequent decline of most of the species listed by the World Conservation Union (IUCN) as threatened. Hunting and international trade contribute to approximately one-third of the bird and mammal species listed as threatened by the IUCN. Furthermore, the situation is striking in Africa due to an increasing number of consumers (>1 billion in 2010), that is expected to reach 1.6 billion around 2040 (Apaza et al., 2002; Ripple et al., 2016). Overexploitation of wildlife resources have recently increased due to the fact that the human population has increased in Tanzania from 12 million people in 1967 to more than 54 million people in 2017 (URT, 2017), accompanied by other factors such as interconnectivity through development of infrastructures such as telephone and road networks, airports, railways as well as shipping which has become significantly cheaper after the 2008 global financial crisis (Brennan and Kalsi, 2015). In Tanzania, illegal logging for timber is a major problem facing virtually all PAs (Kideghesho et al., 2006; Kideghesho, 2015). Illegal timber logging, threaten many species of extinction due to habitat loss caused by environmental degradation and deforestation (Prendergast and Adams, 2003; Essen et al., 2014; Kideghesho, 2015). For example, the black rhino population in Africa dropped by 97.6% since 1960 (Leader-Williams et al., 1990; Metzger et al., 2007; AWF, 2018). The number of mountain gorillas (*Gorilla beringei beringei*) is around 1000 individuals (Robbins et al., 2018), while only 2680 individual Grevy's zebras (*Equus grevyi*) remained on the African continent in 2016, 90% of which are found in northern Kenya (O'Brien et al., 2018). Land conversion, for agriculture and settlements, has reduced the lion's (*Panthera leo*) historical range by more than 80% and reduced the numbers to an estimated total population of 20,000–30,000 across Africa (Lindsey et al., 2012; Bauer et al., 2015; O'Brien et al., 2018). The population of African elephants has been declining over time due to poaching and other crimes. For example, the numbers declined from 3 to 5 million in the 1930s to 1.3 million in the 1970s to less than 500,000 in 2007 (Blanc et al., 2007). The population has further declined to around 350,000 in 2014 (Chase et al., 2016) whereas the Tanzania population consisted of only 42,272 individuals (Chase et al., 2016). The Ruaha-Rungwa ecosystem held ca. 15,000 elephants in 2015 (TAWIRI, 2015).

Understanding the factors and drivers of conservation crimes are important in devising mitigation measures, which will halt conservation crime in PAs. Loibooki et al. (2002) and Nielsen and Meilby (2013) analysed demographic characteristics and socio-economic activities of illegal harvesters of wildlife resources as an alternative in understanding and tackling the poaching activities. Most societies living in rural villages close to protected areas in Tanzania consist of small scale peasant farmers owning no/or a few livestock as well as only small pieces of arable land (Campbell et al., 2001; Sunderland et al., 2009; URT, 2012; Lindsey et al., 2015; Knappa et al., 2017). They therefore frequently seek alternative income activities, of which logging, mining, and hunting are feasible alternatives (Campbell et al., 2001; Frosta and Ivan, 2008; Ayling, 2013). Communities living adjacent to PA depend on these areas for firewood, poles and timber for construction, and bushmeat as a source of protein or income (Knapp, 2012; Kideghesho, 2016; Dudley et al., 2018). Rural dwellers lacking alternative sources of income resort to bushmeat as an important source of protein as it is relatively cheaper compared to other alternative protein sources (beef, chicken, bacon etc.) (Ndibalema and Songorwa, 2007; Mfunda and Røskaft, 2010). Rentsch and Damon (2013) worked out a comparative analysis between the price of bushmeat and the alternative protein sources in eight communities in the Serengeti Ecosystem to establish its influence on bushmeat consumption. Their paper suggested that economic motivation had the biggest effect, while, culture also influenced bushmeat consumption. Most Tanzanians, including those living close to the national parks and game reserves, live below the US $1 a day (URT, 2012). Socio-economic conditions of local communities in most conservation areas have been considered in many discussions of conservation criminology (Prendergast and Adams, 2003; Holmern et al., 2007; Essen et al., 2014).

Various studies (e.g., Mgawe et al. (2012); Ceppi and Nielsen (2014)) have documented that participation in conservation crime in game reserves is driven by factors such as income poverty, lack of accessibility to property ownership (livestock and land), and unemployment. However, in Tanzania, most of these studies have largely been focused on the Serengeti ecosystem (Holmern, 2010), Katavi ecosystem (Mgawe et al., 2012; Martin and Caro, 2013), Tarangire ecosystem (Kiffner et al., 2015) and areas around the Udzungwa mountains (Nielsen, 2006; Nielsen et al., 2013). The conservation crimes are not limited to these ecosystems and are likely common in other areas as well. Rungwa Game Reserve is another part of Tanzania where these crimes are widespread. This has prompted a need for analysis of these crimes by uncovering their drivers. Additionally, this study had an opportunity to use data from arrested alleged criminals which is very rare. The findings of this study provide a more pragmatic way of addressing these crimes in the study area and other PAs of Tanzania.

The main objective of this study was to assess the socio-demographic characteristics of the arrested people in the RKM GRs. Specific objectives were; 1) to assess socio-demographic characteristics of the arrested alleged conservation criminals and 2) to examine drivers behind different categories of conservation crimes in the RKM GRs. First, we hypothesized that different conservation crimes (illegal hunting for bushmeat, illegal timber logging, elephant poaching, illegal mining, and illegal livestock grazing) will decrease with land and livestock ownership (yes/no), as well as availability of employment. Thus, we predicted that people who owned land, livestock and those who were employed would less likely engage themselves in elephant poaching, illegal timber logging and illegal mining. Second, we hypothesized that involvement in illegal hunting for bushmeat, illegal timber logging, elephant poaching, illegal mining, and illegal livestock grazing will increase with decreased distance to the boundary of PA. Third, we hypothesized that young people in the age group 18–36 years and with immigrant tribal background (ethnicity) engaged themselves more in the conservation crimes than the elder or indigenous respondents. Other studies as e.g. Knapp (2012) and Loibooki et al. (2002) indicated that involvement in bushmeat poaching varied with age, sex, ethnic tribe, and property ownership in the western Serengeti National Park, therefore testing the hypotheses will help understanding if the factors also operate in other protected areas such as in our study area.

2. Material and methods

2.1. Study area

The Rungwa-Kizigo-Muhesi Game Reserves (RKM GRs) are mostly located in Manyoni in the Singida Region (98%), Central Tanzania, while 2% of this area is situated in the Chunya District in Mbeya Region (MNRT, 2011). These three reserves are managed as one entity with headquarters based in Rungwa village in the Manyoni district. The reserves also border the Sikonge district (Tabora region), Iringa rural district (Iringa region) and Chamwino district (Dodoma region) (Hariohay et al., 2017). The total area of these three reserves, which is under Tanzania Wildlife Management Authority (TAWA), totals 17,340 km^2 (MNRT, 2011) (Fig. 1). In Tanzania, according to the Wildlife Conservation Act No. 5 of 2009, entry into protected areas without prior permission from the director of wildlife, is considered an unlawful entry and is therefore punishable according to the court of law (URT, 2009). Furthermore, this law also states that grazing livestock, mining, or hunting of game without a permit in a game reserve is regarded as an illegal activity. The crime also includes activities that affect wildlife more indirectly, such as pollution of waterways that results in damage to fish or other wildlife species, or the destruction of protected wildlife habitats through illegal livestock grazing and mining (Eliason, 2009). Human populations, growth rates, human densities (people/square kilometres) of the adjacent districts to the RKM GRs are indicated in Table 1, with an estimated population of more than 900,000 people, in the year 2017 in the four study districts.

The area is home to approximately 300 species of birds and a wide diversity of large mammals. Common mammals are the greater kudu (*Strepsiceros strepsiceros*), lesser kudu (*Strepsiceros imberbis*), African elephant, eland (*Taurotragus oryx*), Maasai giraffe (*Giraffa camelopardalis*), impala (*Aepyceros melampus)*, Coke's hartebeest (*Alcelaphus buselaphus cokii*), southern reedbuck (*Redunca redunca*), roan antelope (*Hippotragus equinus*), sable antelope (*Hippotragus niger*), warthog (*Phacochoerus aethiopicus*), common waterbuck (*Kobus ellipsiprymnus*) and plain zebra (*Equus burchellii*). The elevation ranges from 800 m asl at the Kizigo/Nzombe river and confluence to 1800 m asl at the Ikili hill (MNRT, 2011). The area experiences a long dry season from June to November, and a single rainy season from November to April. The amount of rainfall ranges from 500 mm to 700 mm, and the mean annual temperature is 28 °C (Nahonyo, 2005). The main ethnic groups in the study area include Nyakyusa, Kimbu, Taturu, Nyaturu, Gogo, Safwa, Sangu and Sukuma. Their main social economic activities are crop cultivation (>60%) and livestock ownership (33%), while beekeeping and some formal employment are in the minority (7%).

2.2. Data collection

Data for this study were collected using a semi-structured interview questionnaire survey, which involved a total of 631 respondents. There were two sets of data (alleged conservation criminals n = 316 and control group n = 315) (Table 2). The first set of data was obtained from the arrested alleged conservation criminals (n = 316), from a total of 32 patrols (i.e. 9.9 arrest per patrol) in the Rungwa-Kizigo-Muhesi Game Reserves between January 2014 and April 2015 (1 year and 4 months). Information was obtained using pre-designed semi-structured questionnaires completed by Game Reserve rangers during interviews. The use of game rangers was the only way to access these data as non-rangers or game wardens were not allowed to be partners in the patrol team. However, only one ranger or game warden per group was trained to interview arrested alleged criminals using a predesigned questionnaire in a face-to-face interview. The patrol team went out for patrol approximately every two weeks. The patrol leaders were given forms to record the details of alleged conservation criminals immediately at the time of arresting, including age, sex, tribe, their residency (born in the area, or immigrated), assets owned

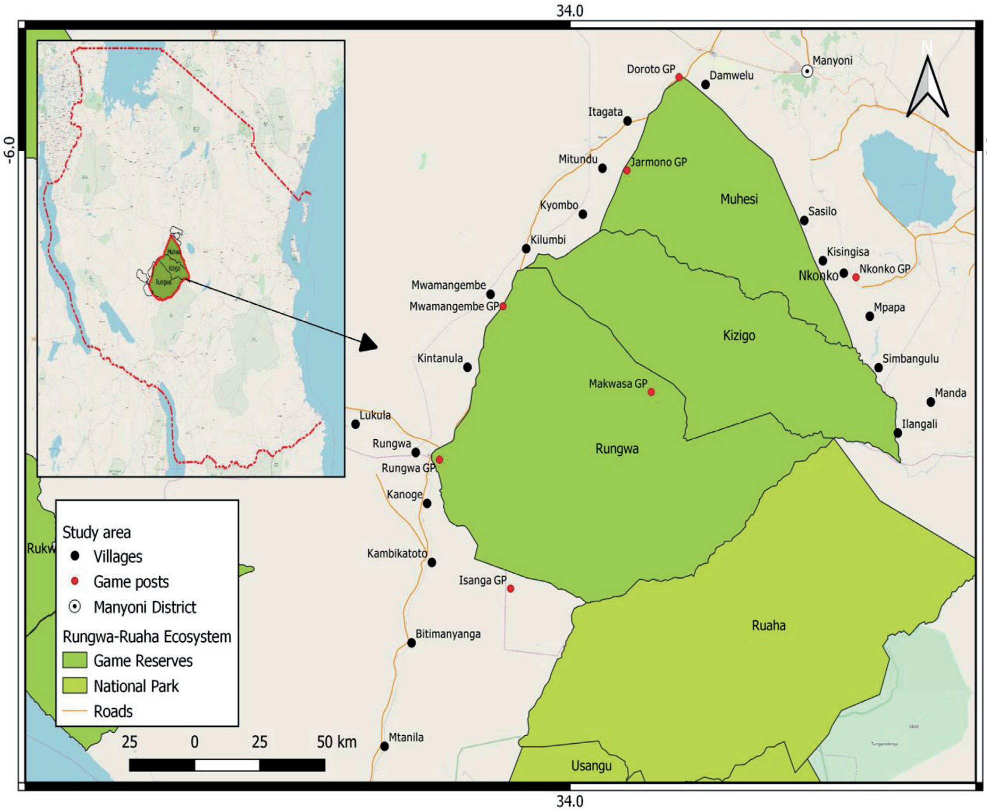

Fig. 1. Map of villages from where the arrested people were living around Rungwa-Kizigo-Muhesi Game Reserves. Villages are indicated by black dots and ranger (or game) posts in red dots. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 1
The human population sizes in the five districts bordering RKMGRs in 2012, 2016 and 2017, as well as then human population increase from 2016 to 2017.

District	2012 n	2016 n	2017 n	2017–2016 n (% increase)	Area (km^2)	Density (people/km^2)
Manyoni DC	146,776	161,054	164,835	3781 (2.3%)	28,934	5.69
Chunya DC	156, 786	172,797	177,049	4252 (2.4%)	29,219	6.06
Sikonge DC	179,883	202,210	208,211	6001 (2.9%)	27,873	7.47
Chamwino DC	330,543	359,244	366,801	7557 (2.1%)	9204	39.9

Modified from (URT, 2017). **"n"** represents number of humans in each district in the respective year.

(land and/or livestock) and other activities, such as formal employment or self-employed. The arrested alleged criminals were always requested for their consent before an interview was conducted. Thus, in this article we only recorded information from those who were willing to participate in the interview. After two weeks the patrol team returned to the office where we collected the filled forms with the list of alleged criminals from patrol leaders and compiled the information in an excel computer program. The names of the alleged conservation criminals were kept anonymous, as they were yet to be convicted in the court. Thus, for ethical reasons, we have not disclosed their names. Almost all arrested respondents were males (98.1%). Moreover, there was some variation in the types of conservation crimes as out of 316 alleged criminals; 71.5% were involved in timber logging, 10.8% in bushmeat poaching, 6.3% in illegal livestock grazing, 6.0% in illegal mining, and 5.4% in elephant poaching. The major ethnic tribe of conservation criminals was Gogo (32.3%), Nyaturu (17.1%), Sukuma (15.2%), Kimbu (13.6%), Nyamwezi (13.3%), and other tribes combined (8.5%).

The second data set came from the control group (n = 315), were collected using a semi-structured interview questionnaire survey conducted from June to August 2015 (Table 2). The researcher randomly stopped respondents at the village

Table 2
Number of respondents interviewed in the control group and the arrested alleged conservation criminals from each respective village.

Village names	Mtanila	Bitimanyanga	Rungwa	Kambikatoto	Kilumbi	Kintanula	Kyombo	Lukula	Mwamagembe	Ilangali	Manda	Nkonko	Damwelu	kanoge	Mitundu	Chisingisa	Sasilo	Simbangulu	Mpapa	Itagata	Total
C	10	15	30	15	30	10	15	10	20	10	10	15	30	10	15	15	10	15	10	20	315
AC	4	12	38	12	43	10	16	9	21	8	8	14	36	6	11	15	8	15	10	20	316
HH	1708	1710	1452	572	678	587	1202	1175	588	2014	1052	1384	668	1144	2244	418	1000	785	1172	1400	22,953
AHH	5.1	5.5	4.5	6.2	5.6	5.5	5.6	5.5	5.5	4.3	4.3	5.4	5.7	6.2	5.8	5.7	5.7	5.7	5.7	5.5	5.45

HH − household, **AHH**-average household, **AC**-arrested alleged criminals, **C**- control.

centres and requested them to participate in the interview one at a time. The researcher interviewed people from the 20 villages from where alleged criminals originated (Table 2). In villages where 1−10 alleged criminals were recorded, ten people were interviewed in the control group. In villages where 11−19 alleged criminals were recorded, 15 people were interviewed, while in villages where 20−29 alleged criminals were recorded, 20 people were interviewed. Finally, in villages where more than 30 alleged criminals were recorded, 30 people were interviewed (Table 2). After a respondent was recruited, a researcher continued to ask questions that were predesigned with face-to-face interview. Before proceeding with the questions, and after the introduction of the researcher to the respondent, researcher ensured that the respondent was a resident of the respective village. Those who were born or lived in the village before 1974 were termed indigenous (non-immigrants), because 1974 is the year in which many villages were formed in Tanzania, whereas those respondents that moved to the respective village after 1974 were termed immigrants in this study. The researcher asked the respondents if she or he would be willing to answer the questions in the questionnaire. The respondents were 18 years of age or above, as arrested alleged criminals were all aged 18 and above years. The researcher chose to do the questionnaire interviews in the village center and moved from one village to another. Within each village, the researcher moved from one sub-village center to another sub-village center. The assumption was that people from the periphery to the center would be coming to the village center or sub-village center to purchase goods for household needs, and therefore, the interviewed people were expected to be representative of the whole village. However, interviewing the respondents in the village or sub-village center might have missed those who were unable to walk and purchase goods in shops located in those center. In the control group, the major ethnic tribes were Gogo (26.6%), Sukuma (24.7%), Kimbu (24.1%), Nyamwezi (10.1%), Nyaturu (5.4%), Kinga (2.8%), Nyiramba (2.5%), Ngoni (1.6%), Hehe (1.3%), and Safwa (0.9%). Further analysis, involved grouping tribes into two categories: 1) indigenous (Gogo, Nyaturu, Kimbu Nyamwezi, and Nyiramba) and 2) immigrants (Kinga, Hehe, Safwa and Sukuma). Demographic and socioeconomic data of the respondents were recorded. We recorded the respondent's age, sex, tribe, place of birth (village), livestock and land ownership, and types of cash income generating activities conducted (Knappa et al., 2017).

2.3. Statistical analysis

To identify characteristics of alleged criminals among types of conservation crimes (timber logging, elephant and bushmeat poaching, illegal mining and illegal livestock grazing) and a control, we performed Chi-square (χ^2) tests for the following variables: age (with two levels: young 18−36 years and old > 36 years), immigration status (with two levels: indigenous, immigrant), and village (with two levels: close; less than 10 km to the PA and far > 10 km to the PA). Other factors include; employment status (with two levels: unemployed, employed), land (with two levels: yes/no), and livestock ownership (with two levels: yes/no) (Presnell, 2000). To examine the importance of factors within each conservation crime, we used generalized linear models (GLMs) with binomial error distribution, to ascertain the most important drivers of conservation crime compared to a control. Separate models were made for each type of conservation crime, using a binary response variable (crime or control) in each respective model. Age, immigration status, village, employment status, land and livestock ownership status were added as explanatory factors. The significance level was set at $P < 0.05$. All statistical analyses were performed using the software R (R Core Team, 2016).

3. Results

3.1. Differences in socio-demographic characteristics of arrested alleged conservation criminals across crime groups

More than 80% of all kinds of the alleged conservation criminals were in the young age category with no statistically significant differences across illegal conservation crimes (Table 3). Immigration status of the arrested alleged conservation criminals statistically significantly varied with less than 60% of the alleged timber loggers and elephant poachers belonged to the indigenous tribes while more than 70% of the bushmeat poachers, illegal livestock grazers, and illegal miners belonged to

Table 3
Distribution of socio-demographic characteristics across crime groups. Differences within crime groups were tested with χ2-tests.

Crime group	Livestock		Land		Age class		Immigration		Employment		Distance		Respondents
	Yes (%)	No (%)	Yes (%)	No (%)	Young (%)	Older (%)	Indigenous (%)	Immigrant (%)	Unemployed (%)	Employed (%)	Close (%)	Far (%)	(n)
Bushmeat	38.2	61.8	32.4	67.6	82.4	17.6	26.5	73.5	67.6	32.4	64.7	35.3	34
Elephant	29.4	70.6	17.6	82.4	82.4	17.6	58.8	41.2	82.4	17.6	58.8	41.2	17
Timber	5.8	94.2	11.5	88.5	80.1	19.9	50.9	49.1	79.2	20.8	90.7	9.3	226
Grazing	85.0	15.0	45.0	55.0	80.0	20.0	15.0	85.0	5.0	95.0	75.0	25.0	20
Miners	5.3	94.7	15.8	84.2	84.2	15.8	10.5	89.5	78.9	21.1	84.2	15.8	19
χ^2	107.57		22.16		0.3		25.57		53.42		27.18		
df	4		4		4		4		4		4		
P	<0.001		<0.001		0.991		<0.001		<0.001		<0.001		

NB: arrested alleged conservation criminals were grouped into bushmeat, elephant poachers, illegal timber loggers, illegal livestock grazing and illegal mining in the Game Reserves.

immigrant tribes (Table 3). The majority of the arrested alleged bushmeat hunters, elephant criminals, timber loggers and illegal miners were unemployed while most illegal livestock grazers were employed with a statistically significant difference (Table 3). Generally, less than 50% owned land for all arrested alleged conservation criminals (Table 3). There was significant differences between different kinds of conservation criminals as 45.0% of illegal livestock grazers and 32.4% of alleged bushmeat criminals owned land while less than 25% of other kinds of alleged conservation criminals owned land (Table 3). Livestock ownership differed significantly between different kinds of conservation crimes (Table 3). Most arrested alleged criminals for bushmeat, elephant poaching, illegal timber loggers and illegal miners did not own livestock while more than 80% illegal livestock grazers owned livestock (Table 3). The frequencies of conservation crimes from different village distances categories from the boundary of RKM GRs differed significantly (Table 3). Generally, more than 50% of arrested alleged criminals were form closest villages with most of them being timber loggers followed by miners, grazers, bushmeat, and elephant criminals (Table 3).

3.2. *Predictors of conservation crimes*

In this set of analyses, we examine the importance of drivers within each conservation crime category.

3.2.1. *Bushmeat poachers*

We used a generalized linear model to examine the importance of factors driving participation in bushmeat poaching, testing with six independent variables; land ownership, livestock ownership, distance from villages to boundary of game reserve, age and employment status (Table 4). Employment status, immigration status, age and land ownership were the significant factors explaining variation in illegal bushmeat poaching. Those who were employed were less likely to be engaged in bushmeat poaching (Table 4). Age of the respondents was an important driver for participating in bushmeat poaching as respondents above 36 years old were less likely to be engaged in bushmeat poaching. On the other hand, immigrants were more likely engaged in bushmeat poaching than indigenous (Table 4). Respondents who did not own land were more likely to be engaged in bushmeat poaching (Table 4). Other factors such as distance to the PA and livestock ownership were not significant (Table 4).

3.2.2. *Illegal timber loggers*

We used a generalized linear model to examine the factors driving participation in illegal timber logging, testing with six independent variables; land ownership, livestock ownership, distance from villages to boundary of game reserve, age and employment status (Table 5). Employment status, immigration status, age, livestock ownership and land ownership were the significant factors in explaining the variation of participation in illegal timer logging. Those who were employed were less likely to be engaged in illegal timber logging (Table 5). Age of the respondents was an important driver for participating in the bushmeat poaching as those respondents above 36 years old were less likely to be engaged in illegal timber logging. Immigrants were more likely to be engaged in illegal timber logging (Table 5). Respondents who did not own land or livestock were more likely to be engaged in illegal timber logging (Table 5). Distance to PA was the only non-significant variable (Table 5).

3.2.3. *Elephant poachers*

We used a generalized linear model analysis to determine the factors driving participation in elephant poaching, with six independent variables (Table 6). The most important drivers were the employment status and land ownership (Table 6). Respondents who were employed were less likely engaged in elephant poaching while those who did not own land were more likely to be involved in elephant poaching (Table 6).

3.2.4. *Illegal livestock grazing*

A generalized linear model was used to examine the factors explaining participation in illegal livestock grazing in the game reserve, with six independent variables (Table 7). Three independent variables were found to be important drivers (Table 7).

Table 4
Arrested alleged bushmeat criminal vs. control and six factors that might predict attendance in illegal activities related to bushmeat. In the table we present parameter estimates from a generalized linear model with alleged bushmeat poachers and control group as a binary response variable (binomial error distribution and logit-link function) and six explanatory factors: employment status, distance, age, land ownership, immigration status, and livestock ownership. OR: odd ratio, Estimate: Z: z-score, SE: standard error and P: p-value.

Variables	Intercept	OR	Estimate	SE	Z	P
		0.49	−0.71	1.17	−0.60	0.548
Do you own land (Yes/No)	No	7.76	2.05	0.74	2.78	**0.005**
Do you own livestock (Yes/No)	No	1.12	0.11	0.67	0.17	0.865
Age (Young/Older)	Older	0.57	−0.56	0.75	−2.09	**0.036**
Distance to PA (Close/Far)	Far	2.88	1.06	0.72	1.47	0.142
Immigration status (Immigrant/Indigenous)	Immigrant	10.07	2.31	0.75	3.09	**0.002**
Employment status (Employed/Un-employed)	Employed	0.01	−4.51	0.79	−5.72	**< 0.001**

Table 5
Timber loggers vs. control and six factors that might predict attendance in illegal activities related to timber logging. In the table we present parameter estimates from a generalized linear model with alleged illegal timber loggers and control as a binary response variable (binomial error distribution and logit-link function) and six independent explanatory variables; employment status, distance, age, land ownership, immigration status, and livestock ownership. OR: odd ratio, Estimate: Z: z-score, SE: standard error and P: p-value.

Variables	Intercept	OR	Estimate	SE	Z	P
		1.568	0.45	0.77	0.58	0.562
Do you own land (Yes/No)	No	4.137	1.42	0.37	3.84	**< 0.001**
Do you own livestock (Yes/No)	No	5.641	1.73	0.41	4.18	**< 0.001**
Age (Young/Older)	Older	0.458	−0.78	0.37	−2.10	**0.035**
Distance to PA (Close/Far)	Far	0.472	−0.75	0.51	−1.48	0.138
Immigration status (Immigrant/Indigenous)	Immigrant	7.099	1.96	0.39	4.97	**< 0.001**
Employment status (Employed/Un-employed)	Employed	0.013	−4.35	0.58	−7.40	**< 0.001**

Table 6
Elephant poachers vs. control and six factors that might predict attendance in illegal activities related to elephant poaching. In the table we present parameter estimates from a generalized linear model with alleged elephant poachers and control as a binary response variable (binomial error distribution and logit-link function) and six explanatory variables: employment status, distance, age, land ownership, immigration status, and livestock ownership. OR: odd ratio, Estimate: Z: z-score, SE: standard error and P: p-value.

Variables	Intercept	OR	Estimate	SE	Z	P
		0.135	−2.00	1.93	−1.04	0.300
Do you own land (Yes/No)	No	15.800	2.76	1.27	2.18	**0.029**
Do you own livestock (Yes/No)	No	4.393	1.48	1.09	1.35	0.176
Age (Young/Older)	Older	0.185	−1.69	1.18	−1.43	0.151
Distance to PA (Close/Far)	Far	3.781	1.33	1.17	1.13	0.258
Immigration status (Immigrant/Indigenous)	Immigrant	2.915	1.07	1.17	0.92	0.358
Employment status (Employed/Un-employed)	Employed	0.006	−5.06	0.97	0.96	**< 0.001**

Table 7
Livestock grazers vs. control and six factors that might predict attendance in illegal activities related to livestock grazing. In the table we present parameter estimates from a generalized linear model with alleged illegal livestock grazers and control as a binary response variable (binomial error distribution and logit-link function) and six explanatory variables: employment status, immigration status, distances of villages, age, land ownership, and livestock ownership. OR: odd ratio, Estimate: Z: z-score, SE: standard error and P: p-value.

Variable	Intercept	OR	Estimate	SE	Z	P
		0.228	−1.48	1.7	−2.04	0.041
Do you own land (Yes/No)	No	7.316	1.99	0.55	3.57	**< 0.001**
Do you own livestock (Yes/No)	No	0.411	−0.89	0.71	−1.26	**0.021**
Age (Young/Older)	Older	0.419	−0.87	0.63	−1.39	0.164
Distance to PA (Close/Far)	Far	1.568	0.45	0.65	0.70	0.484
Immigration status (Immigrant/Indigenous)	Immigrant	11.246	2.42	0.71	3.42	**< 0.001**
Employment status (Employed/Un-employed)	Employed	0.357	−1.03	1.52	−0.68	0.497

Respondents who owned livestock, those from immigrant tribes and those who did not own land were more likely to be involved in illegally grazing of their livestock in the game reserve (Table 7). Distances to boundary, age and employment status of the respondents were not significant (Table 7).

3.2.5. Illegal mining

We used a generalized linear model to examine the factors driving participation in illegal mining in the game reserve, with six independent variables (Table 8). Three independent variables were found to be important drivers (Table 8). Those who were employed were less likely involved in illegal mining than un-employed people (Table 8). Finally, respondents with no livestock and immigrants were more likely to be involved in illegal mining in the game reserve (Table 8).

4. Discussion

Our results indicated that the illegal harvest of wildlife and forest resources from Rungwa-Kizigo-Muhesi Game Reserves is linked with unemployment and lack of asset ownership (livestock and land). Conservation and poverty are separate policy realms in a way that if the conservation policies do not take poverty into consideration, poverty will hamper the success of conservation (Duffy and St John, 2013). Poverty can impede conservation because the poor often pursue poaching and environmental degradation in a short-sighted way. It therefore creates no acceptance of conservation policies by people before poverty reduction is on the political agenda (Duffy and St John, 2013; Kyando et al., 2017). Addressing poverty is

Table 8
Miners vs. control and six factors that might predict attendance in illegal activities related to mining. In the table we present parameter estimates from a generalized linear model with alleged illegal miners and control as a binary response variable (binomial error distribution and logit-link function) and six explanatory variables: employment status, distance of villages, age, immigration status, land ownership, and livestock ownership. OR: odd ratio, Estimate: Z: z-score, SE: standard error and P: p-value.

Variables	Intercept	OR	Estimate	SE	Z	P
		0.006	−5.07	2.28	−2.22	0.026
Do you own land (Yes/No)	No	10.074	2.31	1.25	1.84	0.065
Do you own livestock (Yes/No)	No	16.119	2.78	1.33	2.09	**0.036**
Age (Young/Older)	Older	0.225	−1.49	1.14	−1.31	0.188
Distance to PA (Close/Far)	Far	0.923	−0.08	1.36	−0.06	0.949
Immigration status (Immigrant/Indigenous)	Immigrant	71.522	4.27	1.32	3.24	**0.001**
Employment status (Employed/Un-employed)	Employed	0.019	−3.97	1.31	−3.03	**0.002**

therefore a means of directly and indirectly promoting conservation through sustainable use of resources. Where livelihoods depend on living resources their sustainable use will promote both the resource and the livelihood associated with it (Knappa et al., 2017). In fact commercial poaching, such as elephant poaching, is normally conducted by a chain of syndicate criminals with several levels (porters, shooters, middlemen (transporters), as well as affluent businessmen (in the country of origin or in another country of destination) (Wittemyer et al., 2014; Brennan and Kalsi, 2015). Thus, our data only reported the porters and shooters as this group is most likely the ones prone to be arrested, partly due to imperfect detection, non-linear relation between the effort devoted to searching and the number of encounters (Keane et al., 2011).

4.1. Asset ownership (land and livestock)

In most African societies, land and livestock are considered an investment (Meltzer and Values, 1995). Like businessmen keeping money in the bank, the livestock owners regard their livestock as a bank on hooves. Participation in wildlife crime was influenced by the lack of ownership of livestock and land, as most illegal mining, timber logging, elephant poaching and bushmeat poaching were practiced by those who do not own land or livestock. A similar trend was found in villages surrounding the Serengeti National Park, where those who participated in bushmeat poaching were not livestock owners (Loibooki et al., 2002). Those who went to the PA to cut trees were selling wood or timber to obtain cash to purchase meet for household demands, while some of them pursued the activity as a commercial purpose by doing business as an extra source of income. However, these reasons might not be the same for those who were involved in elephant poaching; they poach for commercial purposes as a significant number of elephant poachers did not own land. Access to land and livestock ownership might not be a good strategy of mitigating conservation crimes as argued by Ceppi and Nielsen (2014) and Lindsey et al. (2015). Access to domestic animal protein did not reduce the bushmeat consumption whilst anti-poaching law enforcement was an effective deterrent of illegal bushmeat consumption. Our results support the first hypothesis that involvement in different conservation crimes decreased with access to land or livestock ownership. However, illegal grazing in the RKM GRs was influenced by ownership of livestock as those who owned livestock were more likely involved in grazing of their livestock in the reserve.

4.2. Lack of employment (neither formal nor self-employed)

Most of the alleged conservation criminals were unemployed. This result support the first hypothesis that involvement in different conservation crimes decreased with employment as people who were employed less likely participated in conservation criminalities. Employment status was also the main driver for people involved in illegal bushmeat hunting, timber logging, elephant poaching, and illegal mining in the RKM GRs. Similar findings, have been reported by other researchers such as Knappa et al. (2017) and Rogana et al. (2017) that lack of income was one of the main driving motives behind poaching. Therefore, the finding that most of those arrested alleged criminals were unemployed might indicate that people in the study area practiced illegal harvesting of natural resources as a coping strategy against unemployment. The link between conservation crimes and the lack employment has also been reported in other parts of Tanzania (Loibooki et al., 2002; Holmern, 2010; Kideghesho, 2010, 2015). The lack employment can drive people to become conservation criminals (Mulder et al., 2007; Kideghesho, 2016). Knappa et al. (2017), reported that employment is related to education level in areas around southern Ruaha National Park which is supporting our findings. The reason for high poaching rates of elephants and rhinos in the 1980s was the price increase for ivory and rhino horns in the international markets. The same driver still exists today (Kyando et al., 2017). The price tag of elephant ivory in the black market drove the poaching of elephants in the Selous Game Reserve and resulted in a 60% population decline from 2009 to 2013 (Kyando et al., 2017) and corruption (Polinsky and Shavell, 2001). Local people, in particular those sharing borders with the wildlife areas, are unemployed or lacked other alternative livelihood options to guarantee food security (Nielsen et al., 2013). Most community conservation services (CCS) programmes by Tanzania National Park have been implemented since the 1990's but little success have been reported in reducing level of poaching (Kaaya and Chapman, 2017). Some of the reasons for the little impact of CCS in reducing poaching levels are probably that these projects focus at the community level such as classrooms, dispensaries e.t.c while at the individual level people are less likely to receive any benefit. Kaaya and Chapman (2017), showed that establishing micro-credit loans and education of entrepreneurship will help individual to reach the necessary benefits as reported in areas around Serengeti National Park. Deterrence methods through law enforcement helps in reducing the poaching level especially when behaviours of both the poacher and the ranger are taken into consideration (Keane et al., 2008; Dobson et al., 2018). Presence of frequent patrols combined with conservation information will help controlling conservation crimes in an area.

4.3. *Age and immigration status as drivers of different conservation crimes*

Most people committing conservation crimes were aged between 18 and 36 years old. This can be attributed to the fact that activities associated with these crimes demand energy and readiness to take risk. People in this age group are more likely to take such risks as being captured by the anti-poaching team. Loibooki et al. (2002), also reported that males aged 15–35 years were more likely involved in hunting for bushmeat in western Serengeti. Age was an important driver for bushmeat and timber whereby those people in the higher age category were less likely involved in these illegal conservation crimes. This might be because such an activity is demanding energy and thus riskier for the older people, therefore young people are more likely involved in conservation criminality as also found in Nigeria (Friant et al., 2015).

Among the participants in this study the immigration status of the conservation criminals varied regarding their participation in type of crime whereby most of the timber loggers were immigrants. This group dominated the illegal timber logging, bushmeat poaching, illegal grazing and illegal mining in the RKM GRs. Differences between ethnic groups in illegal bushmeat hunting have been reported in other parts of Tanzania (Mgawe et al., 2012; Ceppi and Nielsen, 2014). The ethnic tribes from category of immigrants in the study area might have immigrated into to the vicinity of the RKM GRs pulled by the access to resources such as pasture for their cattle, timber and mining to generate cash income. Illegal livestock grazers were, however, from immigrant tribes. Frequently immigrants are the major livestock owners in our study area (Hariohay et al., 2017). The Sukuma tribe keep big herds of cattle. The concurrent shortage of pasture or land for grazing and water outside RKM GRs, might have forced them to graze their livestock inside the Game Reserve (Hariohay et al., 2017). The growing human population in Tanzania (over 54 million people) (URT, 2017) as well as in the study area might have resulted into less availability of land and pasture. Therefore, land conversion to agriculture and settlement is pushing people to take their livestock to the PA. The increasing human population will continue to put pressure on protected areas and will increase impacts on wildlife conservation as protected areas are becoming more isolated due to habitat fragmentation and more overutilization. The growing per capita demand on resources such as bushmeat, timber, and land for cultivation and pasture for livestock will be the main causes. Our results support the third hypothesis that participation in different conservation crimes will be higher among young aged people (18–36 years) as well as immigrants in the study area. However, village distance from the game reserve boundary was not a significant driver in all categories of conservation crimes.

5. Conclusions and recommendations

The key findings on drivers of conservation crimes are that there were multiple drivers for each kind of conservation crime. Firstly, bushmeat poaching was mostly done by people who did not own land, aged 18–36 years, were immigrants and unemployed. Secondly, the arrested timber loggers were unemployed, did not own land and/or livestock, and were young immigrants. Thirdly, elephant poachers did not own land, and were unemployed. Fourthly, livestock grazing in the RKM GRs was mostly done by immigrants, who owned livestock but did not own land. Finally, illegal mining was mainly done by unemployed immigrants who did not own livestock. These characteristics generate poverty and hunger, factors forcing people to adopt conservation crimes as an alternative livelihood and survival strategy. Anti-poaching activities will be more successful if the communities around the protected areas receive tangible benefits and have alternative ways of generating income.

We recommend the following actions as part of the mitigation to reduce conservation crimes risks in most PA in Tanzania. Increasing law enforcements, for instance by ranger patrols in the Game Reserve will deter people from committing crime. Motivating the youth to form groups and offering micro-credit loans to establish businesses, especially to the people who are committing conservation crimes, for subsistence needs is also important. However, we need to be careful doing thorough analyses as people might use extra money to purchase sophisticated weapons and even start hunting valuable species such as elephants. It is important to provide them with education in entrepreneurship so that they can see the tangible benefits of wildlife conservation and PA. Conservation education programmes should be provided in villages around PA and included in the primary school education curriculum. Conservation literacy will spread to the society because the children will learn in schools and teach their parents at home.

Author contributions

KMH and ER designed the study. KMH collected and analysed the data, and wrote the article with support from ER, JRK, RDF and PSR.

Acknowledgements

We are thankful for the Norwegian government and the EU Horizon-2020 financed project under GA 641918 (*AfricanBioServices*) for funding the write up of this research. Furthermore, we extend our gratitude to the Tanzania Wildlife Management Authority (TAWA) and the Tanzania Wildlife Research Institute (TAWIRI) for granting us the access to conduct this research study. We would also like to extend our thanks to Patrice Richard for his help in the field during data collection. Finally, we acknowledge the inputs from four anonymous reviewers whose advice improved this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gecco.2019.e00522.

References

Apaza, L., Wilkie, D., Byron, E., Huanca, T., Leonard, W., Pérez, E., Godoy, R., 2002. Meat prices influence the consumption of wildlife by the Tsimane'Amerindians of Bolivia. Oryx 36 (4), 382–387. http://www.doi.org/10.1017/S003060530200073X.

AWF, 2018. Wildlife Conservation: Black Rhinoceros. https://www.awf.org/wildlife-conservation/rhinoceros.

Ayling, J., 2013. What Sustains Wildlife Crime? Rhino Horn Trading and the Resilience of Criminal Networks. J. Int. Wildl. Law Pol. 16 (1), 57–80. https://doi.org/10.1080/13880292.2013.764776.

Bauer, H., Chapron, G., Nowell, K., Henschel, P., Funston, P., Hunter, L.T.B., Packer, C., 2015. Lion (*Panthera leo*) populations are declining rapidly across Africa, except in intensively managed areas. Proc. Natl. Acad. Sci. Unit. States Am. 112 (48), 14894–14899. https://doi.org/10.1073/pnas.1500664112.

Blanc, J.J., Barnes, R.F.W., Craig, G.C., Dublin, H.T., Douglas-Hamilton, I., Hart, J.A., 2007. African elephant status report 2007. In: IUCN. IUCN, Gland, Switzerand, p. 276.

Brennan, A.J., Kalsi, J.K., 2015. Elephant poaching & ivory trafficking problems in Sub-Saharan Africa: An application of O'Hara's principles of political economy. Ecol. Econ. 120, 312–337. https://doi.org/10.1016/j.ecolecon.2015.08.013.

Campbell, K.L.I., Nelson, V., Loibooki, B., 2001. Sustainable use of wildland resources: Ecological, economic and social interractions: an analysis of illegal hunting of wildlife. In: Serengeti National Park, Tanzania *Natural Resources Institute, Final Technical Report*, 2017. Department for International Development (DFID) Animal Health Programme and Livestock Production Programmes, Chatham, Kent, UK, p. 56.

Ceppi, S.L., Nielsen, M.R., 2014. A comparative study on bushmeat consumption patterns in ten tribes in Tanzania. Trop. Conserv. Sci. 7 (2), 272–287. https://doi.org/10.1177/194008291400700208.

Chase, M.J., Schlossberg, S., Griffin, C.R., Bouché, P.J.C., Djene, S.W., Elkan, P.W., Sutcliffe, R., 2016. Continent-wide survey reveals massive decline in African savannah elephants. PeerJ 4, e2354. https://doi.org/10.7717/peerj.2354.

Cooper, J.E., Cooper, M.E., Budgen, P., 2009. Wildlife crime scene investigation: techniques, tools and technologies. Endanger. Species Res. 9, 229–238. https://doi.org/10.3354/esr00204.

Dobson, A.D.M., Milner-Gulland, E.J., Beale, C.M., Ibbett, H., Keane, A., 2018. Detecting deterrence from patrol data. Conserv. Biol. 0. September 2018. https://doi.org/10.1111/cobi.13222.

Dudley, N., Jonas, H., Nelson, F., Parrish, J., Pyhälä, A., Stolton, S., Watson, J.E.M., 2018. The essential role of other effective area-based conservation measures in achieving big bold conservation targets. Glob. Ecol. Conserv. 15, e00424. https://doi.org/10.1016/j.gecco.2018.e00424.

Duffy, R., St John, F.A.V., 2013. Poverty, Poaching and Trafficking: What are the links? Department for International Development (DFID), UK, p. 24.

Eliason, S.L., 2009. Game warden perceptions of change in conservation law enforcement. Police J.: Theo. Pract. Prin. 89 (3), 218–226. https://doi.org/10.1177/0032258X16642450.

Essen, E.V., Hansen, H.P., Källström, H.N., Peterson, M.N., Peterson, T.R., 2014. Deconstructing the poaching phenomenon: A review of typologies for understanding illegal hunting. Br. J. Criminol. 54 (4), 632–651. https://doi.org/10.1093/bjc/azu022.

Friant, S., Paige, S.B., Goldberg, T.L., 2015. Drivers of bushmeat hunting and perceptions of zoonoses in Nigerian hunting communities. PLoS Neglected Trop. Dis. 9 (5), 1–16. https://doi.org/10.1371/journal.pntd.0003792.

Frosta, P.G.H., Ivan, B., 2008. 2008. People, wildlife and natural resources-the CAMPFIRE approach to rural development in Zimbabwe. Ecol. Econ. 65, 776–787. https://doi.org/10.1016/j.ecolecon.2007.09.018.

Gibbs, C., Gore, M.L., McGarrell, E.F., Rivers, I.I.I.L., 2010. Introducing Conservation Criminology Towards Interdisciplinary Scholarship on Environmental Crimes and Risks. Br. J. Criminol. 50 (1), 124–144. https://doi.org/10.1093/bjc/azp045.

Gore, M.L., 2011. The Science of Conservation Crime. Conserv. Biol. 25 (4), 659–661. https://doi.org/10.1111/j.1523-1739.2011.01701.x.

Hariohay, K.M., Fyumagwa, R.D., Kideghesho, J.R., Røskaft, E., 2017. Assessing crop and livestock losses along the Rungwa-Katavi Wildlife Corridor, South-Western Tanzania. Int. J. Biodivers. Conserv. 9 (8), 273–283. https://doi.org/10.5897/IJBC2017.1116.

Holmern, T., 2010. Bushmeat hunting in Western Serengeti: Implications for community-based conservation. In: Gereta, E., Røskaft, E. (Eds.), Conservation of Natural Reources; Some African & Asian Examples. Tapir Academic Press, Trondheim, pp. 211–236.

Holmern, T., Muya, J., Røskaft, E., 2007. Local law enforcement and illegal bushmeat hunting outside the Serengeti National Park, Tanzania. Environ. Conserv. 34 (1), 55–63. https://doi.org/10.1017/S0376892907003712.

Kaaya, E., Chapman, M., 2017. Micro-Credit and Community Wildlife Management: Complementary Strategies to Improve Conservation Outcomes in Serengeti National Park, Tanzania. Environ. Manag. 60 (3), 464–475. https://doi.org/10.1007/s00267-017-0856-x.

Keane, A., Jones, J.P.G., Edwards-Jones, G., Milner-Gulland, E.J., 2008. The sleeping policeman: understanding issues of enforcement and compliance in conservation. Anim. Conserv. 11 (2), 75–82. https://doi.org/10.1111/j.1469-1795.2008.00170.x.

Keane, A., Jones, J.P.G., Milner-Gulland, E.J., 2011. Encounter data in resource management and ecology: pitfalls and possibilities. J. Appl. Ecol. 48, 1164–1173. https://doi.org/10.1111/j.1365-2664.2011.02034.x.

Kideghesho, J.R., 2010. Wildlife conservation and local land-use conflicts in the western Serengeti corridor, Tanzania. In: Gereta, E., Røskaft, E. (Eds.), Conservation of Natural Resources; Some African & Asian Examples. Tapir Academic Press, Trondheim, pp. 130–154.

Kideghesho, J.R., 2015. Realities on deforestation in Tanzania: trends, drivers, implications and the way forward. In: Zlatic, M. (Ed.), Precious Forests. IntechOpen. https://doi.org/10.5772/61002.

Kideghesho, J.R., 2016. Reversing the trend of wildlife crime in Tanzania: challenges and opportunities. Biodiv. Conserv. 25 (3), 427–449. https://doi.org/10.1177/194008291600900120.

Kideghesho, J.R., Nyahongo, J.W., Hassan, S.N., Thadeo, C., Mbije, N.E., 2006. Factors and ecological impacts of wildlife habitat destruction in the Serengeti ecosystem in northern Tanzania. AJEAM-RAGEE 11 (August 2006), 917–932.

Kiffner, C., Peters, L., Stroming, A., Kioko, J., 2015. Bushmeat Consumption in the Tarangire-Manyara Ecosystem, Tanzania. Trop. Conserv. Sci. 8 (2), 318–332. https://doi.org/10.1177/194008291500800204.

Knapp, E.J., 2012. Why poaching pays: a summary of risks and benefits illegal hunters face in Western Serengeti, Tanzania. Trop. Conserv. Sci. 5 (4), 434–445. https://doi.org/10.1177/194008291200500403.

Knappa, E.J., Peaceb, N., Bechtelb, L., 2017. Poachers and poverty: Assessing objective and subjective measures of poverty among illegal hunters outside Ruaha National Park, Tanzania. Conserv. Soc. 15 (1), 24–32. https://doi.org/10.4103/0972-4923.201393.

Kyando, M., Ikanda, D., Røskaft, E., 2017. Hotspot elephant-poaching areas in the Eastern Selous Game Reserve, Tanzania. Afr. J. Ecol. 55 (3), 365–371. https://doi.org/10.1111/aje.12363.

Leader-Williams, N., Albon, S.D., Berry, P.S.M., 1990. Illegal Exploitation of Black Rhinoceros and Elephant Populations: Patterns of Decline, Law Enforcement and Patrol Efforts in Luangwa Valley, Zambia. J. Appl. Ecol. 27, 1055–1087. http://www.doi.org/10.2307/2404395.

Lindsey, P., Balme, G., Becker, M., Begg, C., Bento, C., Bocchino, C., Zisadza, P., 2015. Illegal hunting and the bush-meat trade in savanna africa: drivers, impacts and solutions to address the problem *Panthera/Zoological society of london/Wildlife conservation society report*. Food and Agriculture Organization of the United Nations, New York, p. 74.

Lindsey, P.A., Balme, G.A., Booth, V.R., Midlane, N., 2012. The significance of African lions for the financial viability of trophy hunting and the maintenance of wild land. PLoS One 7 (1), e29332. https://doi.org/10.1371/journal.pone.0029332.

Loibooki, M., Hofer, H., Campbell, K.L.I., East, M.L., 2002. Bushmeat hunting by communities adjacent to the Serengeti National Park, Tanzania: the importance of livestock ownership and alternative sources of protein and income. Environ. Conserv. 29 (3), 391–398. https://doi.org/10.1017/S0376892902000279.

Martin, A., Caro, T., 2013. Illegal hunting in the Katavi-Rukwa ecosystem. Afr. J. Ecol. 51 (1), 172–175. https://doi.org/10.1111/aje.12000.

Meltzer, M.I., Values, H., 1995. Livestock in africa: The economics of ownership and production, and the potential for improvement. Agric. Hum. Val. 12 (2), 4–18. https://doi.org/10.1007/bf02217292.

Metzger, K.L., Sinclair, A.R.E., Campbell, K.L.I., Hilborn, R., Hopcraft, J.G.C., Mduma, S.A.R., Reich, R.M., 2007. Using historical data to establish baselines for conservation: The black rhinoceros (*Diceros bicornis*) of the Serengeti as a case study. Biol. Conserv. 139 (3), 358–374. https://doi.org/10.1016/j.biocon.2007.06.l026.

Mfunda, I.M., Røskaft, E., 2010. Bushmeat hunting in Serengeti, Tanzania: An important economic activity to local people. Int. J. Biodivers. Conserv. 2 (9), 263–272. https://doi.org/10.5897/IJBC2010.16541.

Mgawe, P., Mulder, M.B., Caro, T., Martin, A., Kiffner, C., 2012. Factors affecting bushmeat consumption in the Katavi-Rukwa ecosystem of Tanzania. Trop. Conserv. Sci. 5 (4), 446–462. https://doi.org/10.1177/194008291200500404.

MNRT, 2011. Rungwa-Kizigo-Muhesi Game Reserves general management plan. Dar es Salaam: Government Printers.

Mulder, B.M., Caro, T., Msago, O.A., 2007. The role of research in evaluating conservation strategies in Tanzania: the case of the Katavi-Rukwa ecosystem. Conserv. Biol. 21 (3), 647–658. https://doi.org/10.1111/j.1523-1739.2007.00703.x.

Nahonyo, C.L., 2005. Assessment of anti-poaching effort in Ruaha national park, Tanzania. Tanzan. J. Sci. 31 (2), 13–22. https://doi.org/10.4314tjs.v31i2.18416.

Ndibalema, V.G., Songorwa, A.N., 2007. Illegal meat hunting in Serengeti: dynamics in consumption and preferences. Afr. J. Ecol. 46 (3), 311–319. https://doi.org/10.1177/194008291100400407.

Nielsen, M.R., 2006. Importance, cause and effect of bushmeat hunting in the Udzungwa mountains, Tanzania: Implications for community-based wildlife management. Biol. Conserv. 128 (4), 509–516. https://doi.org/10.1016/j.biocon.2005.10.017.

Nielsen, M.R., Jacobsen, J.B., Thorsen, B.J., 2013. Factors determining the choice of hunting and trading bushmeat in the Kilombero valley, Tanzania. Conserv. Biol. https://doi.org/10.1111/cobi.12197.

Nielsen, M.R., Meilby, H., 2013. Determinants of Compliance with Hunting Regulations Under Joint Forest Management in Tanzania. S. Afr. J. Wildl. Res. 43 (2), 120–137. https://doi.org/10.3957/056.043.0210.

O'Brien, T.G., Kinnaird, M.F., Ekwanga, S., Wilmers, C., Williams, T., Oriol-Cotteril, A.l., Frank, L.G., 2018. Resolving a conservation dilemma: Vulnerable lions eating endangered zebras. PLoS One 13 (8), 1–16. https://doi.org/10.1371/journal.pone.0201983.

Polinsky, A.M., Shavell, S., 2001. Corruption and optimal law enforcement. J. Publ. Econ. 81 (1), 1–24. https://doi.org/10.1016/S0047-2727(00)00127-4.

Potter, G.R., Nurse, A., Hall, M. (Eds.), 2016. The Geography of Environmental Crime: Conservation, Wildlife Crime and Environmental Activism. Springer, UK.

Prendergast, D.K., Adams, W.M., 2003. Colonial wildlife conservation and the origins of the Society for the Preservation of the Wild Fauna of the Empire (1903–1914). Oryx 37 (2), 251–260. https://doi.org/10.1017/S0030605316000971.

Presnell, B., 2000. 23.10.2017. An introduction to categorical data analysis using R. http://web.stat.ufl.edu/~presnell/Courses/sta4504-2000sp/R/R-CDA.pdf.

R Core Team, 2016. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org/.

Rentsch, D., Damon, A., 2013. 2013. Prices, poaching, and protein alternatives: An analysis of bushmeat consumption around Serengeti National Park, Tanzania. Ecol. Econ. 91, 1–9. https://doi.org/10.1016/j.ecolecon.2013.03.021.

Ripple, W.J., Abernethy, K., Betts, M.G., Chapron, G., Dirzo, R., Galetti, M., Young, H., 2016. Bushmeat hunting and extinction risk to the world's mammals. R. Soc. Open Sci. 3 (10), 160498. http://www.doi.org/10.1098/rsos.160498.

Rizzolo, J.B., Gore, M.L., Ratsimbazafy, J.H., Rajaonson, A., 2017. Cultural influences on attitudes about the causes and consequences of wildlife poaching. Crime Law Soc. Change 67 (4), 415–437. https://doi.org/10.1007/s10611-016-9665-z.

Robbins, M., Vigilant, L., Jacob, S., 2018. Number of wild mountain gorillas exceeds 1000: The population of mountain gorillas in the Virunga Volcanoes has more than doubled in the past three decades. https://www.mpg.de/12057180/number-of-wild-mountain-gorillas-exceeds-1-0001.

Rogana, M.S., Lindsey, P.A., Tamblinge, C.J., Golabeka, K.A., Chaseh, M.J., Collinsd, K., McNutta, J.W., 2017. 2017. Illegal bushmeat hunters compete with predators and threaten wild herbivore populations in a global tourism hotspot. Biol. Conserv. 210, 233–242. https://doi.org/10.1016/j.biocon.2017.04.020.

Sunderland, T., Sunderland-Groves, J., Shanley, P., Campbell, B., 2009. Bridging the gap: How can information access and exchange between conservation biologist and field practitioners be improved for better conservation outcomes? Biotropica 41 (5), 549–554. https://doi.org/10.1111/j.1744-7429.2009.00557.x.

TAWIRI, 2015. Aerial census of large animals in the Ruaha-Rungwa ecosystem, dry season, Population status of African elephant. Tanzania Wildlife Research Institute: Conservation Information and Monitoring Unit, Ausha.

URT, 2009. Wildlife Conservation Act No 5 of 2009. Dar es Salaam: Government Printers.

URT, 2012. Population and housing census: Population distribution by administrative areas. http://www.nbs.go.tz/nbstz/index.php/english/census-and-surveys.

URT, 2017. Tanzania Total Population by District - Regions -2016-2017: Sub-Divisional Population Projection for Year 2016, 2017 Based on 2012 Population and Housing Census. http://www.nbs.go.tz/nbstz/index.php/english/statistics-by-subject/population-and-housing-census/844-tanzania-total-population-by-district-regions-2016.

Wittemyer, G., Northrup, J.M., Blanc, J.J., Douglas-Hamilton, I., Omondi, P., Burnham, K.P., 2014. Illegal killing for ivory drives global decline in African elephant. Proc. Natl. Acad. Sci. Unit. States Am. 111, 13117–13121. https://doi.org/10.1073/pnas.1403984111.

Catalogue

Doctoral theses in Biology
Norwegian University of Science and Technology
Department of Biology

Year	Name	Degree	Title
1974	Tor-Henning Iversen	Dr. philos Botany	The roles of statholiths, auxin transport, and auxin metabolism in root gravitropism
1978	Tore Slagsvold	Dr. philos Zoology	Breeding events of birds in relation to spring temperature and environmental phenology
1978	Egil Sakshaug	Dr. philos Botany	The influence of environmental factors on the chemical composition of cultivated and natural populations of marine phytoplankton
1980	Arnfinn Langeland	Dr. philos Zoology	Interaction between fish and zooplankton populations and their effects on the material utilization in a freshwater lake
1980	Helge Reinertsen	Dr. philos Botany	The effect of lake fertilization on the dynamics and stability of a limnetic ecosystem with special reference to the phytoplankton
1982	Gunn Mari Olsen	Dr. scient Botany	Gravitropism in roots of *Pisum sativum* and *Arabidopsis thaliana*
1982	Dag Dolmen	Dr. philos Zoology	Life aspects of two sympartic species of newts (*Triturus, Amphibia*) in Norway, with special emphasis on their ecological niche segregation
1984	Eivin Røskaft	Dr. philos Zoology	Sociobiological studies of the rook *Corvus frugilegus*
1984	Anne Margrethe Cameron	Dr. scient Botany	Effects of alcohol inhalation on levels of circulating testosterone, follicle stimulating hormone and luteinzing hormone in male mature rats
1984	Asbjørn Magne Nilsen	Dr. scient Botany	Alveolar macrophages from expectorates – Biological monitoring of workers exposed to occupational air pollution. An evaluation of the AM-test
1985	Jarle Mork	Dr. philos Zoology	Biochemical genetic studies in fish
1985	John Solem	Dr. philos Zoology	Taxonomy, distribution and ecology of caddisflies (*Trichoptera*) in the Dovrefjell mountains
1985	Randi E. Reinertsen	Dr. philos Zoology	Energy strategies in the cold: Metabolic and thermoregulatory adaptations in small northern birds
1986	Bernt-Erik Sæther	Dr. philos Zoology	Ecological and evolutionary basis for variation in reproductive traits of some vertebrates: A comparative approach
1986	Torleif Holthe	Dr. philos Zoology	Evolution, systematics, nomenclature, and zoogeography in the polychaete orders *Oweniimorpha* and *Terebellomorpha*, with special reference to the Arctic and Scandinavian fauna
1987	Helene Lampe	Dr. scient Zoology	The function of bird song in mate attraction and territorial defence, and the importance of song repertoires
1987	Olav Hogstad	Dr. philos Zoology	Winter survival strategies of the Willow tit *Parus montanus*
1987	Jarle Inge Holten	Dr. philos Botany	Autecological investigations along a coust-inland transect at Nord-Møre, Central Norway

1987	Rita Kumar	Dr. scient Botany	Somaclonal variation in plants regenerated from cell cultures of *Nicotiana sanderae* and *Chrysanthemum morifolium*
1987	Bjørn Åge Tømmerås	Dr. scient Zoology	Olfaction in bark beetle communities: Interspecific interactions in regulation of colonization density, predator - prey relationship and host attraction
1988	Hans Christian Pedersen	Dr. philos Zoology	Reproductive behaviour in willow ptarmigan with special emphasis on territoriality and parental care
1988	Tor G. Heggberget	Dr. philos Zoology	Reproduction in Atlantic Salmon (*Salmo salar*): Aspects of spawning, incubation, early life history and population structure
1988	Marianne V. Nielsen	Dr. scient Zoology	The effects of selected environmental factors on carbon allocation/growth of larval and juvenile mussels (*Mytilus edulis*)
1988	Ole Kristian Berg	Dr. scient Zoology	The formation of landlocked Atlantic salmon (*Salmo salar* L.)
1989	John W. Jensen	Dr. philos Zoology	Crustacean plankton and fish during the first decade of the manmade Nesjø reservoir, with special emphasis on the effects of gill nets and salmonid growth
1989	Helga J. Vivås	Dr. scient Zoology	Theoretical models of activity pattern and optimal foraging: Predictions for the Moose *Alces alces*
1989	Reidar Andersen	Dr. scient Zoology	Interactions between a generalist herbivore, the moose *Alces alces*, and its winter food resources: a study of behavioural variation
1989	Kurt Ingar Draget	Dr. scient Botany	Alginate gel media for plant tissue culture
1990	Bengt Finstad	Dr. scient Zoology	Osmotic and ionic regulation in Atlantic salmon, rainbow trout and Arctic charr: Effect of temperature, salinity and season
1990	Hege Johannesen	Dr. scient Zoology	Respiration and temperature regulation in birds with special emphasis on the oxygen extraction by the lung
1990	Åse Krøkje	Dr. scient Botany	The mutagenic load from air pollution at two work-places with PAH-exposure measured with Ames Salmonella/microsome test
1990	Arne Johan Jensen	Dr. philos Zoology	Effects of water temperature on early life history, juvenile growth and prespawning migrations of Atlantic salmon (*Salmo salar*) and brown trout (*Salmo trutta*): A summary of studies in Norwegian streams
1990	Tor Jørgen Almaas	Dr. scient Zoology	Pheromone reception in moths: Response characteristics of olfactory receptor neurons to intra- and interspecific chemical cues
1990	Magne Husby	Dr. scient Zoology	Breeding strategies in birds: Experiments with the Magpie *Pica pica*
1991	Tor Kvam	Dr. scient Zoology	Population biology of the European lynx (*Lynx lynx*) in Norway
1991	Jan Henning L'Abêe Lund	Dr. philos Zoology	Reproductive biology in freshwater fish, brown trout *Salmo trutta* and roach *Rutilus rutilus* in particular
1991	Asbjørn Moen	Dr. philos Botany	The plant cover of the boreal uplands of Central Norway. I. Vegetation ecology of Sølendet nature reserve; haymaking fens and birch woodlands
1991	Else Marie Løbersli	Dr. scient Botany	Soil acidification and metal uptake in plants
1991	Trond Nordtug	Dr. scient Zoology	Reflectometric studies of photomechanical adaptation in superposition eyes of arthropods
1991	Thyra Solem	Dr. scient Botany	Age, origin and development of blanket mires in Central Norway

1991	Odd Terje Sandlund	Dr. philos Zoology	The dynamics of habitat use in the salmonid genera *Coregonus* and *Salvelinus*: Ontogenic niche shifts and polymorphism
1991	Nina Jonsson	Dr. philos Zoology	Aspects of migration and spawning in salmonids
1991	Atle Bones	Dr. scient Botany	Compartmentation and molecular properties of thioglucoside glucohydrolase (myrosinase)
1992	Torgrim Breiehagen	Dr. scient Zoology	Mating behaviour and evolutionary aspects of the breeding system of two bird species: the Temminck's stint and the Pied flycatcher
1992	Anne Kjersti Bakken	Dr. scient Botany	The influence of photoperiod on nitrate assimilation and nitrogen status in timothy (*Phleum pratense* L.)
1992	Tycho Anker-Nilssen	Dr. scient Zoology	Food supply as a determinant of reproduction and population development in Norwegian Puffins *Fratercula arctica*
1992	Bjørn Munro Jenssen	Dr. philos Zoology	Thermoregulation in aquatic birds in air and water: With special emphasis on the effects of crude oil, chemically treated oil and cleaning on the thermal balance of ducks
1992	Arne Vollan Aarset	Dr. philos Zoology	The ecophysiology of under-ice fauna: Osmotic regulation, low temperature tolerance and metabolism in polar crustaceans.
1993	Geir Slupphaug	Dr. scient Botany	Regulation and expression of uracil-DNA glycosylase and O^6-methylguanine-DNA methyltransferase in mammalian cells
1993	Tor Fredrik Næsje	Dr. scient Zoology	Habitat shifts in coregonids.
1993	Yngvar Asbjørn Olsen	Dr. scient Zoology	Cortisol dynamics in Atlantic salmon, *Salmo salar* L.: Basal and stressor-induced variations in plasma levels and some secondary effects.
1993	Bård Pedersen	Dr. scient Botany	Theoretical studies of life history evolution in modular and clonal organisms
1993	Ole Petter Thangstad	Dr. scient Botany	Molecular studies of myrosinase in Brassicaceae
1993	Thrine L. M. Heggberget	Dr. scient Zoology	Reproductive strategy and feeding ecology of the Eurasian otter *Lutra lutra*.
1993	Kjetil Bevanger	Dr. scient Zoology	Avian interactions with utility structures, a biological approach.
1993	Kåre Haugan	Dr. scient Botany	Mutations in the replication control gene trfA of the broad host-range plasmid RK2
1994	Peder Fiske	Dr. scient Zoology	Sexual selection in the lekking great snipe (*Gallinago media*): Male mating success and female behaviour at the lek
1994	Kjell Inge Reitan	Dr. scient Botany	Nutritional effects of algae in first-feeding of marine fish larvae
1994	Nils Røv	Dr. scient Zoology	Breeding distribution, population status and regulation of breeding numbers in the northeast-Atlantic Great Cormorant *Phalacrocorax carbo carbo*
1994	Annette-Susanne Hoepfner	Dr. scient Botany	Tissue culture techniques in propagation and breeding of Red Raspberry (*Rubus idaeus* L.)
1994	Inga Elise Bruteig	Dr. scient Botany	Distribution, ecology and biomonitoring studies of epiphytic lichens on conifers
1994	Geir Johnsen	Dr. scient Botany	Light harvesting and utilization in marine phytoplankton: Species-specific and photoadaptive responses

1994	Morten Bakken	Dr. scient Zoology	Infanticidal behaviour and reproductive performance in relation to competition capacity among farmed silver fox vixens, *Vulpes vulpes*
1994	Arne Moksnes	Dr. philos Zoology	Host adaptations towards brood parasitism by the Cockoo
1994	Solveig Bakken	Dr. scient Botany	Growth and nitrogen status in the moss *Dicranum majus* Sm. as influenced by nitrogen supply
1994	Torbjørn Forseth	Dr. scient Zoology	Bioenergetics in ecological and life history studies of fishes.
1995	Olav Vadstein	Dr. philos Botany	The role of heterotrophic planktonic bacteria in the cycling of phosphorus in lakes: Phosphorus requirement, competitive ability and food web interactions
1995	Hanne Christensen	Dr. scient Zoology	Determinants of Otter *Lutra lutra* distribution in Norway: Effects of harvest, polychlorinated biphenyls (PCBs), human population density and competition with mink *Mustela vision*
1995	Svein Håkon Lorentsen	Dr. scient Zoology	Reproductive effort in the Antarctic Petrel *Thalassoica antarctica*; the effect of parental body size and condition
1995	Chris Jørgen Jensen	Dr. scient Zoology	The surface electromyographic (EMG) amplitude as an estimate of upper trapezius muscle activity
1995	Martha Kold Bakkevig	Dr. scient Zoology	The impact of clothing textiles and construction in a clothing system on thermoregulatory responses, sweat accumulation and heat transport
1995	Vidar Moen	Dr. scient Zoology	Distribution patterns and adaptations to light in newly introduced populations of *Mysis relicta* and constraints on Cladoceran and Char populations
1995	Hans Haavardsholm Blom	Dr. philos Botany	A revision of the *Schistidium apocarpum* complex in Norway and Sweden
1996	Jorun Skjærmo	Dr. scient Botany	Microbial ecology of early stages of cultivated marine fish; inpact fish-bacterial interactions on growth and survival of larvae
1996	Ola Ugedal	Dr. scient Zoology	Radiocesium turnover in freshwater fishes
1996	Ingibjørg Einarsdottir	Dr. scient Zoology	Production of Atlantic salmon (*Salmo salar*) and Arctic charr (*Salvelinus alpinus*): A study of some physiological and immunological responses to rearing routines
1996	Christina M. S. Pereira	Dr. scient Zoology	Glucose metabolism in salmonids: Dietary effects and hormonal regulation
1996	Jan Fredrik Børseth	Dr. scient Zoology	The sodium energy gradients in muscle cells of *Mytilus edulis* and the effects of organic xenobiotics
1996	Gunnar Henriksen	Dr. scient Zoology	Status of Grey seal *Halichoerus grypus* and Harbour seal *Phoca vitulina* in the Barents sea region
1997	Gunvor Øie	Dr. scient Botany	Eevalution of rotifer *Brachionus plicatilis* quality in early first feeding of turbot *Scophtalmus maximus* L. larvae
1997	Håkon Holien	Dr. scient Botany	Studies of lichens in spruce forest of Central Norway. Diversity, old growth species and the relationship to site and stand parameters
1997	Ole Reitan	Dr. scient Zoology	Responses of birds to habitat disturbance due to damming
1997	Jon Arne Grøttum	Dr. scient Zoology	Physiological effects of reduced water quality on fish in aquaculture

1997	Per Gustav Thingstad	Dr. scient Zoology	Birds as indicators for studying natural and human-induced variations in the environment, with special emphasis on the suitability of the Pied Flycatcher
1997	Torgeir Nygård	Dr. scient Zoology	Temporal and spatial trends of pollutants in birds in Norway: Birds of prey and Willow Grouse used as
1997	Signe Nybø	Dr. scient Zoology	Impacts of long-range transported air pollution on birds with particular reference to the dipper *Cinclus cinclus* in southern Norway
1997	Atle Wibe	Dr. scient Zoology	Identification of conifer volatiles detected by receptor neurons in the pine weevil (*Hylobius abietis*), analysed by gas chromatography linked to electrophysiology and to mass spectrometry
1997	Rolv Lundheim	Dr. scient Zoology	Adaptive and incidental biological ice nucleators
1997	Arild Magne Landa	Dr. scient Zoology	Wolverines in Scandinavia: ecology, sheep depredation and conservation
1997	Kåre Magne Nielsen	Dr. scient Botany	An evolution of possible horizontal gene transfer from plants to sail bacteria by studies of natural transformation in *Acinetobacter calcoacetius*
1997	Jarle Tufto	Dr. scient Zoology	Gene flow and genetic drift in geographically structured populations: Ecological, population genetic, and statistical models
1997	Trygve Hesthagen	Dr. philos Zoology	Population responses of Arctic charr (*Salvelinus alpinus* (L.)) and brown trout (*Salmo trutta* L.) to acidification in Norwegian inland waters
1997	Trygve Sigholt	Dr. philos Zoology	Control of Parr-smolt transformation and seawater tolerance in farmed Atlantic Salmon (*Salmo salar*) Effects of photoperiod, temperature, gradual seawater acclimation, NaCl and betaine in the diet
1997	Jan Østnes	Dr. scient Zoology	Cold sensation in adult and neonate birds
1998	Seethaledsumy Visvalingam	Dr. scient Botany	Influence of environmental factors on myrosinases and myrosinase-binding proteins
1998	Thor Harald Ringsby	Dr. scient Zoology	Variation in space and time: The biology of a House sparrow metapopulation
1998	Erling Johan Solberg	Dr. scient Zoology	Variation in population dynamics and life history in a Norwegian moose (*Alces alces*) population: consequences of harvesting in a variable environment
1998	Sigurd Mjøen Saastad	Dr. scient Botany	Species delimitation and phylogenetic relationships between the Sphagnum recurvum complex (Bryophyta): genetic variation and phenotypic plasticity
1998	Bjarte Mortensen	Dr. scient Botany	Metabolism of volatile organic chemicals (VOCs) in a head liver S9 vial equilibration system in vitro
1998	Gunnar Austrheim	Dr. scient Botany	Plant biodiversity and land use in subalpine grasslands. – A conservation biological approach
1998	Bente Gunnveig Berg	Dr. scient Zoology	Encoding of pheromone information in two related moth species
1999	Kristian Overskaug	Dr. scient Zoology	Behavioural and morphological characteristics in Northern Tawny Owls *Strix aluco*: An intra- and interspecific comparative approach
1999	Hans Kristen Stenøien	Dr. scient Botany	Genetic studies of evolutionary processes in various populations of nonvascular plants (mosses, liverworts and hornworts)
1999	Trond Arnesen	Dr. scient Botany	Vegetation dynamics following trampling and burning in the outlying haylands at Sølendet, Central Norway

1999	Ingvar Stenberg	Dr. scient Zoology	Habitat selection, reproduction and survival in the White-backed Woodpecker *Dendrocopos leucotos*
1999	Stein Olle Johansen	Dr. scient Botany	A study of driftwood dispersal to the Nordic Seas by dendrochronology and wood anatomical analysis
1999	Trina Falck Galloway	Dr. scient Zoology	Muscle development and growth in early life stages of the Atlantic cod (*Gadus morhua* L.) and Halibut (*Hippoglossus hippoglossus* L.)
1999	Marianne Giæver	Dr. scient Zoology	Population genetic studies in three gadoid species: blue whiting (*Micromisistius poutassou*), haddock (*Melanogrammus aeglefinus*) and cod (*Gadus morhua*) in the North-East Atlantic
1999	Hans Martin Hanslin	Dr. scient Botany	The impact of environmental conditions of density dependent performance in the boreal forest bryophytes *Dicranum majus*, *Hylocomium splendens*, *Plagiochila asplenigides*, *Ptilium crista-castrensis* and *Rhytidiadelphus lokeus*
1999	Ingrid Bysveen Mjølnerød	Dr. scient Zoology	Aspects of population genetics, behaviour and performance of wild and farmed Atlantic salmon (*Salmo salar*) revealed by molecular genetic techniques
1999	Else Berit Skagen	Dr. scient Botany	The early regeneration process in protoplasts from *Brassica napus* hypocotyls cultivated under various g-forces
1999	Stein-Are Sæther	Dr. philos Zoology	Mate choice, competition for mates, and conflicts of interest in the Lekking Great Snipe
1999	Katrine Wangen Rustad	Dr. scient Zoology	Modulation of glutamatergic neurotransmission related to cognitive dysfunctions and Alzheimer's disease
1999	Per Terje Smiseth	Dr. scient Zoology	Social evolution in monogamous families:
1999	Gunnbjørn Bremset	Dr. scient Zoology	Young Atlantic salmon (*Salmo salar* L.) and Brown trout (*Salmo trutta* L.) inhabiting the deep pool habitat, with special reference to their habitat use, habitat preferences and competitive interactions
1999	Frode Ødegaard	Dr. scient Zoology	Host specificity as a parameter in estimates of arthropod species richness
1999	Sonja Andersen	Dr. scient Zoology	Expressional and functional analyses of human, secretory phospholipase A2
2000	Ingrid Salvesen	Dr. scient Botany	Microbial ecology in early stages of marine fish: Development and evaluation of methods for microbial management in intensive larviculture
2000	Ingar Jostein Øien	Dr. scient Zoology	The Cuckoo (*Cuculus canorus*) and its host: adaptions and counteradaptions in a coevolutionary arms race
2000	Pavlos Makridis	Dr. scient Botany	Methods for the microbial control of live food used for the rearing of marine fish larvae
2000	Sigbjørn Stokke	Dr. scient Zoology	Sexual segregation in the African elephant (*Loxodonta africana*)
2000	Odd A. Gulseth	Dr. philos Zoology	Seawater tolerance, migratory behaviour and growth of Charr, (*Salvelinus alpinus*), with emphasis on the high Arctic Dieset charr on Spitsbergen, Svalbard
2000	Pål A. Olsvik	Dr. scient Zoology	Biochemical impacts of Cd, Cu and Zn on brown trout (*Salmo trutta*) in two mining-contaminated rivers in Central Norway
2000	Sigurd Einum	Dr. scient Zoology	Maternal effects in fish: Implications for the evolution of breeding time and egg size
2001	Jan Ove Evjemo	Dr. scient Zoology	Production and nutritional adaptation of the brine shrimp *Artemia* sp. as live food organism for larvae of marine cold water fish species

2001	Olga Hilmo	Dr. scient Botany	Lichen response to environmental changes in the managed boreal forest systems
2001	Ingebrigt Uglem	Dr. scient Zoology	Male dimorphism and reproductive biology in corkwing wrasse (*Symphodus melops* L.)
2001	Bård Gunnar Stokke	Dr. scient Zoology	Coevolutionary adaptations in avian brood parasites and their hosts
2002	Ronny Aanes	Dr. scient Zoology	Spatio-temporal dynamics in Svalbard reindeer (*Rangifer tarandus platyrhynchus*)
2002	Mariann Sandsund	Dr. scient Zoology	Exercise- and cold-induced asthma. Respiratory and thermoregulatory responses
2002	Dag-Inge Øien	Dr. scient Botany	Dynamics of plant communities and populations in boreal vegetation influenced by scything at Sølendet, Central Norway
2002	Frank Rosell	Dr. scient Zoology	The function of scent marking in beaver (*Castor fiber*)
2002	Janne Østvang	Dr. scient Botany	The Role and Regulation of Phospholipase A_2 in Monocytes During Atherosclerosis Development
2002	Terje Thun	Dr. philos Biology	Dendrochronological constructions of Norwegian conifer chronologies providing dating of historical material
2002	Birgit Hafjeld Borgen	Dr. scient Biology	Functional analysis of plant idioblasts (Myrosin cells) and their role in defense, development and growth
2002	Bård Øyvind Solberg	Dr. scient Biology	Effects of climatic change on the growth of dominating tree species along major environmental gradients
2002	Per Winge	Dr. scient Biology	The evolution of small GTP binding proteins in cellular organisms. Studies of RAC GTPases in *Arabidopsis thaliana* and the Ral GTPase from *Drosophila melanogaster*
2002	Henrik Jensen	Dr. scient Biology	Causes and consequences of individual variation in fitness-related traits in house sparrows
2003	Jens Rohloff	Dr. philos Biology	Cultivation of herbs and medicinal plants in Norway – Essential oil production and quality control
2003	Åsa Maria O. Espmark Wibe	Dr. scient Biology	Behavioural effects of environmental pollution in threespine stickleback *Gasterosteus aculeatur* L.
2003	Dagmar Hagen	Dr. scient Biology	Assisted recovery of disturbed arctic and alpine vegetation – an integrated approach
2003	Bjørn Dahle	Dr. scient Biology	Reproductive strategies in Scandinavian brown bears
2003	Cyril Lebogang Taolo	Dr. scient Biology	Population ecology, seasonal movement and habitat use of the African buffalo (*Syncerus caffer*) in Chobe National Park, Botswana
2003	Marit Stranden	Dr. scient Biology	Olfactory receptor neurones specified for the same odorants in three related Heliothine species (*Helicoverpa armigera, Helicoverpa assulta* and *Heliothis virescens*)
2003	Kristian Hassel	Dr. scient Biology	Life history characteristics and genetic variation in an expanding species, *Pogonatum dentatum*
2003	David Alexander Rae	Dr. scient Biology	Plant- and invertebrate-community responses to species interaction and microclimatic gradients in alpine and Artic environments
2003	Åsa A Borg	Dr. scient Biology	Sex roles and reproductive behaviour in gobies and guppies: a female perspective
2003	Eldar Åsgard Bendiksen	Dr. scient Biology	Environmental effects on lipid nutrition of farmed Atlantic salmon (*Salmo salar* L.) parr and smolt
2004	Torkild Bakken	Dr. scient Biology	A revision of Nereidinae (Polychaeta, Nereididae)

2004	Ingar Pareliussen	Dr. scient Biology	Natural and Experimental Tree Establishment in a Fragmented Forest, Ambohitantely Forest Reserve, Madagascar
2004	Tore Brembu	Dr. scient Biology	Genetic, molecular and functional studies of RAC GTPases and the WAVE-like regulatory protein complex in *Arabidopsis thaliana*
2004	Liv S. Nilsen	Dr. scient Biology	Coastal heath vegetation on central Norway; recent past, present state and future possibilities
2004	Hanne T. Skiri	Dr. scient Biology	Olfactory coding and olfactory learning of plant odours in heliothine moths. An anatomical, physiological and behavioural study of three related species (*Heliothis virescens, Helicoverpa armigera* and *Helicoverpa assulta*)
2004	Lene Østby	Dr. scient Biology	Cytochrome P4501A (CYP1A) induction and DNA adducts as biomarkers for organic pollution in the natural environment
2004	Emmanuel J. Gerreta	Dr. philos Biology	The Importance of Water Quality and Quantity in the Tropical Ecosystems, Tanzania
2004	Linda Dalen	Dr. scient Biology	Dynamics of Mountain Birch Treelines in the Scandes Mountain Chain, and Effects of Climate Warming
2004	Lisbeth Mehli	Dr. scient Biology	Polygalacturonase-inhibiting protein (PGIP) in cultivated strawberry (*Fragaria* x *ananassa*): characterisation and induction of the gene following fruit infection by *Botrytis cinerea*
2004	Børge Moe	Dr. scient Biology	Energy-Allocation in Avian Nestlings Facing Short-Term Food Shortage
2005	Matilde Skogen Chauton	Dr. scient Biology	Metabolic profiling and species discrimination from High-Resolution Magic Angle Spinning NMR analysis of whole-cell samples
2005	Sten Karlsson	Dr. scient Biology	Dynamics of Genetic Polymorphisms
2005	Terje Bongard	Dr. scient Biology	Life History strategies, mate choice, and parental investment among Norwegians over a 300-year period
2005	Tonette Røstelien	PhD Biology	Functional characterisation of olfactory receptor neurone types in heliothine moths
2005	Erlend Kristiansen	Dr. scient Biology	Studies on antifreeze proteins
2005	Eugen G. Sørmo	Dr. scient Biology	Organochlorine pollutants in grey seal (*Halichoerus grypus*) pups and their impact on plasma thyrid hormone and vitamin A concentrations
2005	Christian Westad	Dr. scient Biology	Motor control of the upper trapezius
2005	Lasse Mork Olsen	PhD Biology	Interactions between marine osmo- and phagotrophs in different physicochemical environments
2005	Åslaug Viken	PhD Biology	Implications of mate choice for the management of small populations
2005	Ariaya Hymete Sahle Dingle	PhD Biology	Investigation of the biological activities and chemical constituents of selected *Echinops* spp. growing in Ethiopia
2005	Anders Gravbrøt Finstad	PhD Biology	Salmonid fishes in a changing climate: The winter challenge
2005	Shimane Washington Makabu	PhD Biology	Interactions between woody plants, elephants and other browsers in the Chobe Riverfront, Botswana
2005	Kjartan Østbye	Dr. scient Biology	The European whitefish *Coregonus lavaretus* (L.) species complex: historical contingency and adaptive radiation

2006	Kari Mette Murvoll	PhD Biology	Levels and effects of persistent organic pollutans (POPs) in seabirds, Retinoids and α-tocopherol – potential biomakers of POPs in birds?
2006	Ivar Herfindal	Dr. scient Biology	Life history consequences of environmental variation along ecological gradients in northern ungulates
2006	Nils Egil Tokle	PhD Biology	Are the ubiquitous marine copepods limited by food or predation? Experimental and field-based studies with main focus on *Calanus finmarchicus*
2006	Jan Ove Gjershaug	Dr. philos Biology	Taxonomy and conservation status of some booted eagles in south-east Asia
2006	Jon Kristian Skei	Dr. scient Biology	Conservation biology and acidification problems in the breeding habitat of amphibians in Norway
2006	Johanna Järnegren	PhD Biology	*Acesta oophaga* and *Acesta excavata* – a study of hidden biodiversity
2006	Bjørn Henrik Hansen	PhD Biology	Metal-mediated oxidative stress responses in brown trout (*Salmo trutta*) from mining contaminated rivers in Central Norway
2006	Vidar Grøtan	PhD Biology	Temporal and spatial effects of climate fluctuations on population dynamics of vertebrates
2006	Jafari R Kideghesho	PhD Biology	Wildlife conservation and local land use conflicts in Western Serengeti Corridor, Tanzania
2006	Anna Maria Billing	PhD Biology	Reproductive decisions in the sex role reversed pipefish *Syngnathus typhle*: when and how to invest in reproduction
2006	Henrik Pärn	PhD Biology	Female ornaments and reproductive biology in the bluethroat
2006	Anders J. Fjellheim	PhD Biology	Selection and administration of probiotic bacteria to marine fish larvae
2006	P. Andreas Svensson	PhD Biology	Female coloration, egg carotenoids and reproductive success: gobies as a model system
2007	Sindre A. Pedersen	PhD Biology	Metal binding proteins and antifreeze proteins in the beetle *Tenebrio molitor* - a study on possible competition for the semi-essential amino acid cysteine
2007	Kasper Hancke	PhD Biology	Photosynthetic responses as a function of light and temperature: Field and laboratory studies on marine microalgae
2007	Tomas Holmern	PhD Biology	Bushmeat hunting in the western Serengeti: Implications for community-based conservation
2007	Kari Jørgensen	PhD Biology	Functional tracing of gustatory receptor neurons in the CNS and chemosensory learning in the moth *Heliothis virescens*
2007	Stig Ulland	PhD Biology	Functional Characterisation of Olfactory Receptor Neurons in the Cabbage Moth, (*Mamestra brassicae* L.) (Lepidoptera, Noctuidae). Gas Chromatography Linked to Single Cell Recordings and Mass Spectrometry
2007	Snorre Henriksen	PhD Biology	Spatial and temporal variation in herbivore resources at northern latitudes
2007	Roelof Frans May	PhD Biology	Spatial Ecology of Wolverines in Scandinavia
2007	Vedasto Gabriel Ndibalema	PhD Biology	Demographic variation, distribution and habitat use between wildebeest sub-populations in the Serengeti National Park, Tanzania
2007	Julius William Nyahongo	PhD Biology	Depredation of Livestock by wild Carnivores and Illegal Utilization of Natural Resources by Humans in the Western Serengeti, Tanzania

2007	Shombe Ntaraluka Hassan	PhD Biology	Effects of fire on large herbivores and their forage resources in Serengeti, Tanzania
2007	Per-Arvid Wold	PhD Biology	Functional development and response to dietary treatment in larval Atlantic cod *(Gadus morhua* L.) Focus on formulated diets and early weaning
2007	Anne Skjetne Mortensen	PhD Biology	Toxicogenomics of Aryl Hydrocarbon- and Estrogen Receptor Interactions in Fish: Mechanisms and Profiling of Gene Expression Patterns in Chemical Mixture Exposure Scenarios
2008	Brage Bremset Hansen	PhD Biology	The Svalbard reindeer (*Rangifer tarandus platyrhynchus*) and its food base: plant-herbivore interactions in a high-arctic ecosystem
2008	Jiska van Dijk	PhD Biology	Wolverine foraging strategies in a multiple-use landscape
2008	Flora John Magige	PhD Biology	The ecology and behaviour of the Masai Ostrich (*Struthio camelus massaicus*) in the Serengeti Ecosystem, Tanzania
2008	Bernt Rønning	PhD Biology	Sources of inter- and intra-individual variation in basal metabolic rate in the zebra finch, *Taeniopygia guttata*
2008	Sølvi Wehn	PhD Biology	Biodiversity dynamics in semi-natural mountain landscapes - A study of consequences of changed agricultural practices in Eastern Jotunheimen
2008	Trond Moxness Kortner	PhD Biology	The Role of Androgens on previtellogenic oocyte growth in Atlantic cod (*Gadus morhua*): Identification and patterns of differentially expressed genes in relation to Stereological Evaluations
2008	Katarina Mariann Jørgensen	Dr. scient Biology	The role of platelet activating factor in activation of growth arrested keratinocytes and re-epithelialisation
2008	Tommy Jørstad	PhD Biology	Statistical Modelling of Gene Expression Data
2008	Anna Kusnierczyk	PhD Biology	*Arabidopsis thaliana* Responses to Aphid Infestation
2008	Jussi Evertsen	PhD Biology	Herbivore sacoglossans with photosynthetic chloroplasts
2008	John Eilif Hermansen	PhD Biology	Mediating ecological interests between locals and globals by means of indicators. A study attributed to the asymmetry between stakeholders of tropical forest at Mt. Kilimanjaro, Tanzania
2008	Ragnhild Lyngved	PhD Biology	Somatic embryogenesis in *Cyclamen persicum.* Biological investigations and educational aspects of cloning
2008	Line Elisabeth Sundt-Hansen	PhD Biology	Cost of rapid growth in salmonid fishes
2008	Line Johansen	PhD Biology	Exploring factors underlying fluctuations in white clover populations – clonal growth, population structure and spatial distribution
2009	Astrid Jullumstrø Feuerherm	PhD Biology	Elucidation of molecular mechanisms for pro-inflammatory phospholipase A2 in chronic disease
2009	Pål Kvello	PhD Biology	Neurons forming the network involved in gustatory coding and learning in the moth *Heliothis virescens:* Physiological and morphological characterisation, and integration into a standard brain atlas
2009	Trygve Devold Kjellsen	PhD Biology	Extreme Frost Tolerance in Boreal Conifers
2009	Johan Reinert Vikan	PhD Biology	Coevolutionary interactions between common cuckoos *Cuculus canorus* and *Fringilla* finches

2009	Zsolt Volent	PhD Biology	Remote sensing of marine environment: Applied surveillance with focus on optical properties of phytoplankton, coloured organic matter and suspended matter
2009	Lester Rocha	PhD Biology	Functional responses of perennial grasses to simulated grazing and resource availability
2009	Dennis Ikanda	PhD Biology	Dimensions of a Human-lion conflict: Ecology of human predation and persecution of African lions (*Panthera leo*) in Tanzania
2010	Huy Quang Nguyen	PhD Biology	Egg characteristics and development of larval digestive function of cobia (*Rachycentron canadum*) in response to dietary treatments - Focus on formulated diets
2010	Eli Kvingedal	PhD Biology	Intraspecific competition in stream salmonids: the impact of environment and phenotype
2010	Sverre Lundemo	PhD Biology	Molecular studies of genetic structuring and demography in *Arabidopsis* from Northern Europe
2010	Iddi Mihijai Mfunda	PhD Biology	Wildlife Conservation and People's livelihoods: Lessons Learnt and Considerations for Improvements. The Case of Serengeti Ecosystem, Tanzania
2010	Anton Tinchov Antonov	PhD Biology	Why do cuckoos lay strong-shelled eggs? Tests of the puncture resistance hypothesis
2010	Anders Lyngstad	PhD Biology	Population Ecology of *Eriophorum latifolium*, a Clonal Species in Rich Fen Vegetation
2010	Hilde Færevik	PhD Biology	Impact of protective clothing on thermal and cognitive responses
2010	Ingerid Brænne Arbo	PhD Medical technology	Nutritional lifestyle changes – effects of dietary carbohydrate restriction in healthy obese and overweight humans
2010	Yngvild Vindenes	PhD Biology	Stochastic modeling of finite populations with individual heterogeneity in vital parameters
2010	Hans-Richard Brattbakk	PhD Medical technology	The effect of macronutrient composition, insulin stimulation, and genetic variation on leukocyte gene expression and possible health benefits
2011	Geir Hysing Bolstad	PhD Biology	Evolution of Signals: Genetic Architecture, Natural Selection and Adaptive Accuracy
2011	Karen de Jong	PhD Biology	Operational sex ratio and reproductive behaviour in the two-spotted goby (*Gobiusculus flavescens*)
2011	Ann-Iren Kittang	PhD Biology	*Arabidopsis thaliana* L. adaptation mechanisms to microgravity through the EMCS MULTIGEN-2 experiment on the ISS:– The science of space experiment integration and adaptation to simulated microgravity
2011	Aline Magdalena Lee	PhD Biology	Stochastic modeling of mating systems and their effect on population dynamics and genetics
2011	Christopher Gravningen Sørmo	PhD Biology	Rho GTPases in Plants: Structural analysis of ROP GTPases; genetic and functional studies of MIRO GTPases in Arabidopsis thaliana
2011	Grethe Robertsen	PhD Biology	Relative performance of salmonid phenotypes across environments and competitive intensities
2011	Line-Kristin Larsen	PhD Biology	Life-history trait dynamics in experimental populations of guppy (*Poecilia reticulata*): the role of breeding regime and captive environment
2011	Maxim A. K. Teichert	PhD Biology	Regulation in Atlantic salmon (*Salmo salar*): The interaction between habitat and density
2011	Torunn Beate Hancke	PhD Biology	Use of Pulse Amplitude Modulated (PAM) Fluorescence and Bio-optics for Assessing Microalgal

			Photosynthesis and Physiology
2011	Sajeda Begum	PhD Biology	Brood Parasitism in Asian Cuckoos: Different Aspects of Interactions between Cuckoos and their Hosts in Bangladesh
2011	Kari J. K. Attramadal	PhD Biology	Water treatment as an approach to increase microbial control in the culture of cold water marine larvae
2011	Camilla Kalvatn Egset	PhD Biology	The Evolvability of Static Allometry: A Case Study
2011	AHM Raihan Sarker	PhD Biology	Conflict over the conservation of the Asian elephant (*Elephas maximus*) in Bangladesh
2011	Gro Dehli Villanger	PhD Biology	Effects of complex organohalogen contaminant mixtures on thyroid hormone homeostasis in selected arctic marine mammals
2011	Kari Bjørneraas	PhD Biology	Spatiotemporal variation in resource utilisation by a large herbivore, the moose
2011	John Odden	PhD Biology	The ecology of a conflict: Eurasian lynx depredation on domestic sheep
2011	Simen Pedersen	PhD Biology	Effects of native and introduced cervids on small mammals and birds
2011	Mohsen Falahati-Anbaran	PhD Biology	Evolutionary consequences of seed banks and seed dispersal in *Arabidopsis*
2012	Jakob Hønborg Hansen	PhD Biology	Shift work in the offshore vessel fleet: circadian rhythms and cognitive performance
2012	Elin Noreen	PhD Biology	Consequences of diet quality and age on life-history traits in a small passerine bird
2012	Irja Ida Ratikainen	PhD Biology	Foraging in a variable world: adaptations to stochasticity
2012	Aleksander Handå	PhD Biology	Cultivation of mussels (*Mytilus edulis):* Feed requirements, storage and integration with salmon (*Salmo salar*) farming
2012	Morten Kraabøl	PhD Biology	Reproductive and migratory challenges inflicted on migrant brown trout (*Salmo trutta* L.) in a heavily modified river
2012	Jisca Huisman	PhD Biology	Gene flow and natural selection in Atlantic salmon
2012	Maria Bergvik	PhD Biology	Lipid and astaxanthin contents and biochemical post-harvest stability in *Calanus finmarchicus*
2012	Bjarte Bye Løfaldli	PhD Biology	Functional and morphological characterization of central olfactory neurons in the model insect *Heliothis virescens*.
2012	Karen Marie Hammer	PhD Biology	Acid-base regulation and metabolite responses in shallow- and deep-living marine invertebrates during environmental hypercapnia
2012	Øystein Nordrum Wiggen	PhD Biology	Optimal performance in the cold
2012	Robert Dominikus Fyumagwa	Dr. Philos Biology	Anthropogenic and natural influence on disease prevalence at the human –livestock-wildlife interface in the Serengeti ecosystem, Tanzania
2012	Jenny Bytingsvik	PhD Biology	Organohalogenated contaminants (OHCs) in polar bear mother-cub pairs from Svalbard, Norway. Maternal transfer, exposure assessment and thyroid hormone disruptive effects in polar bear cubs
2012	Christer Moe Rolandsen	PhD Biology	The ecological significance of space use and movement patterns of moose in a variable environment

2012	Erlend Kjeldsberg Hovland	PhD Biology	Bio-optics and Ecology in *Emiliania huxleyi* Blooms: Field and Remote Sensing Studies in Norwegian Waters
2012	Lise Cats Myhre	PhD Biology	Effects of the social and physical environment on mating behaviour in a marine fish
2012	Tonje Aronsen	PhD Biology	Demographic, environmental and evolutionary aspects of sexual selection
2012	Bin Liu	PhD Biology	Molecular genetic investigation of cell separation and cell death regulation in *Arabidopsis thaliana*
2013	Jørgen Rosvold	PhD Biology	Ungulates in a dynamic and increasingly human dominated landscape – A millennia-scale perspective
2013	Pankaj Barah	PhD Biology	Integrated Systems Approaches to Study Plant Stress Responses
2013	Marit Linnerud	PhD Biology	Patterns in spatial and temporal variation in population abundances of vertebrates
2013	Xinxin Wang	PhD Biology	Integrated multi-trophic aquaculture driven by nutrient wastes released from Atlantic salmon (*Salmo salar*) farming
2013	Ingrid Ertshus Mathisen	PhD Biology	Structure, dynamics, and regeneration capacity at the sub-arctic forest-tundra ecotone of northern Norway and Kola Peninsula, NW Russia
2013	Anders Foldvik	PhD Biology	Spatial distributions and productivity in salmonid populations
2013	Anna Marie Holand	PhD Biology	Statistical methods for estimating intra- and inter-population variation in genetic diversity
2013	Anna Solvang Båtnes	PhD Biology	Light in the dark – the role of irradiance in the high Arctic marine ecosystem during polar night
2013	Sebastian Wacker	PhD Biology	The dynamics of sexual selection: effects of OSR, density and resource competition in a fish
2013	Cecilie Miljeteig	PhD Biology	Phototaxis in *Calanus finmarchicus* – light sensitivity and the influence of energy reserves and oil exposure
2013	Ane Kjersti Vie	PhD Biology	Molecular and functional characterisation of the IDA family of signalling peptides in *Arabidopsis thaliana*
2013	Marianne Nymark	PhD Biology	Light responses in the marine diatom *Phaeodactylum tricornutum*
2014	Jannik Schultner	PhD Biology	Resource Allocation under Stress - Mechanisms and Strategies in a Long-Lived Bird
2014	Craig Ryan Jackson	PhD Biology	Factors influencing African wild dog *(Lycaon pictus*) habitat selection and ranging behaviour: conservation and management implications
2014	Aravind Venkatesan	PhD Biology	Application of Semantic Web Technology to establish knowledge management and discovery in the Life Sciences
2014	Kristin Collier Valle	PhD Biology	Photoacclimation mechanisms and light responses in marine micro- and macroalgae
2014	Michael Puffer	PhD Biology	Effects of rapidly fluctuating water levels on juvenile Atlantic salmon (*Salmo salar* L.)
2014	Gundula S. Bartzke	PhD Biology	Effects of power lines on moose *(Alces alces)* habitat selection, movements and feeding activity
2014	Eirin Marie Bjørkvoll	PhD Biology	Life-history variation and stochastic population dynamics in vertebrates
2014	Håkon Holand	PhD Biology	The parasite *Syngamus trachea* in a metapopulation of house sparrows
2014	Randi Magnus Sommerfelt	PhD Biology	Molecular mechanisms of inflammation – a central role for cytosolic phospholiphase A2

2014	Espen Lie Dahl	PhD Biology	Population demographics in white-tailed eagle at an on-shore wind farm area in coastal Norway
2014	Anders Øverby	PhD Biology	Functional analysis of the action of plant isothiocyanates: cellular mechanisms and in vivo role in plants, and anticancer activity
2014	Kamal Prasad Acharya	PhD Biology	Invasive species: Genetics, characteristics and trait variation along a latitudinal gradient.
2014	Ida Beathe Øverjordet	PhD Biology	Element accumulation and oxidative stress variables in Arctic pelagic food chains: *Calanus*, little auks (*Alle alle*) and black-legged kittiwakes (*Rissa tridactyla*)
2014	Kristin Møller Gabrielsen	PhD Biology	Target tissue toxicity of the thyroid hormone system in two species of arctic mammals carrying high loads of organohalogen contaminants
2015	Gine Roll Skjervø	Dr. philos Biology	Testing behavioral ecology models with historical individual-based human demographic data from Norway
2015	Nils Erik Gustaf Forsberg	PhD Biology	Spatial and Temporal Genetic Structure in Landrace Cereals
2015	Leila Alipanah	PhD Biology	Integrated analyses of nitrogen and phosphorus deprivation in the diatoms *Phaeodactylum tricornutum* and *Seminavis robusta*
2015	Javad Najafi	PhD Biology	Molecular investigation of signaling components in sugar sensing and defense in *Arabidopsis thaliana*
2015	Bjørnar Sporsheim	PhD Biology	Quantitative confocal laser scanning microscopy: optimization of in vivo and in vitro analysis of intracellular transport
2015	Magni Olsen Kyrkjeeide	PhD Biology	Genetic variation and structure in peatmosses (*Sphagnum*)
2015	Keshuai Li	PhD Biology	Phospholipids in Atlantic cod (*Gadus morhua* L.) larvae rearing: Incorporation of DHA in live feed and larval phospholipids and the metabolic capabilities of larvae for the de novo synthesis
2015	Ingvild Fladvad Størdal	PhD Biology	The role of the copepod *Calanus finmarchicus* in affecting the fate of marine oil spills
2016	Thomas Kvalnes	PhD Biology	Evolution by natural selection in age-structured populations in fluctuating environments
2016	Øystein Leiknes	PhD Biology	The effect of nutrition on important life-history traits in the marine copepod *Calanus finmarchicus*
2016	Johan Henrik Hårdensson Berntsen	PhD Biology	Individual variation in survival: The effect of incubation temperature on the rate of physiological ageing in a small passerine bird
2016	Marianne Opsahl Olufsen	PhD Biology	Multiple environmental stressors: Biological interactions between parameters of climate change and perfluorinated alkyl substances in fish
2016	Rebekka Varne	PhD Biology	Tracing the fate of escaped cod (*Gadus morhua* L.) in a Norwegian fjord system
2016	Anette Antonsen Fenstad	PhD Biology	Pollutant Levels, Antioxidants and Potential Genotoxic Effects in Incubating Female Common Eiders (*Somateria mollissima*)
2016	Wilfred Njama Marealle	PhD Biology	Ecology, Behaviour and Conservation Status of Masai Giraffe (*Giraffa camelopardalis tippelskirchi*) in Tanzania
2016	Ingunn Nilssen	PhD Biology	Integrated Enviromental Mapping and Monitoring: A Methodological approach for end users.
2017	Konika Chawla	PhD Biology	Discovering, analysing and taking care of knowledge.

2017	Øystein Hjorthol Opedal	PhD Biology	The Evolution of Herkogamy: Pollinator Reliability, Natural Selection, and Trait Evolvability.
2017	Ane Marlene Myhre	PhD Biology	Effective size of density dependent populations in fluctuating environments
2017	Emmanuel Hosiana Masenga	PhD Biology	Behavioural Ecology of Free-ranging and Reintroduced African Wild Dog (*Lycaon pictus*) Packs in the Serengeti Ecosystem, Tanzania
2017	Xiaolong Lin	PhD Biology	Systematics and evolutionary history of *Tanytarsus* van der Wulp, 1874 (Diptera: Chironomidae)
2017	Emmanuel Clamsen Mmassy	PhD Biology	Ecology and Conservation Challenges of the Kori bustard in the Serengeti National Park
2017	Richard Daniel Lyamuya	PhD Biology	Depredation of Livestock by Wild Carnivores in the Eastern Serengeti Ecosystem, Tanzania
2017	Katrin Hoydal	PhD Biology	Levels and endocrine disruptive effects of legacy POPs and their metabolites in long-finned pilot whales of the Faroe Islands
2017	Berit Glomstad	PhD Biology	Adsorption of phenanthrene to carbon nanotubes and its influence on phenanthrene bioavailability/toxicity in aquatic organism
2017	Øystein Nordeide Kielland	PhD Biology	Sources of variation in metabolism of an aquatic ectotherm
2017	Narjes Yousefi	PhD Biology	Genetic divergence and speciation in northern peatmosses (*Sphagnum*)
2018	Signe Christensen-Dalgaard	PhD Biology	Drivers of seabird spatial ecology - implications for development of offshore wind-power in Norway
2018	Janos Urbancsok	PhD Biology	Endogenous biological effects induced by externally supplemented glucosinolate hydrolysis products (GHPs) on *Arabidopsis thaliana*
2018	Alice Mühlroth	PhD Biology	The influence of phosphate depletion on lipid metabolism of microalgae
2018	Franco Peniel Mbise	PhD Biology	Human-Carnivore Coexistence and Conflict in the Eastern Serengeti, Tanzania
2018	Stine Svalheim Markussen	PhD Biology	Causes and consequences of intersexual life history variation in a harvested herbivore population
2018	Mia Vedel Sørensen	PhD Biology	Carbon budget consequences of deciduous shrub expansion in alpine tundra ecosystems
2018	Hanna Maria Kauko	PhD Biology	Light response and acclimation of microalgae in a changing Arctic
2018	Erlend I. F. Fossen	PhD Biology	Trait evolvability: effects of thermal plasticity and genetic correlations among traits
2019	Peter Sjolte Ranke	PhD Biology	Demographic and genetic and consequences of dispersal in house sparrows
2019	Mathilde Le Moullec	PhD Biology	Spatiotemporal variation in abundance of key tundra species: from local heterogeneity to large-scale synchrony
2019	Endre Grüner Ofstad	PhD Biology	Causes and consequences of variation in resource use and social structure in ungulates
2019	Yang Jin	PhD Biology	Development of lipid metabolism in early life stage of Atlantic salmon (*Salmo salar*)
2019	Elena Albertsen	PhD Biology	Evolution of floral traits: from ecological context to functional integration