Fortified Bomas and Vigilant Herding are Perceived to Reduce Livestock Depredation by Large Carnivores in the Tarangire-Simanjiro Ecosystem, Tanzania

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Abstract

Human-carnivore conflict (HCC) is an increasingly important issue in Tanzania, especially where humans live adjacent to protected areas (hereafter PAs). We conducted semi-structured interviews (n = 300) to compile information on livestock husbandry practices and evaluate people's perceptions about the effectiveness of these methods in the Tarangire-Simanjiro ecosystem of northern Tanzania. Fortified bomas were perceived to be very effective (97.7%) to reduce nighttime depredations, while adult herders were perceived to be effective (71%) to reduce daytime depredations. Domestic dogs were perceived to be more effective at night, but an equal number of people found them to be effective during herding as did those who found them to be not effective. Our results also showed that boma type had a significant effect on livestock depredation. We recommend the use of fortified bomas as a long-term solution to prevent livestock loss at night and adult herders to herd livestock during the day.

Keywords: Fortified bomas; human-carnivore conflict (HCC); livestock husbandry practices; livestock depredation; Tarangire-Simanjiro ecosystem

Introduction

Conflict with local people, particularly over livestock depredation, is arguably one of the most important challenges in large carnivore conservation. This is one of the major threats to large carnivore populations around the world (Dickman 2008; Holmern *et al.* 2007; Woodroffe and Ginsberg 1998). Most of the world's large-bodied carnivores are in rapid global decline (Ripple *et al.* 2014), which call for alternative strategies of promoting tolerance and coexistence of large carnivores with people and livestock. In order to address human-carnivore conflict (HCC), there is need to find the most effective, cost-effective and sustainable solutions that allow people

(living adjacent to a protected area) and large carnivores to coexist. Mitigation methods to reduce conflict between humans and predators can be divided into two management groups: lethal and non-lethal control. Both lethal (Woodroffe and Frank 2005) and non-lethal control methods (Ogada *et al.* 2003; Woodroffe *et al.* 2007) have been experimentally tested for their effectiveness. Cost-benefit analyses of lethal and non-lethal conflict mitigation methods demonstrate that non-lethal methods of human–wildlife conflict mitigation are cheaper, more effective and economically feasible compared to lethal methods (McManus *et al.* 2014). Lethal control methods such as shooting, poisoning, spearing, trapping or snaring are considered to be ineffective, inhumane, and often conducted indiscriminately, resulting in the deaths of non-target species (Treves and Naughton-Treves 2005).

Empirical evidence from Kenya, North America and Europe suggests the importance of husbandry practices, and shows that various forms of livestock husbandry can effectively reduce livestock depredation by wild carnivores (Breitenmoser *et al.* 2005; Ogada *et al.* 2003; Woodroffe *et al.* 2007). Effective livestock husbandry practices such as boma enclosures, herders and guarding dogs play a crucial role in reducing livestock depredation (Kolowski and Holekamp 2006; Kissui 2008; Loveridge *et al.* 2010; Ogada *et al.* 2003; Woodroffe *et al.* 2007). Recent studies show that fortified bomas (also called Living Wall bomas or bomas reinforced with chain-link fences) are more effective at reducing nighttime depredation of livestock by over 90% (Lichtenfeld *et al.* 2014). With effective husbandry strategies, it is presumed that large carnivores and livestock might coexist successfully on communal land bordering Tarangire National Park (TNP). In this study, *livestock husbandry* refers to the movement and management of livestock to reduce the number killed by predators. Despite studies which have suggested that livestock husbandry practices can be more effective at reducing conflict with large carnivores

(Lichtenfeld *et al.* 2014; Ogada *et al.* 2003; Ukio 2010; Woodroffe *et al*. 2007), our knowledge regarding the perceived effectiveness of different livestock husbandry practices as a tool for mitigating conflict with large carnivores in the Tarangire-Simanjiro ecosystem (TSE) is still limited. Previously, Lichtenfeld *et al.* (2014) tested the actual effectiveness of fortified bomas versus traditional bomas but no previous studies have tried to understand the perceived effectiveness of this method in relationship to other methods in mitigating conflict with large carnivores in this ecosystem. Alternatively, Ukio (2010) evaluated husbandry techniques used in different villages in the Maasai Steppe and the actual effectiveness of each in reducing the conflicts, but not the perceived effectiveness of these methods. This study evaluated the perceived effectiveness of livestock husbandry techniques in the TSE and contributed theoretical insight and information that can be directly integrated into the management decisions for effective human-carnivore conflict mitigation and carnivore conservation. Specifically, the objectives of this study were (1) to assess the livestock husbandry practices employed by pastoral communities in mitigating livestock depredation in the TSE and (2) to evaluate people's perceptions about the effectiveness of these techniques in preventing livestock depredation.

Materials and Methods

Study Area

This study was conducted in Simanjiro district in Manyara region, northern Tanzania (3°52′ and 4°24′ S and 36°05′ and 36°39′ E). Simanjiro district lies within the Maasai Steppe with a land area of 20,591 km^2. On the western part lies the TNP that protects only 15% (2,850 km^2) of the approximately 20,000 km^2 in the TSE (Figure 1). The area is characterized by semi-arid climatic condition with erratic rainfall of 400-600 mm per annum (Kahurananga 1979). The climate is highly seasonal with the dry season (June – October) and wet season (November - May). Rainfall

is bi-modal in pattern with short rains occurring between November to December and long rains from March to May. Generally, the climate is warm and dry, coolest from July to December and warmest from January to June, with an average daily temperature ranging from 16 ˚C to 27˚C.

The vegetation in this area can be classified into four broad types as (i) grassland (*Digitaria macroblephara* and *Panicum coloratum)*, (ii) woodland (*Acacia tortillis* and *Commiphora schimperi)*, (iii) bushland (*Acacia stuhlmannii* and *A. drepanolobium)* and (iv) seasonally water-logged bushed grassland (*Pennisetum mezianum* and *Acacia stuhlmannii)* (Kahurananga 1979).

The study area consists of four land use types: PAs (TNP), commercial farmland, communal grazing lands and settlement. The Simanjiro plains are the main dispersal areas for wildlife during the wet season and grazing for pastoralists during the dry season. The plains are primarily used by migrating herbivores especially wildebeest (*Connochaetes taurinus*), zebra (*Equus burchellii*), hartebeest (*Alcelaphus buselaphus*) and fringe eared oryx (*Oryx beisacallotis)* for grazing and calving and non-migrant herbivores such as Thomson's gazelle (*Gazella thomsoni*), impala (*Aepyceros melampus*) and greater kudu (*Tragelaphus strepsiceros*) (Kahurananga and Silkiluwasha 1997). During the rainy season, the majority of the migratory large ungulates leave the TNP, dispersing eastwards to the Simanjiro plains, or northwards towards Lakes Manyara and Natron. They eventually return to TNP during the dry season.

The TSE is also inhabited by large carnivore species (including lions *Panthera leo,* cheetahs *Acinonyx jubatus*, leopards *Panthera pardus,* African wild dogs *Lycaon pictus*, striped hyenas *Hyena hyena* and spotted hyenas *Crocuta crocuta*) that may prey upon game and livestock. In this ecosystem, large carnivores may be vulnerable to natural prey base depletion because they have large home ranges, occur at relatively low densities and require extensive, intact habitats to

survive (Sillero-Zubiri & Laurenson 2001). Nevertheless, the rapidly growing human population, expanding cultivation and settlements in the plains are progressively excluding wildlife and livestock (Msoffe *et al.* 2011), suggesting that large carnivores will be increasingly shifting their diets to livestock over time. African wild dogs are listed as Endangered, lions, cheetahs and leopard are listed as Vulnerable, whereas striped hyenas are Near Threatened and spotted hyenas are Least Concern (IUCN 2016). The underlying volcanic soils on the plains possess phosphorus-rich grasses important for lactating female animals and their young (Kahurananga and Silkiluwasha 1997). The flood plains contain black cotton soils while the well-drained areas contain the dark red, sandy clay loam (Kahurananga and Silkiluwasha 1997).

The communities in this area are of diverse ethnic groups. The major ethnic groups are the Maasai, Waarusha and Ndorobo. Others in small numbers are Barbaig, Datoga, Pare, Hadzabe, Sandawe, Sonjo, Chagga, Fipa, Nyaturu and Iraqw. In the study area, livestock are taken out from the village in the early morning (between 06:30 – 08:00am) to graze during the day, and then returned before sunset and kept in enclosures throughout the night. Livestock is often herded by 1–2 adults, but sometimes also by young boys, girls and women.

Traditional livestock husbandry is still practiced across the Simanjiro district which involves grazing livestock herds by day and penning them into the traditional corrals or kraal known as '*bomas*' throughout the night. A boma is a Swahili name for the livestock enclosures where Maasai livestock owners keep their animals at night or a household compound enclosing structure (Lichtenfeld *et al.* 2014). These circular fenced bomas were traditionally built with acacia thorn branches, but a recent innovation of reinforcing them with chain-link fencing has

proven effective in preventing nighttime depredations. Usually, cattle and donkeys are kept together in one boma of an approximately 125m circumference, while small stock are kept in small bomas of a 25-50m circumference. However, the size of boma depends on the number of livestock owned. Each village has multiple bomas spread around and that one or more survey respondents in the same village share the same boma. At night, livestock are kept inside traditional bomas (made either of acacia thorn bush branches; planted native trees only (i.e., *Commiphora africana*); a combination of acacia thorn bush branches and planted native trees) or fortified bomas (Plate 1a-d). Boma fortification project is implemented by a local non-government organization (NGO) (i.e., Tanzania People's and Wildlife Foundation, TPW) where traditional bomas are upgraded by adding planted native trees (*Commiphora africana*) that act as fence posts with chain-link fencing. The construction of fortified bomas can be somehow expensive for pastoralist communities, therefore TPW supports them through a cost-sharing program, with community members contributing 25% of the material and operation costs (Lichtenfeld *et al.* 2014).

Interview methods

We conducted semi-structured interviews (SSIs) in five villages in the vicinity of TNP, northern Tanzania, to compile information on livestock husbandry practices and evaluate respondents' perceptions about the effectiveness of these methods. Interviews were conducted between June and July in 2014, and were designed using a similar format to those used by Maddox (2003) and again by Dickman (2008) as a guide. The questionnaire contained both closed-ended as well as open-ended questions in order to gain more information on participant's attitudes and reasoning. Questionnaires are a useful tool to examine human attitudes and behaviors towards wildlife species (White *et al.* 2005). Semi-structured interviews (SSIs) were chosen instead of fully

structured interviews because SSIs allow for more elaborate and complete answers, and are flexible enough to allow respondents to express their ideas and views in their own terms (Hunter & Brehm, 2003). In the course of conducting the interviews, anonymity and confidentiality of the interviewee was preserved. This study focused on five villages: Emboret, Terat, Sukuro, Loiborsoit and Loibor Siret (Figure 1). The layout of the villages was similar – all showing a clustered settlement pattern. A questionnaire was administered in person by the principal investigator (PI) with the help of a local assistant and translator to 300 respondents via face-to-face personal interviews from 300 households. We obtained a list of households from village offices and randomly selected an equal proportion from each sub-village. Sixty respondents were selected from each village at random. Within each boma (here referring to entire bush-fenced settlements), we counted the total number of households and utilized a random number generator to select a single household. The sample included the head of the family (usually a man), the head's wife, or elder son according to seniority. The most senior members of the household were requested to participate in the survey, expecting that they would be more informative and could more freely express themselves than junior members. Women often deferred to men, so respondents were predominantly male, but interviews were conducted with women where they were comfortable to do so. All interviewees were adults (≥18 years of age). The household was chosen as the sampling unit, adapting Maddox (2003) and Dickman (2008), and interviews were restricted to one respondent per household.

During the interviews, we tested the respondents' knowledge of carnivores using the cards of coloured photographs. If the identification was incorrect, the respondent was told the correct animal before proceeding further, with discussions and explanations provided so that the

respondent was clear exactly which species was being discussed, before moving on to questions on livestock depredation. In particular, in order to demonstrate whether respondents could tell leopards, servals and cheetahs apart, picture cards of leopard, serval and cheetah were presented to them during the interviews.

The main topics covered by the final questionnaire were (1) livestock husbandry practices and (2) perceptions of conflict mitigation methods. More specifically, we asked the respondents to give details of how they look after their livestock at night and during the day and what measures they took to avoid livestock depredation. We also noted down the explanations for their answers. In order to assess the perceived effectiveness of the mitigation methods used by pastoral communities, respondents were further asked to rate how effective they thought potential mitigation methods were in preventing livestock depredation by predators during both day and night. These were subjectively graded on a four-point Likert scale of (0) - not effective, (1) - slightly effective, (2) - effective, (3) - very effective. For those having fortified bomas and also reported cases of livestock depredation, we asked them to state whether depredation in their bomas occurred before or after boma fortification.

Interviews were conducted in the local language (i.e., Swahili language - with the aid of a translator speaking Maasai where needed) and took approximately one hour to complete. Questionnaires completed in Swahili were back-translated into English for statistical analysis. The research was cleared by the Tanzanian authorities. The Tanzania Commission for Science and Technology reviewed and approved the research protocol (Ref. # 2014-370-NA-97-20). This research also underwent clearance and approval by the Joint Management Research Committee

(JMRC) and Research Program Committee (RPC) of the Tanzania Wildlife Research Institute. Verbal Informed Consent was obtained from all the subjects prior to participation and data were kept anonymously.

Statistical analyses

We used *SPSS v*. 22.0 software package (SPSS Inc., Chicago, Illinois, USA) to perform all analyses. Questionnaire data were numerically coded and entered into *SPSS v*. 22.0 software package before analysis. All categorical and continuous variables were analyzed using standard descriptive statistics (mean, standard deviation (SD), range, percentages and frequencies of counts, tables and charts). A one-sample Kolmogorov-Smirnov test was used to determine if continuous variables were normally distributed and non-parametric tests were chosen especially where we felt that our data did not meet the assumptions of normality. Chi-squared tests using Yate's correction factor for tests with one degree of freedom were used to compare proportions. All statistical tests were two-tailed and significance was measured at $P< 0.05$.

Results

Livestock husbandry practices

All respondents acknowledged using livestock husbandry practices to reduce livestock depredation by large carnivores. Protective enclosures (bomas) to keep livestock at night were used by all respondents (100%, $n = 300$), guard dogs by 88.3% ($n = 265$) and herders by 100% ($n = 300$). Solar-powered lights around bomas were used by 1.7% ($n = 5$) of the respondents.

Boma types

The majority of the respondents used traditional bomas made of acacia thorn bush branches or a combination of acacia thorn bush branches and planted native trees (Figure 2). Overall, fewer respondents used fortified bomas and planted trees enclosures. Fortified bomas were the most

commonly used enclosures in Loibor Siret. In Loiborsoit, fortified bomas were used by 1.7% and 21.7% of the respondents to keep cattle/donkeys and small stock respectively; but were used by a relatively small proportion in Emboret, Terat and by no households in Sukuro (Figure 2).

Guarding dogs

Dogs are used to protect livestock against predators. Despite the fact that 88.3% (n = 265) of respondents reported having dogs in their households, only 54% (n = 162) reported having livestock accompanied by dogs, with an average of 1.46 ± 0.50 (range: 1 - 2) dogs per herd. Presence or absence of dogs did not have any significant influence on livestock depredation in the grazing areas (χ^2 = 451.97, df = 480, P = 0.816).

Herders

According to Maasai tradition, females and males of all age groups are responsible for herding livestock. However, males have a greater responsibility for herding livestock than females. In this study, the majority of the respondents employed adults (33%), young boys (32.5%) and a combination of adults and young boys (30.7%) to herd livestock. However, in some cases, women (1.9%), girls (1.3%) or a combination of young boys and women (0.3%), or young boys and girls (0.3%) were used. Herders' age groups were associated with herding different livestock types. Young boys were cited by 56.4% of respondents to participate in herding cattle, small stock and donkeys, while 36.6% herding cattle and small stock, 5.9% herding only small stock and 1% herding cattle and donkeys (Table 1). The majority of adults (66.4%) were reported to participate in herding cattle and small stock, 26.9% herding cattle, small stock and donkeys, 6.7% herding cattle and donkeys, but none were reported to be involved in herding small stock alone. However, a combination of young boys and adults were reported to participate in herding

cattle and small stock (63.8%), while 33% herding cattle, small stock and donkeys, 2.1% herding small stock and 1.1% herding cattle and donkeys (Table 1). All other responses regarding the association between herders' age group and livestock type are presented in Table 1. Age group of the herders was significantly associated with herding particular type of livestock ($\chi^2 = 46.35$, $df = 18$, $P < 0.001$, Table 1, Appendix 1).

Effectiveness of livestock husbandry practices

When asked which strategies they considered to be effective for protecting livestock from predators, 97.7% ($n = 293$) of the respondents scored fortified bomas a 3 (very effective), however, the majority did not use this type of enclosure (Figure 2). Most respondents (91%, $n = 273$) rated the traditional bomas (made either of acacia thorn bush, poles and thorn bush or planted native trees) as 2 (effective). While 71% ($n = 213$) of the respondents considered adult herders to be effective in reducing attacks on grazing stock, 50.7% ($n = 152$) considered young boys to be slightly effective (Table 2). Sixty-seven percent of respondents rated domestic dogs to be "effective" at night (Table 2). Despite 44% of respondents said dogs are not effective during the day but equally, 43.7% said that they are effective. We compared the reported livestock depredation in different types of bomas (Figure 3). Overall, depredation was frequently reported from traditional bomas (i.e., bomas made of acacia thorn bush, planted native trees and thorn bush) than in fortified bomas. There was a significant relationship between boma type and number of livestock reported lost to predators ($\chi^2 = 79.73$, $df = 4$, $P < 0.001$, $n = 1312$, Figure 3, Appendix 2).

When asked whether it is possible to avoid livestock depredation, 60% ($n = 181$) of the respondents said no while 40% ($n = 119$) said yes. Again, some respondents gave multiple reasons as to why it is impossible to avoid livestock depredation, for instance, 43.4% ($n = 103$)

of respondents were skeptical about using young boys, women or girls to herd livestock as they gave negative assessments of their competence (Table 3). In addition, other respondents (18.1%, n = 74) claimed that carnivores and livestock live alongside one another; therefore some amount of livestock depredation is inevitable. Another 8% (n = 32) of the respondents claimed that bomas made of thorn bush branches are not strong enough to keep the predators out. However, 15% (n = 61) of the respondents claimed that it is possible to avoid livestock depredation only if the herders could always be vigilant while grazing in the field and also strengthening the security around bomas during the night. Although 20% (n = 81) of the respondents asserted that it is possible to avoid livestock depredation through boma fortification, 14% (n = 57) emphasized the importance of using adults than young boys to herd the stock. The main reason given for this was that stock herded by adults may be less exposed to higher depredation risk.

Our results showed that 44% (n = 132) of respondents thought that killing of predators could be a good strategy to reduce livestock depredation, while 56% (n = 168) were against retaliatory killing (χ^2= 4.08, df = 1, P = 0.04). Around 9% (n = 26) of surveyed respondents admitted to having killed a predator since they came to the area, due to real or perceived risk of depredation on livestock. The major reasons given by survey respondents for not killing predators were either because they did not have enough conflict with them yet (3.3%, n = 6), scared of killing the predators (6%, n = 11), unlawful (79.8%, n = 146), predators do not wait (6.6%, n = 12) or too busy with other tasks (4.4%, n = 8). A lack of formal education was associated with support for retaliatory or preventative carnivore killing (χ^2= 5.03, df = 1, P = 0.025, Figure 4).

Discussion

Our findings revealed the existence of various livestock husbandry strategies used by livestock keepers in the study area to reduce livestock depredation by large carnivores including kraaling

stock (in bomas) at night, use of herders and guarding dogs. Our results showed that pastoral communities maintained traditional livestock husbandry practices which involve sending herders out with grazing livestock by day and penning them into livestock enclosures (bomas) throughout the night. Previous studies in other regions have indicated that appropriate husbandry and herding practices ensures livestock security and reduce depredation by large carnivores in the grazing areas and around boma enclosures (Ogada *et al.* 2003; Woodroffe *et al.* 2007). About two-thirds (67%) of respondents perceived domestic dogs to be effective at night, perhaps by alerting people of predators approaching enclosures. However, an equal number of people found dogs to be effective during herding as did those who found them to be not effective. Previous studies by Holmern *et al.* (2007) and Kissui (2008) found that domestic dogs were victims of depredation by leopards and hyenas, which could possibly account for the reduced effectiveness of dogs during herding. Nevertheless, most of the dogs in the surveyed households are likely domestic dogs, and are not trained as guards, as highlighted in other studies (Ogada *et al.* 2003). Basically, guarding dogs are trained specifically to protect livestock from predators, while domestic dogs are family dogs that will protect and defend their family in any situation they feel is threatening. Guarding dogs have been reported to be associated with a reduced depredation risk at bomas and in grazing areas (Hemson 2003; Ogada *et al.* 2003; Woodroffe *et al.* 2007). Our study did not survey respondents as to whether their dogs were trained or not, so this could be related to our split equal perception of effectiveness. Therefore, it is most likely that having trained domestic dogs as "guards" would significantly increase the effectiveness of this strategy.

Boma enclosures and herders were perceived to be effective in reducing attacks at night and during the day, respectively. Yet, characteristics of the boma enclosures and the age/gender of

herders are believed to determine how effective they could be in reducing livestock depredation. In this study, herding by adults was perceived to be a more effective method of reducing depredation than when herds were accompanied by young boys. The use of adults to herd the stock and their greater vigilance while grazing in the field has been found a more efficient conflict mitigation strategy than the use of young boys (Ikanda and Packer 2008; Kolowski and Holekamp 2006). Adult herders may avoid areas where large carnivores are likely to be found (e.g., thick bushes or denning sites) and even chase away predators when encountered (Hemson *et al.* 2009; Kolowski and Holekamp 2006). There is considerable evidence that the presence of herders can reduce the rate of depredation compared to unattended livestock (Breitenmoser *et al.* 2005; Ogada *et al.* 2003). However, the main challenge is that greater numbers of Maasai children are now going to school, meaning that fewer individuals are currently available to look after their livestock. In some cases, some households especially those with younger children must rely on younger boys to supervise grazing livestock associated with reduced effectiveness. To counteract this effect, some individuals merge the herds of various households together and use adults to supervise most of the grazing stock or hire people to herd their livestock (Lichtenfeld L. Pers. Comm. 2014).

We did not test the actual effect of fortified bomas, but rather our information relied on respondents' perceived depredation incidences between fortified bomas versus unfortified bomas. In this ecosystem, fortified bomas have been previously tested and found to be effective in mitigating HCC (Lichtenfeld *et al.* 2014). While fortified bomas are perceived by more (97.7%) respondents to be effective, they are not widely used because they are expensive to construct. However, it is important to note that, though they are relatively expensive to build, the

benefits may be worthing more than the costs (Mkonyi et al. submitted-a) and the related reduction in livestock depredation ensures a good return on investment (Lichtenfeld *et al.* 2014). Most respondents perceived that fortified bomas accompanied by improved herding practices could help reduce depredation of livestock in the study area, but also actual evidence from this ecosystem supports this perception where fortification of bomas resulted in the reduction of livestock depredation by 90% (Lichtenfeld *et al.* 2014). While fortified bomas are highly effective at preventing livestock depredation at night, when properly constructed and regularly maintained, a criticism of some fortified bomas in the area is that poor maintenance sometimes leads to failure (Mkonyi F. Pers.obs. 2014).

Despite the greater livestock losses due to depredation and related perceived costs as evaluated in the previous study (Mkonyi *et al.* submitted-a), only 3.7% of respondents admitted to having used lethal methods (poison or traps) to control predators. This is greater than the percentage of people (2%) who reported the same in Ruaha National Park (Dickman 2008), and much less compared to the 25-40% of respondents who reported the same in Loliondo and Ngorongoro (Maddox 2003). The overwhelming reason provided for using lethal methods in the study area was due to perceived risk that carnivores posed to livestock. However, retaliatory or preventative carnivore killing is still a common problem outside PAs. For example, six lions were reported to have been killed in a single poisoning event (before this study period) after killing six cattle in Loibor Siret village in 2012 (Lichtenfeld L. Pers. Comm. 2014). Our results showed that the current reported level of retaliatory or preventative carnivore killing is relatively low. However, there is the possibility of observer bias in this study, with people being possibly unwilling to report some behaviours (e.g., carnivore killings) to an outsider, particularly one linked to

conservation organizations and authorities. Therefore, further work would be required through direct monitoring of carnivore mortality to assess the true impact of anthropogenic killing.

Despite the low level of lethal control reported in this area, 98.7% of respondents clearly stated that wild animals, particularly large carnivores need to be controlled (Mkonyi *et al.* submitted-b). This perception is worrisome and poses the biggest threat to large carnivore species survival in the study area. It is obvious the major reasons for not trapping or poisoning carnivores were practical, moral as well as environmental (practical in the sense that respondents were unable to access the poisons or traps, moral in the sense that it is unlawful and wrong, and environmentally unfriendly for being a threat to unintended animals). Generally, most respondents were against retaliatory or preventative carnivore killing because it is an illegal activity and it would not be an immediate solution as killing the specific culprit might not stop other predators from preying on livestock. Therefore, more rigorous law enforcement, stiffer penalties for offenders, education and awareness are needed to ensure long-term conservation of large carnivores and other wildlife species in the study area.

While compensation for financial losses due to large carnivore depredation on livestock was suggested by 85% of respondents, it may be difficult to implement in the Tanzanian context where there is a lack of funds, management capacity and no chance of verification of depredation. Fifteen-percent of respondents were skeptical about the implementation of a compensation scheme, worried that it might be too difficult to determine the fair payment and verify the losses due to predators. Although there is already a consolation scheme that pays for livestock loss in Tanzania for some predators - namely lions and spotted hyenas (The Wildlife

conservation (Dangerous Animals Damage Consolation) regulation 2011), this is not implemented because of lack of capacity and verification.

Conclusion and management implications

Despite the efforts made by pastoral communities in improving livestock husbandry practices, livestock depredation is still a recurring management problem across the TSE. The conflict between livestock and predators will continue to exist as long as carnivore and livestock ranges overlap. Generally, there is no single management option or solution that can entirely resolve the HCC problems but rather it depends solely on a combination of strategies. Our study showed that mitigation methods are different depending on whether depredation is at boma or in the grazing areas. Understanding which livestock husbandry practices were more effective in different contexts facilitates informed decision making when humans and carnivores come into conflict. In addition, our findings have broader significance to the conservation community involved in mitigating human–carnivore conflicts. Our study suggests that livestock depredation by large carnivores could be significantly reduced through boma fortification to keep livestock safe during the night, herding by adults, vigilant herding and strengthening the security around bomas during the night. Although this study did not test the actual effect of fortified bomas or improved grazing techniques, but the perceived effectiveness as indicated by livestock owners is important in evaluating their impact and determining whether they are locally recognized strategies for conflict mitigation. In terms of fortified bomas, the TPW installs fortified bomas in local communities' bomas through a cost-sharing programme where the livestock owner pays 25 % of the total costs (approximately $500 per boma) over an individually-tailored repayment period (Lichtenfeld *et al.* 2014). Community members are also responsible for various stages of the fortified bomas installation. Naturally, affordability and cultural acceptability by local

pastoralists are critical to the success of any mitigation method. Fortifying all bomas in the study villages might be too costly but on an individual basis, the cost is unlikely to be higher than that of the depredation prevented. In this study, the cost of fortified bomas was cited by the majority of respondents as a prohibitive factor. Therefore, we assume that if a donor can share most of this cost, then many people may have their bomas fortified. This might ultimately reduce depredation on livestock by carnivores and improve carnivore conservation in the area. However, donor funds are always scarce and overstretched intended to achieve a high level of satisfactory outcomes in limited areas. The benefit of fortified bomas for carnivore conservation can only be realized if this method could be adopted by the majority of pastoralists in the area. Moreover, the cost-sharing program could give people a greater sense of fortified boma ownership and actively participate in the maintenance responsibilities than when the costs are fully covered by the donors.

Education programmes and training on environmental issues are also important and should be incorporated into village meetings and seminars and even in primary and secondary schools curricula. This would raise a greater awareness of the conservation value and role of wildlife, particularly large carnivores among the youth and local communities and build local capacity in conflict mitigation techniques. Interestingly, some of these recommendations are being implemented in the study area by the TPW (Lichtenfeld L. Pers. Comm. 2014). Tanzania National Parks (TANAPA)'s outreach programmes should work towards addressing problems such as human–carnivore conflicts and involve local communities in conservation initiatives. Positive attitudes and tolerance for carnivores may increase over time if conflicts can be addressed, and this is very interesting to see that around 20% of respondents accept carnivores as

part of the landscape (Mkonyi *et al.* submitted-b). Improved livestock husbandry practices and access to wildlife-related benefits such as tourism revenue (Parry and Campbell 1992) may improve the attitude of local people and increase tolerance towards large carnivores. Therefore, financial incentives and better sharing of overall benefits from the national park and promotion of ecotourism should be used in combination with sound livestock management programmes devised to reduce depredation.

This study contributes valuable information that could help pastoral communities to adopt effective human–carnivore conflict mitigation strategies and promote conservation of large carnivores. It also provides information necessary to direct further quantitative or follow-up study such as measuring the actual effectiveness of different livestock husbandry practices in mitigating human-carnivore conflict in the study area. It is therefore important that further research should examine the relationship between reality (actual depredation) and people's perceptions of the efficacy of various livestock husbandry practices. Clearly, additional research is required to test the effectiveness of trained domestic dogs as guards in protecting livestock from predators in the study area. We also recommend the simultaneous application of different conflict management practices to reduce or resolve HCC. Finally, based on our findings, we recommend that livestock keepers should fortify their bomas to reduce nighttime depredations, use adult herders to herd the stock and increase vigilance of livestock during grazing to reduce daytime depredations.

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Compliance with Ethical Standards:

Verbal informed consent was obtained from all individual participants included in the study.

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Conflict of interest

The authors declare that they have no conflict of interest

Literature cited

Breitenmoser, U., Angst, C., Landary, J.-M., Breitenmoser-wursten, C., Linnell, J.D and Weber, J.-M. (2005). Non-lethal techniques for reducing depredation, in: Rosie Woodroffe, S.T. and A.R. (Ed.), *People & Wildlife: Conflict or Coexistence*? Cambridge University Press, London, pp. 49–71.

Dickman, A.J. (2008). *Key determinants of conflict between people and wildlife, particularly large carnivores, around Ruaha National Park, Tanzania,* Ph.D. Thesis. University College London, Institute of Zoology, Zoological Society of London.

Hemson, G. (2003). *The Ecology and Conservation of Lions: Human-Wildlife Conflict in semi-*

arid Botswana. Ph.D. Thesis. The University of Oxford, Oxford, England.

Hemson, G., Maclennan, S., Mills, G., Johnson, P and Macdonald, D. (2009). Community, lions, livestock and money: A spatial and social analysis of attitudes to wildlife and the conservation value of tourism in a human-carnivore conflict in Botswana. *Biological Conservation* 142: 2718 – 2725.

Holmern, T., Nyahongo, J and Røskaft, E. (2007). Livestock loss caused by predators outside the Serengeti National Park, Tanzania. *Biological Conservation* 135: 534–542.

Hunter, L. M., & Brehm, J. (2003). Qualitative Insight Into Public Knowledge of, and ConcernWith, Biodiversity. *Human Ecology* 31: 309–320.

Ikanda, D.K and Packer, C. (2008). Ritual vs. retaliatory killing of African lions in the Ngorongoro Conservation Area, Tanzania. *Endangered Species Research* 6: 67–74.

IUCN. (2016). IUCN Red List of threatened species: A Global Assessment.Gland, Switzerland. Retrieved from http://www.iucnredlist.org/. accessed on November 2016.

Kahurananga, J. (1979). The vegetation of the Simanjiro Plains, Northern Tanzania. *African Journal of Ecology*17: 65–83.

Kahurananga, J and Silkiluwasha, F. (1997). The migration of zebra and wildebeest between Tarangire National Park and Simanjiro Plains, northern Tanzania, in 1972 and recent trends. *African Journal of Ecology* 35: 179–185.

Kissui, B.M. (2008). Livestock predation by lions, leopards, spotted hyenas, and their vulnerability to retaliatory killing in the Maasai steppe, Tanzania. *Animal Conservation* 11: 1–11.

Kolowski, J.M and Holekamp, K.E. (2006). Spatial, temporal, and physical characteristics of livestock depredations by large carnivores along a Kenyan reserve border. *Biological*

Conservation 128: 529–541.

Lichtenfeld, L.L., Trout, C and Kisimir, E.L. (2014). Evidence-based conservation: predator-proof bomas protect livestock and lions. *Biodiversity Conservation* 24: 483–491.

Loveridge, A.J., Wang, S.W., Frank, L.G and Seidensticker, J. (2010). People and wild felids: conservation of cats and management of conflict., in: MacDonald, D.W., L., A.J. (Eds.), *Biology and Conservation of Wild Felids*. Oxford University Press, Oxford, UK, pp. 161–195.

Maddox, T.M. (2003). *The ecology of cheetahs and other large carnivores in a pastoralist-dominated buffer zone*, Ph.D. Thesis. University College London, Institute of Zoology, Zoological Society of London.

McManus, J.S., Dickman, A.J., Gaynor, D., Smuts, B.H and Macdonald, D.W. (2014). Dead or alive? Comparing costs and benefits of lethal and non-lethal human–wildlife conflict mitigation on livestock farms. *Oryx* 1–9.

Mkonyi F.J., Durant, S.M., Estes, A.B., Msuha, M.J., Lichtenfeld, L.L., submitted - (a). Livestock depredation by large carnivores in the Tarangire ecosystem, Northern Tanzania. *International Journal of Biodiversity Science, Ecosystem Services & Management.*

Mkonyi F.J., Durant, S.M., Estes, A.B., Msuha, M.J., Lichtenfeld, L.L., submitted - (b). Local Attitudes and Perceptions Towards Large Carnivores in a Human-dominated Landscape of Northern Tanzania. *Human Dimensions of Wildlife*

Msoffe, F.U., Said, M.Y., Ogutu, J.O., Kifugo, S.C., De, J., Gardingen, P.V and Reid, R.S. (2011). Spatial correlates of land-use changes in the Maasai-Steppe of Tanzania: Implications for conservation and environmental planning. *International Journal of Biodiversity and Conservation* 3(7): 280–290.

Ogada, M.O., Woodroffe, R., Oguge, N.O and Frank, L.G. (2003). Limiting Depredation by African Carnivores: The Role of Livestock Husbandry. *Conservation Biology* 17: 1521–1530.

Parry, D and Campbell, B. (1992). Attitudes of Rural Communities to Animal Wildlife and Its Utilization in Chobe Enclave and Mababe Depression, Botswana. *Environmental Conservation* 19: 245–252.

Ripple, W.J., Estes, J.A., Beschta, R.L., Wilmers, C.C., Ritchie, E.G., Hebblewhite, M., Berger, J., Elmhagen, B., Letnic, M., Nelson, M.P., Schmitz, O.J., Smith, D.W., Wallach, A.D and Wirsing, A.J. (2014). Status and ecological effects of the world's largest carnivores. *Science* 343: 1241484–1 – 1241484–11.

Sillero-Zubiri, C and Laurenson, M. K. (2001). Interactions between carnivores and local communities: Conflict or co-existence? In M. Gittleman, J.L., Funk, S.M. & R. K. D.W., Wayne (Eds.), *Carnivore Conservation* (pp. 282–312). Cambridge: Cambridge University Press.

Treves, A and Naughton-Treves, L. (2005). Evaluating lethal control in the management of human-wildlife conflict, in: Woodroffe, R; Thirgood, S & Rabinowitz, A. (Ed.), *People and Wildlife, Conflict or Coexistence?* Cambridge University Press, London, pp. 86–106.

Ukio, I. (2010). *Husbandry practices and mitigation of human-carnivore conflicts: A case of the Maasai steppe, Tanzania,* Msc. Thesis. University of KwaZulu-Natal, South Africa.

United Republic of Tanzania (2011). The Wildlife conservation (Dangerous Animals Damage Consolation) regulation. Government printer press, Dar es salaam.

White, P.C.L., Jennings, N.V., Renwick, A.R and Barker, N.H.L. (2005). Questionnaires in ecology: a review of past use and recommendations for best practice. *Journal of Applied*

Ecology 42: 421–430.

Woodroffe, R and Frank, L.G. (2005). Lethal control of African lions (*Panthera leo*): local and regional population impacts. *Animal Conservation* 8: 91–98.

Woodroffe, R., Frank, L.G., Lindsey, P.A., ole Ranah, S.M.K and Romañach, S. (2007). Livestock husbandry as a tool for carnivore conservation in Africa's community rangelands: a case–control study. *Biodiversity Conservation* 16: 1245–1260.

Woodroffe, R and Ginsberg, J.R. (1998). Edge Effects and the Extinction of Populations Inside Protected Areas. *Science* 280: 2126–2128.

Figure legends

Figure 1. Map showing the location of the studied villages and the households interviewed in the survey.

Figure 2. Boma types used by pastoral communities in the studied villages in Simanjiro district, Tanzania, in 2014 (a) cattle and donkeys, (b) small stock.

Figure 3. Number of livestock reportedly killed by predators on different types of bomas.

Figure 4. Respondents' opinion about killing carnivore as an option to reduce livestock depredation in relationship to education level.

Plate 1. Types of bomas used by pastoral communities in Loibor Siret village in Simanjiro district (A) acacia thorn bush (B) planted native trees (C) a combination of acacia thorn bush and planted native trees (D) a fortified boma with chain link visible.