Boma fortification is cost-effective at reducing predation of livestock in a high-predation zone in the Western Mara region, Kenya

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SUMMARY

Lions *Panthera leo* kill livestock in the pastoral steppe of East Africa. The subsequent lethal retaliation by livestock owners has helped reduce lion numbers by more than 80% and driven the species from most of its historic range. This conflict is especially intense along the western edge of the Maasai Mara National Reserve in Kenya, where some of the densest lion and livestock populations in Africa overlap. We evaluated the effectiveness of implementation for one proposed solution – the Anne K. Taylor Fund's subsidized construction of fortified, chain-link livestock fences ('bomas') – in reducing livestock loss to depredation. Between 2013 and 2015 we collected 343 predation reports, based on semi-structured interviews and predation records. We used these data to study the impact of subsidised boma fortification on the depredation of cattle, sheep and goats. Of 179 fortified bomas, 67% suffered no losses over one year whereas only 15% of 60 unfortified bomas had no losses over one year. Furthermore, losses of greater than five animals per year occurred at only 17% of fortified bomas, compared to 57% of unfortified bomas. The overall reduction in losses to predation at fortified bomas equated to savings of more than $1,200 USD per household per year.

BACKGROUND

Human-wildlife conflict is a global threat to large mammals (Dickman 2010). In East Africa, conflict often arises in the form of livestock depredation that poses a significant threat to pastoral livelihoods (Woodroffe *et al.* 2005, Mponzi *et al*. 2014), and the retaliatory killing of predators is a major challenge to conservation efforts (Patterson *et al.* 2004, Kolowski & Holekamp 2006, Ikanda & Packer 2008, Kissui 2008).

The lion *Panthera leo* is an iconic, charismatic and well-studied animal whose range once extended across the entirety of the African continent. Lions now occupy less than 30% of their former range, with many small remnant populations likely to be extinct by 2050 (Riggio *et al*. 2012).

Nowhere is the conflict between humans and lions more acute than in the area surrounding the Maasai Mara National Reserve. The Mara is in Narok County, home to more than three million head of livestock and 850,000 people, 93% of which live in rural or semi-rural areas (Kenya Open Data 2014, Commission on Revenue Allocation 2014). This region is also a lion population stronghold, where between 2,870 and 7,126 lions occupy just over 35,000 km^2 (Blackburn *et al*. 2016). This area, though largely protected, places high numbers of lions adjacent to some of the highest densities of cattle in Africa (UN FAO 2005, Robinson *et al*. 2014), leading to conflict. Projections of lion population shifts and cattle density increase suggest that this conflict is likely to intensify (Kahi *et al*. 2006, Herrero *et al.* 2008, UN Secretariat 2012, Kenya Open Data 2014, Robinson *et al*. 2014).

Within the East African region, the greatest concentrations of cattle occur in a semi-circle on the southern side of Lake Victoria. Our study site on the western Mara is at the northeastern edge of this area (Figure 1). The western Mara possesses both high cattle numbers and high lion numbers, with a resultant potential for livestock depredation conflict greater than anywhere else in Africa.

This conflict can be mitigated or exacerbated by the style of livestock husbandry, with some husbandry styles inherently incurring greater predation risk than others. In the western Mara, animals are herded out of the night-time enclosure ('boma') in the mornings, and moved toward known grazing areas and water sources. In the evenings, livestock are returned to the boma and guarded by the fencing structure, the presence of dogs around the homestead, and the physical proximity of the home to the boma. This style of husbandry produces limited daytime predation, as the presence and vigilance of the herder acts as a deterrent. However, animals remain vulnerable to night-time predation, and this can be exacerbated by poor fencing structures, such as traditional acacia fences (Figure 2a).

Over the past twelve years, those working to save lions have sought to de-escalate the conflict by reducing the threat of night-time depredation with the construction of predator-proof bomas (Figure 2; Ogada *et al*. 2003, Lichtenfeld *et al*. 2015, Manoa & Mwaura 2016). The Anne K. Taylor Fund (AKTF) has operated its Boma Fortification Program since 2009. The programme provides materials and labour support for the construction of wire-and-post livestock enclosures across the western Mara. In this study, we report its efficacy in reducing reported livestock depredation losses and make recommendations for its future role.

ACTION

From April 2013 to July 2015, we collected 375 in-person interviews about depredation experience from 308 Maasai households that owned bomas. The interviews took place in two subsections (the Mara North Conservancy and the Trans-Mara region) of an area of approximately 550 km^2 along the western

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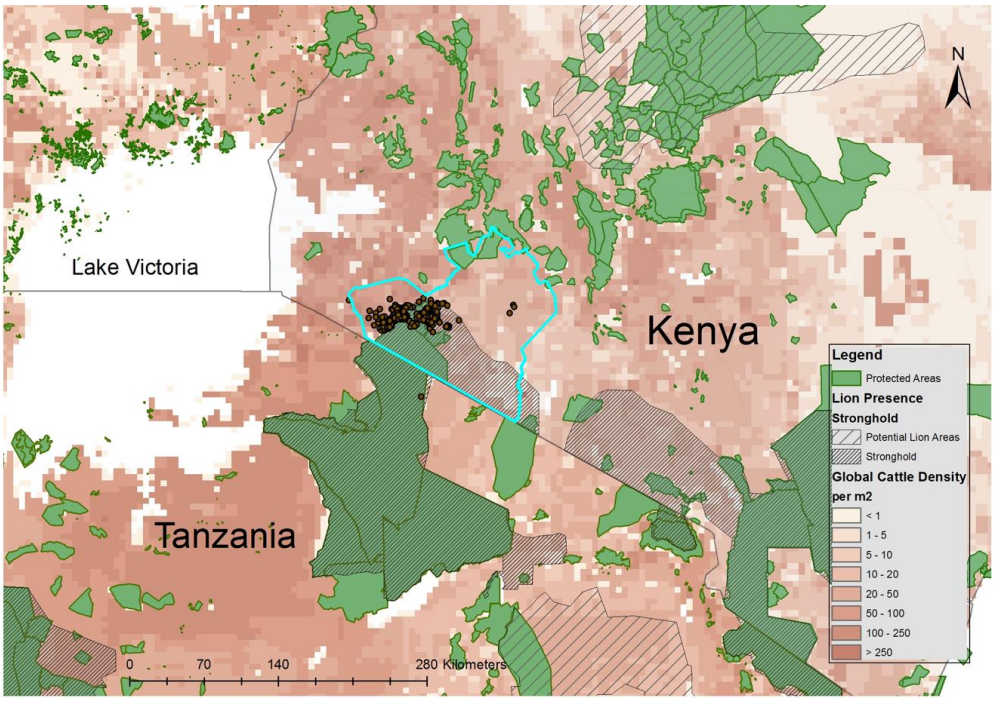

Figure 1. Study region in East Africa, showing boma visit sites as dark red dots, and Narok County outlined in blue. Map also shows cattle densities and lion strongholds and potential habitats, based on Riggio *et al*. (2012). Protected areas are shaded green.

edge of the Maasai Mara Natural Reserve in Narok South (Figure 1). This area has an estimated human population of 12,000 and a known livestock population that exceeds 2.1 million.

Our study relied on information collected through semi-structured, retrospective household interviews. The semi-structured interview approach was the most appropriate because we sought to record perceptions, opinions, experiences and phenomena across a varied population. Other methods of data collection, such as written surveys, were deemed inappropriate, as Narok County had a self-reported literacy rate of 46.2% for men and 34.5% for women in 2007 (Kenya Bureau of Statistics 2007).

To ensure comparability between our data and other sets relating to predation, we measured our impact in boma-months (i.e. the number of months in which a boma was monitored).

Validity and reliability of interview data: In qualitative research, reliability refers to the reproducibility of interview results, validity is how well the resultant data reflects a specific phenomenon, and triangulation refers to a process whereby multiple sources of data confirm each other's accuracy (Bush 2007). The itinerant nature of predation and the limited infrastructure for official reporting make it difficult to accurately triangulate predation losses in the Mara. We therefore focused our efforts on improving the validity and reliability of our interview results.

We improved reliability by modifying the survey instrument in response to ambiguities in respondents' answers to specific questions, as well as in response to specific problems, such as overlooked animal types. Having multiple interviewers helped to test the reliability of our questions by highlighting any ambiguities in the wording or presentation of the survey instrument.

In order to maximise the validity of our surveys we (i) restricted our surveys to a 12-month retrospective; (ii) structured our queries in easily memorable time blocks (i.e. rainy seasons/dry seasons), and (iii) employed a repeat-query process that allowed us to approximate the likelihood that respondents were overstating their losses in general inquiries. This multi-query process consisted of the following approach:

(1) Inquire about general estimates of predation loss (i.e. 'How many cattle did you lose last year to predation?')
(2) Ask respondents to estimate each loss of the current season (e.g. 'How many animals did you lose this rainy season?')
(3) Ask respondents to estimate each loss of the previous season (e.g. 'How many animals did you lose in the dry season?')
(4) Ask respondents to estimate each loss of the last season of the current type (e.g. 'It is now the rainy season. How many animals did you lose last rainy season?')
(5) Ask respondents to detail each loss of the last season of the opposite type (e.g. 'How many animals did you lose in the dry season before this last one?')
(6) Ask respondents to detail their problems with each predator, and how many animals they lost in the last year to the predator (e.g. 'How many times have lions attacked your boma this rainy season? How many animals did they take? How about hyenas?')

In this way, we gained two separate measures of self-reported predation estimates: (1) an estimate of loss; and (2) an accounting of losses. We were then able to compare the more general response to the more specific (and presumably more credible) accounting.

After completing the interview, we thanked participants and asked to visit any livestock structures within their landholding. We assessed the quality of the overall landholding on a 5-point Likert scale (Likert 1932); in later revisions of the survey instrument, we assessed quality for each individual livestock structure.

The protocols in 2013, 2014, and 2015 were different, so we present them separately. The experiences in 2013 informed our protocols for the second round of interviews. Our data collection methods were approved as exempt by the Duke Institutional Review Board (IRB Exemption: Protocol [B0371]), because of the very limited risk to participants. Participants in the household interviews provided verbal consent after having the process explained in both English and kiSwalhili (and, when necessary, in Maa).

ISSN 1758-2067

Figure 2. Contrasting Maasai boma styles: a) a traditional unfortified Maasai boma; b) a boma fortified in the Mara North by the Anne K. Taylor Fund using posts, chain link wire, galvanized wire, and immature thorny plants.

Household interviews, set 1 of 3 (2013): The first phase of data collection was from 5 April to 15 July 2013 at various sites in the Trans-Mara Community and the Mara North Conservancy of western Narok County. Sutton, Munyao, and Kamande collected 12-month retrospective interviews from 131 bomas, resulting in 1,572 boma-months of data. During this time, Munyao and Kamande were employed by the AKTF.

We selected interviewees at random from within two known groups: those who had already received a boma fortification from the AKTF more than six months prior, and those who had not yet received a boma fortification, or whose bomas had been fortified less than six months ago.

Sutton, Munyao and Kamande separately conducted in-person interviews of an average duration of 65 minutes. Interviews took place in or around the primary residence structure within each landholding. We conducted interviews preferentially with the senior male head-of-household. In the absence of the senior male ('mzee'), interviews were conducted (in declining preference) with the senior female head-of-household ('mama'); the eldest son; the senior male's brother or other male relative; a senior employee responsible for the care of the cattle; or another relative or friend or neighbour whom the head-of-household had designated to speak in his stead. We collected data only about the cattle owned by a single mzee at a single boma; adjacent herds from related households were not included, nor were secondary bomas located in other places.

Sutton, Munyao and Kamande did not interview the same households, raising the risk of between-interviewer variability as a threat to validity. To minimize this, all interviewers participated in one pre-interview training session and daily end-of-day data reviews during which any discrepancies in data collection (e.g. differently-worded questions; missing data; outlying numbers) were noted and discussed. If methodological errors were identified, the question or interview was removed.

We adaptively revised the survey instrument seven times during the first round of data collection in response to suggestions from interviewees, surveyors, and other project partners; or to fill gaps in data; or to uncover additional information to enhance understanding of emergent patterns. Our edits did not impact the core question phrasing or location information for questions related to predation data.

Household interviews, set 2 of 3 (2014): From May to July 2014, Sutton, Munyao and Kamande conducted follow-up interviews with residents of the Mara North Conservancy who had not had boma fortifications in the previous year, but who had received boma fortifications between July and December 2013. This meant that their fortified bomas had been constructed more than nine months before the current interview, but not had not yet been fortified at the time of the previous interview in 2013. This provided before-and-after data to augment the paired sampling (treatment versus control) data collected in set 1 interviews. The interview and boma assessment process was the same as in 2013. We gathered 12-month retrospective interviews from 23 bomas, resulting in 276 boma-months of data.

Household interviews, set 3 of 3 (2015): From July 2014 to July 2015, Downey and Munyao collected abbreviated interviews from 154 bomas, providing 1,962 boma-months of data. These interviews took place with boma owners who were either previous recipients or those who were scheduled to receive boma fortifications from the AKTF. These interviews covered the same area (the Trans-Mara region and the Mara North Conservancy) as in 2013, but the 2015 bomas had not been previously surveyed.

The interview and boma assessment process, including introductions and consent, followed the approaches developed in 2013 as closely as possible. As in previous rounds, interviews were preferentially conducted with the senior male head-of-the-household at the site of the boma. However, when the head-of-the-household was absent, we attempted to reach them by phone to conduct the interview, instead of deferring to family members.

These interviews were collected with an abbreviated version of the survey instrument developed in 2013. Guided interviews were completed in less than five minutes, and focused on the boma's stock and predation history, as well as its state of repair. Notably, this survey instrument did not ask for the 'Accounted Losses' data collected in 2013; it only collected 'Estimated Losses'.

We interviewed boma owners opportunistically during installations of new bomas by AKTF or during routine inspections and maintenance visits to bomas that AKTF had previously fortified between 2008 and 2014. Fewer than ten had been previously interviewed by Sutton.

We collected information describing the costs of boma construction from the purchase records of the AKTF, and information about the valuation of livestock from the Kenya Meat Commission (2014).

ISSN 1758-2067

Data preparation and analysis: To draw the most useful information from our data, we combined interview results from the years 2013 – 2015. We visited a total of 308 bomas and made 462 inquiries, from which we collected 375 successful depredation interviews. We collected more interviews than bomas visited because in 2015 we inquired not only about residents' current (this year) depredation experiences, but also previous (past year) depredation experiences prior to fortification. This doubled the number of interview inquiries in 2015 from 154 to 308, and raised the total number of inquiries overall to 462. However, only 375 of these inquiries resulted in a successful interview, and 26 of these contained duplicate or insufficient data, or were lost to a data storage failure, resulting in 349 cleared and de-duplicated depredation interviews. Six interviewees declined to report their losses, resulting in 343 final analysable depredation reports.

Because of differences in information gathered from the interviews in 2013 and 2014 and the briefer 2015 interviews, we compared stock loss data between only two categories: those who had participated in the fortification programme (and thus possessed any form of chain link: 'fortified'; n=179) and those who had not (and therefore possessed no chain link whatsoever: 'unfortified'; n=164). This simplification to two categories allowed us to compare more readily across phases of monitoring, and to compare bomas longitudinally (i.e. if a boma owner fortified in the time between our interviews, he or she could have provided past information about the unfortified experience, as well as current information about the fortified experience).

To ensure that boma fortification was not a proxy for wealth, we collected general data on the total number of animals owned at each boma (cattle, and the combined total of sheep and goats), then compared averages between boma types.

We used χ^2 tests to determine the significance of differences in demographic factors and stock losses between households who chose to fortify and those who did not. We followed this with a comparison of stock losses at the two fortification types only for bomas of known and comparable size (n=179 fortified, n=60 unfortified), to account for the potential influence of herd size/group size on losses.

We carried out a cost-benefit analysis using stock loss reduction numbers from our boma interviews collected in 2013 and 2014 of our original three boma types: fully fortified, partially fortified, and unfortified. We defined fully fortified households as those who had performed complete fortification using chain-link fencing to reinforce multiple structures within the homestead; partially fortified households as those who had performed incomplete (50%) fortification using chain-link fencing; and unfortified households as those who had performed no fortification with chain-link. We used a standard discount rate of 12% (the 2015 bank rate at the Central Bank of Kenya), an exchange rate of 87.47 KSh to one US dollar, and an approximate boma lifespan of five years, with an annual maintenance cost of 5,000 KSh (these latter two measures were determined by AKTF records).

CONSEQUENCES

Efficacy of boma fortification: We found that fortification using chain-link fencing, regardless of the quality of the construction or maintenance of that fencing, was an effective means of reducing significant and costly losses of livestock to depredation. Thus, 67% of fortified bomas lost no animals compared to only 15% of unfortified ones ($\chi^2 = 49$ d.f. = 1, $p < 0.0001$). Conversely 32% of unfortified bomas lost 10 or more animals, while only 7% of fortified ones lost so many ($\chi^2 = 4.7$, d.f. = 1 , $p < 0.03$).

In our study region between 2013 and 2015, we recorded 1,895 heads of livestock lost over 1,968 monitored boma-months at 164 traditional (unfortified) bomas, equivalent to a monthly loss rate of 0.96 animals. At 179 fortified bomas, 564 heads of livestock were lost over 1,611 monitored boma-months, equivalent to a monthly loss rate of 0.35 animals.

Despite the high predation pressure in the region, 67% of fortified bomas suffered no losses over one year; by contrast, only 15% of unfortified bomas experienced such a reprieve (Table 1). Only 17% of fortified bomas lost more than five animals in a year compared to 57% of unfortified bomas (Table 1). These numbers were collected from 239 boma owners who reported the total number of stock they held as well as predation numbers.

The number of animals present in both boma types was broadly similar: 59% of fortified compared to 57% of unfortified

Table 1. Number of households reporting varying levels of annual livestock losses to depredation in fortified and unfortified bomas containing different numbers of animals. Only data where numbers of animals present were known are included.

		Number of livestock lost							
		Zero		1 to 4 heads		5 to 9 heads		10 or greater	
		Unfortified	Fortified	Unfortified	Fortified	Unfortified	Fortified	Unfortified	Fortified
Number of animals in the boma	< 60	2	18	2	2	1	0	2	0
	60 to 119	2	16	5	11	0	1	2	4
	120 to 179	0	20	1	2	3	1	3	1
	180 to 239	3	21	4	5	2	2	2	1
	240 to 299	1	8	2	0	1	3	3	1
	300 to 359	1	14	1	4	4	4	2	2
	360 to 419	0	10	0	1	0	2	1	2
	420 - 479	0	3	1	0	0	2	1	0
	> 480	0	10	1	3	4	3	3	2
	TOTAL	**9**	**120**	**17**	**28**	**15**	**18**	**19**	**13**
	Percentage	*15%*	*67%*	*28%*	*16%*	*25%*	*10%*	*32%*	*7%*

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bomas held fewer than 240 animals. Large bomas, holding more than 420 animals, were 13% of fortified bomas and 16% of unfortified bomas. However, the number of cattle owned, and number of sheep and goats owned differed significantly between fortified and unfortified households, with larger herds more common among households with fortified bomas (χ^2 =17.23, df= 8, p = 0.028 for cattle and χ^2 =18.99, df=8, p = 0.015, for sheep and goats). This may indicate that herd size (and correlated wealth) plays a role in the decision to fortify.

Cost-benefit analysis: modelling the economic costs of livestock loss to depredation. In our original (2013 and 2014) categorization, we recorded 40 accounted losses to predation at our 22 fully fortified bomas. Because of breaks in our boma monitoring, we monitored each boma for an average of nine months, a total of 198 boma-months. This gave an average annual loss of 2.42 heads of livestock (0.20 animals per month) per boma household. Using the average market value of a cow, sheep or goat of $450 USD, $80 and $80 respectively (Kenya Meat Commission 2014) this amounted to an average loss per animal of $203, and an average annual loss of $492 per boma household.

We also recorded 386 accounted losses to predation at our 163 partially fortified bomas. We monitored each boma for an average of nine months, and a total of 1,467 boma-months. This gave an average annual loss of 3.16 heads of livestock (0.26 animals per month), amounting to an average annual loss of $641 per boma household.

Finally, we recorded 562 accounted losses to predation at our 61 unfortified bomas over a 12-month span, for a total of 732 boma-months. This gave an average annual loss of 9.21 heads of livestock (0.77 animals per month) per household, amounting to an annual loss of $1,870.

Is building a boma worth the cost? In 2013, the average resources needed to construct a fully-fortified boma were: four rolls of chain-link (5,000 KSh each); treated wood posts (eight at 900 KSh); high tensile wire (1180 feet at 2KSh / foot); one door (2,000 KSh); steel corners (four at 2,500 KSh each); miscellaneous amounts: cement, sand, and rocks (approximately 1,000 KSh total); one box of binding wire and 3 kg nails etc. (approximately 1,500 KSh total). Additional costs include construction labour (two day labourers at 1,000 KSh per day each), welding labour (one skilled labourer at 4,800 KSh) and transportation from Nairobi (approximately half a lorry at 50,000 KSh each). We calculated the total cost to build a fully fortified boma in to be approximately $890.13 (77,860 KSh). The Eden Wildlife Trust and AKTF provided $638.62 (55,860 KSh), leaving an average cost to Maasai livestock owners of $251.51 (22,000 KSh).

In 2013, the resources needed to construct a partially fortified boma were, on average: four rolls of chain-link fencing (5,000 KSh each), one door (2,000 KSh), 3 kg nails (180 KSh per kg), found local materials (no cost), plus labour (two day labourers at 1,000 KSh per day each) and cost of chain link transportation from Nairobi (approximately a quarter of a lorry at 50,000 KSh each). We estimated the total cost to build an average partially fortified boma to be approximately US$446.32 (35,040 KSh). The Eden Wildlife Trust and AKTF provided approximately $320.56 (28,040 KSh), leaving an average cost to Maasai livestock owners of $125.76.

In 2013, the resources needed to construct an unfortified (traditional) boma were, on average: one day's labour for a boma owner. The total cost to build an unfortified (traditional/acacia thorn) boma in the western Mara region was estimated to be approximately $11.43 (1,000 KSh), and the expense was entirely borne by the livestock owner.

With these numbers, our analysis produces an estimated net present value of $5,899.93 for owners of fully fortified bomas. With a boma cost of $890.13, the project provides a return on total project investment of approximately 349%. A partially fortified boma results in an estimated net present value of $5,332.83 for livestock owners, with a 778% return on project investment.

DISCUSSION

Livestock depredation is a costly problem that jeopardizes both wildlife populations and human livelihoods. Fortified bomas protect livestock and prevent depredation, which in turn can reduce the number of retaliatory predator killings. These fortifications reduce danger while livestock are held within them, but additional measures are needed during livestock transit and grazing.

The predation incident reports we collected targeted loss to lions, but also loss to hyenas, leopards, wild dogs, honey badgers, cheetah and baboon. We found inconsistencies in identification of the predator in our reports – confusion persisted between the spotted cats (leopard and cheetah) that are named by coat pattern in Maa ('olmara' and 'olwarumara,' respectively). Occasional there was confusion in distinguishing the spotted cats from spotted hyenas ('orokonoi'). We also witnessed over-attribution of predation incidents to lions, a phenomenon that has been documented previously in the literature as leading to higher rates of species removal (Rust & Marker 2013). We therefore concluded that attempting to distinguish loss incidents by the depredating species would be difficult and likely inaccurate. Instead, we decided to use generalized predation rate to give a general sense of the pressure that livestock owners experience. This approach was consistent with previous reports of predation rates in the literature.

Anticipating and studying depredation across Africa: The rates of use of improved husbandry practices, in combination with maps of inherent landscape characteristics (Abade *et al*. 2014, Kushnir *et al*. 2014), can help identify 'easy target' areas for depredation. These maps and risk factors should be integrated into part of an open-access tool for conservationists and local managers to use in the field to proactively avert conflict before it can arise.

Such a tool would be made much more useful by consistent, accurate collection of data relating to depredation in Africa. Without straining additional resources, wildlife agencies and conservancies could act in two ways: (1) implement improved employee training on the collection of accurate, timely depredation reports; and (2) provide a platform for standardized reporting by mobile phone, which could make timely reporting easier for livestock owners.

The future of fortification in Africa: Although fully fortified bomas in our study offered better protection to livestock (averting the loss of 0.74 more animals per year per boma household than partially fortified bomas), partial fortification still appeared to be a more cost-effective way to protect livestock. With a return on investment of 778%, partially fortified bomas are vastly more cost effective than fully fortified bomas (return on investment = 349%). This means that for the same price, nearly twice as many bomas can be partially fortified as fully fortified. In addition, it takes at least two days to

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construct a fully fortified boma versus less than one day to partially fortify a boma by wrapping an existing structure with chain-link fencing. Therefore, partial fortification can be completed with only a portion of the time (and without the additional skilled labour) it takes to fully fortify. They may also be easier to maintain, as the simpler construction and fewer parts make replacement or repair less complex.

Partial fortification may also be a more sustainable solution to the problem of wire supply. At present in our study area, all building materials are distributed and construction is controlled via a single, centralized supplier (AKTF). Although this results in more effective fully fortified bomas, this single-supplier model also makes the programme more vulnerable to failure, as the loss of this single supplier would undermine the entire process. But partial fortification requires fewer materials, and could also be achieved through a decentralized, multiple-suppler model. Indeed, focusing on partially fortifying bomas by simply making the baseline materials (wire, nails) widely available in local shops would allow herders (or NGOs) to create effective fortifications with materials available from local shops. Since 2013, we have witnessed at least one shop in our region begin to stock and sell rolls of chain-link wire.

Resolving the complex issues of human-wildlife conflict and disrupting the predation-retaliation cycle will be key to ensuring the sustainable maintenance of local biodiversity and the successful protection of local economies. Centralized, high-quality boma fortification can be one powerful and effective element of a holistic approach to mitigating human-lion conflict in East Africa. However, its implementation relies on: (i) a long-term commitment by a stable organization that can subsidize the cost of materials, transport, and construction; (ii) a population with sufficient capital to 'buy in' to the program; and (iii) a local willingness to participate in construction and maintenance of such structures. In cases where these three preconditions are met, the approach detailed herein may provide guidance for conservation action elsewhere on the African continent. In cases where the first condition is not met, decentralized partial fortification may provide a more cost-effective and sustainable approach to protecting livestock and reducing depredation conflict.

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