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ORIGINAL PAPER

# Livestock husbandry as a tool for carnivore conservation in Africa's community rangelands: a case–control study

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**Abstract** Conflict between people and wildlife is a major issue in both wildlife conservation and rural development. In African rangelands, species such as African wild dogs (*Lycaon pictus*), cheetahs (*Acinonyx jubatus*), lions (*Panthera leo*), leopards (*Panthera pardus*), and spotted hyaenas (*Crocuta crocuta*) may kill livestock and are therefore themselves killed by local pastoralists. Such conflict has led to the extirpation of these species from many areas, and also impacts the livelihoods of local livestock farmers. To investigate the possibilities for coexistence of people, livestock, and large predators in community rangelands, we measured the effectiveness of traditional livestock husbandry in reducing depredation by wild carnivores, using a case–control approach. Different measures were effective against different predator species but, overall, the risk of predator attack by day was lowest for small herds, accompanied by herd dogs as well as human herders, grazing in open habitat. By night, the risk of attack was lowest for herds held in enclosures ('bomas') with dense walls, pierced by few gates, where both men and domestic dogs were present. Unexpectedly, the presence of scarecrows increased the risks of attack on bomas. Our findings suggest that improvements to livestock husbandry can contribute to the conservation and recovery of large carnivores in community rangelands, although other measures such as prey conservation and control of domestic dog diseases are also likely to be necessary for some species.

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## Introduction

Conflict between people and wildlife is a major issue in both wildlife conservation and rural development. Deliberate killing of animals that are considered pests has driven several species to extinction, and has contributed to the endangerment of many others (Woodroffe et al. 2005b). Despite conservation concern about such lethal control, there is no doubt that some rare and endangered species genuinely threaten human lives and livelihoods (Thirgood et al. 2005). Human–wildlife conflict is a particularly serious issue in the conservation of large mammalian carnivores, which can prey on livestock (and occasionally people), and are therefore frequently killed by farmers or wildlife managers.

Lethal control is often carried out in response to specific attacks on livestock (e.g. Angst 2001; Bangs et al. 2005; Woodroffe and Frank 2005); hence any measure which reduces livestock depredation is also likely to reduce offtake from carnivore populations (Ogada et al. 2003), benefiting both people and wildlife. There is a clear need, therefore, to identify measures which demonstrably reduce livestock depredation by wild carnivores. Such measures may be particularly valuable where populations of highly threatened carnivores live alongside people and livestock, and where local people may benefit from carnivores' presence through tourism or hunting.

There is evidence that various forms of livestock husbandry can effectively reduce livestock depredation by wild carnivores (Breitenmoser et al. 2005). While modern approaches such as electric fencing and radio-activated guards appear useful in North America and Europe (Breitenmoser et al. 2005), they are costly and may be inappropriate for use in less developed areas with little infrastructure. In contrast, Ogada et al. (2003) showed that, on commercial ranches in East Africa, livestock husbandry similar to that practiced for generations by local Masai pastoralists was very effective at reducing conflict between predators and livestock farmers.

Building on Ogada et al.'s (2003) findings from commercial ranches, we conducted a case–control study of livestock depredation on neighbouring community lands. The study aimed to reduce predators' impacts on local people's livelihoods by identifying the most effective husbandry methods, and also to investigate the possibilities for sustainable conservation of African wild dogs (*Lycaon pictus*), cheetahs (*Acinonyx jubatus*), lions (*Panthera leo*), leopards (*Panthera pardus*), and spotted hyaenas (*Crocuta crocuta*) on community lands.

## Methods

### Study area

This study was carried out between January 2001 and June 2005 in northern Kenya, in Laikipia District (37°2′ E, 0°6′ N), and parts of neighbouring Samburu, Isiolo and Baringo Districts (Figs. 1, 2). The area is mainly semi-arid bush land and savanna, used for subsistence pastoralism and commercial ranching, as well as for tourism and small-scale agriculture. Within the study area, some properties are owned by private individuals, but this study was conducted primarily on land owned or occupied by local communities (Figs. 1, 2). None of the area is formally protected, and livestock occur throughout the region. However, wildlife is abundant in some areas (Khaemba et al. 2001; Mizutani 1999). Populations of leopards, lions, cheetahs and spotted hyaenas have persisted in the region despite extensive human use of the landscape, and wild dogs recolonised Laikipia naturally in 2000 (Frank et al. 2005).

## Data collection

Most of the data were gathered by 18 staff employed in partnership with local non-governmental conservation organisations and paid, in whole or in part, by the project. These staff were educated people chosen from, and resident within, local communities, well placed to gather often-sensitive information about depredation. The staff did not collect data over the whole area, and their home locations (shown in Fig. 1) and work schedules were dictated by their other duties: hence the number and distribution of predator attacks that they investigated may not give an accurate picture of the relative depredation rate in different areas or by different predators.

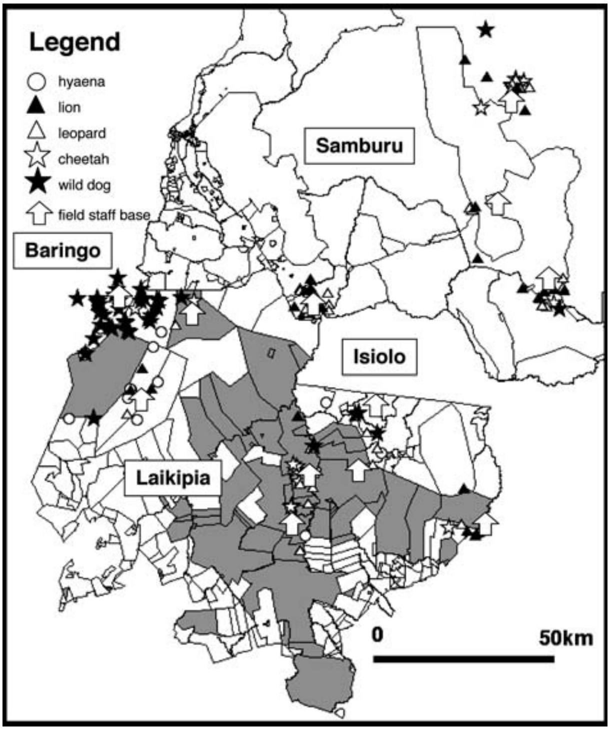


**Fig. 1** The distribution within the study area of reported predator attacks on herds grazing by day, along with the approximate home locations of field staff investigating attacks. The number of field staff locations is smaller than the number of field staff because some staff worked in pairs. Commercial ranches are shaded in grey; communities inhabit remaining areas

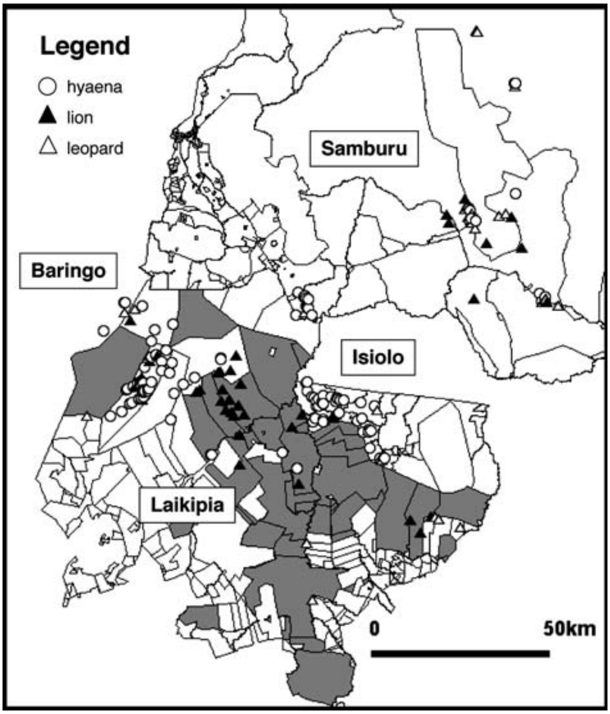


**Fig. 2** The distribution within the study area of predator attacks on herds enclosed in bomas at night. Commercial ranches are shaded in grey; communities inhabit remaining areas

In particular two staff were employed in the north-west of the study areas specifically to monitor a pack of wild dogs that were chronic predators of livestock; attacks by this pack were highly localised (Woodroffe et al. 2005a) and the proportion of the investigated livestock attacks that were made by wild dogs is therefore very unlikely to be representative of true proportion across the entire study area.

Field staff investigating reported attacks initially confirmed the veracity of each report; no compensation was available for livestock losses, so farmers had no financial incentive to misrepresent their losses and a separate analysis of predator diet showed that, for wild dogs at least, reports of livestock loss were reliable (Woodroffe et al. 2005a). Staff recorded the location and timing of each attack, whether livestock were killed while out grazing or when enclosed in a boma, and the number and age of livestock killed or injured. For attacks on grazing herds, they also recorded the herder's perception of whether the predator(s) initiated the attack by approaching the herd, or whether the herd stumbled upon a resting predator. Detailed data on livestock husbandry on the day of the attack were then collected for the herd or boma which had been attacked (the case herd) and between one and three nearby control herds or bomas that had not been attacked. Controls were selected on the basis of proximity alone and were not matched to cases in any other way. The median distance between case grazing herds and their controls was 656 m, and the median distance between case and control bomas was 323 m; hence a high proportion of control herds and bomas are likely to have been detectable to the predators that attacked the case herds.

For each grazing herd, observers recorded the number of livestock of different species present, and the number of herders (men, women and children), and domestic dogs, accompanying the herd. The type of terrain grazed was recorded in five categories (flat, rolling hills, single escarpment, hilly, mountainous), and the density of the vegetation in the grazing area was recorded in four categories (open grassland, light bush, dense bush, very dense bush), using reference photographs provided to all observers. For case herds, details of terrain and habitat density were recorded for the site of the attack, as well as for the grazing area in general.

For each boma, observers categorised the type of construction as thornbrush (constructed of whole trees or large branches cut and laid on their sides), solid (constructed of solid poles or stone), wire, or open (an area where livestock are bedded down with no physical barrier between them and the surrounding environment). A small number of bomas were constructed from a combination of solid posts and wire; classifying these as either ‘‘solid’’ or ‘‘wire’’ did not influence overall conclusions. For thornbrush, solid and wire bomas, the number of gates into the boma was also recorded. The height (in cm) of the boma walls was recorded at 10 m intervals around the perimeter of the boma. Likewise, for thornbrush bomas, the thickness of the boma walls was measured at 10 m intervals using a thin pole and a tape-measure. In addition, the density of thornbrush boma walls was estimated every 10 m by measuring the transparency of the wall; transparency was scored by having an assistant hold a ‘chequerboard’ marked with 100 2 cm $\times$ 2 cm squares, shaded alternately black and white, against the inside boma wall at a height of 1 m from the ground, and recording the number of white squares which were more than 50% visible to an observer outside the boma with their eye also 1 m from the ground (hence maximum transparency received a score of 50). Analyses used the minimum height and width, and the maximum transparency, excluding (where appropriate) any site where the predator or livestock had broken through the boma wall. For thornbrush bomas, observers also recorded whether the majority of tree branches were facing the inside or the outside of the boma, and also the time since the boma walls were last repaired.

In addition to gathering information on the construction of the boma itself, observers recorded the number of possible predator deterrents present at the boma on the night of the attack, including the number of people (men, women and children), the number of houses, the number of domestic dogs, the number of guns, the number of fires left burning outside boma walls, and the number of scarecrows (pieces of cloth hung in nearby trees or on boma walls). Details of the numbers of livestock present were also recorded (cattle, sheep and goats, camels and donkeys); for cattle the presence or absence of adult bulls was noted because these animals are the largest and strongest and hence considered most likely to break through boma walls if panicked by a predator attack. Finally, the terrain and habitat density surrounding the boma were recorded using the same categories as for grazing herds.

Sample sizes quoted in descriptions of livestock husbandry and depredation vary slightly due to occasional missing data.

## Data analysis

The characteristics of matched case and control herds or bomas were compared using conditional logistic regression, using the program Egret (Cytel Software Corporation; Cambridge, MA, USA). The two primary analyses considered all data on all attacks on either (i) grazing herds, or (ii) bomas, pooling data for all predators and all livestock prey species. Data were pooled in this way because farmers experience the same loss whether a calf is, for example, killed by a lion or a hyaena. Subsequent analyses were restricted to attacks by single species of predator, to investigate the husbandry measures most effective against each. Some predator species apparently specialised on particular livestock prey (e.g. cheetahs killed sheep and goats, but never cattle); hence a nearby control herd might have been ignored by the predator not because of differences in husbandry, but because it did not contain the preferred prey species. Analyses of attacks by specific predator species were therefore restricted to the cases involving only the most common prey species, omitting also any control herds or bomas not including the favoured prey. Hence, for example, analyses for leopards involved 39 attacks on grazing sheep and goat herds (excluding nine attacks on grazing cattle) and 35 attacks on sheep and goats in bomas (excluding one attack on cattle).

Initially, univariate analyses were carried out on each characteristic of livestock husbandry or habitat in turn. Where sample sizes were restricted, the data on habitat density were collapsed into two categories (open grassland + light bush, and dense bush + very dense bush). Data on numbers of domestic dogs were also simplified to presence/absence of domestic dogs. Variables with univariate test results at $P \leq 0.25$ were subsequently entered into multivariate analyses. Final models were selected by including all of the selected variables, and then dropping terms from the model one by one until only significant predictors remained.

Exploratory analyses showed that some husbandry characteristics were significantly intercorrelated. For example, grazing herds accompanied by domestic dogs also had more men herding them ($t_{498} = 4.90$, $P < 0.001$), and the thickness of boma walls was correlated with their transparency ($r = -0.11$, $n = 412$, $P = 0.024$). We investigated the robustness of the final models by analysing their sensitivity to these intercorrelations. In models that included predictor variables that were significantly intercorrelated with other possible predictors, we replaced each predictor in turn with its correlate(s) to determine whether this improved the fit of the model.

The results of case–control analyses are presented as odds ratios (and their associated 95% confidence intervals (CI)). These odds ratios indicate the magnitude of the estimated effects; for example the odds ratio of 0.371 (95% CI 0.195–0.705) associated with domestic dogs' presence in Table 1 indicates that dogs reduce the probability of attack by a factor of about 0.37, i.e. a 63% reduction.

In addition to these case–control comparisons, we also compared the habitat density and terrain at sites where attacks occurred on grazing herds, with those in the

**Table 1** Predictors of the probability of attack, by any predator species, on herds grazing during the daytime, based on conditional logistic regression analysis of 147 matched case–control sets

| Variable | Odds ratio (95% CI) | $\chi^2$ | *df* | *P* |
|---|---|---|---|---|
| Domestic dogs | | | | |
| Present vs. absent | 0.371 (0.195–0.705) | 9.14 | 1 | 0.003 |
| Herd size | 1.006 (1.002–1.011) | 7.27 | 1 | 0.007 |
| Habitat density | | 11.71 | 3 | 0.008 |
| Light bush vs. open | 1.667 (0.635–4.381) | | | |
| Dense bush vs. open | 4.059 (1.278–12.894) | | | |
| Very dense bush vs. open | 25.372 (2.312–278.45) | | | |

general area grazed by that herd on that day. For these analyses, habitat density and terrain were ranked on ordinal scales (from "open" = 1 to "very dense bush" = 4, and "flat" = 1 to "mountainous" = 5) and compared using Wilcoxon paired rank tests.

## Results

### Characteristics of predator attacks

The timing and nature of attacks on livestock varied among predators. As shown in Fig. 3, hyaenas mainly attacked herds enclosed in bomas at night, cheetahs and wild dogs attacked herds only when they were grazing by day, and leopards and lions attacked both grazing herds and those enclosed in bomas. Daytime attacks on herds

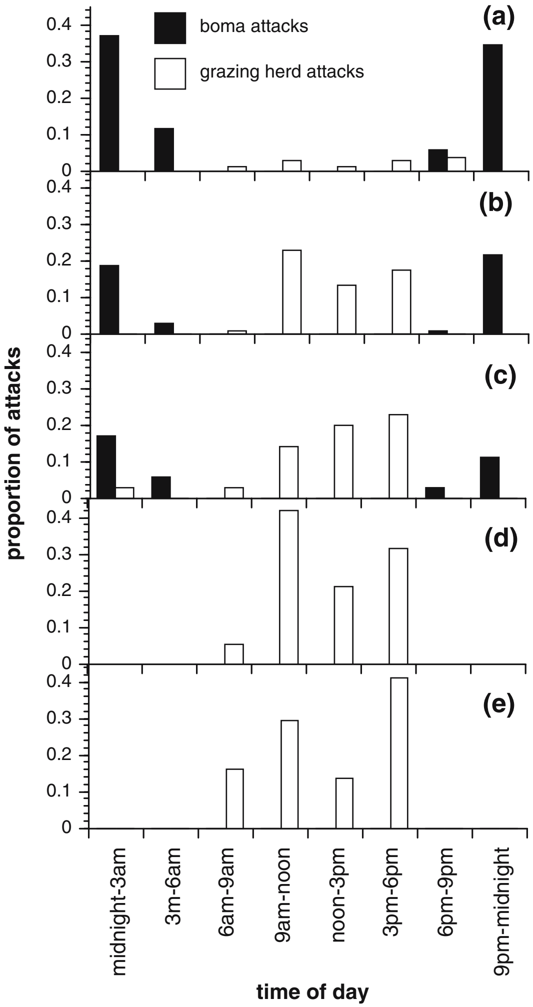


**Fig. 3** Timing of predator attacks on livestock which were either enclosed in bomas at night (shaded bars) or grazing by day (open bars), by (**a**) spotted hyaenas ($n$ = 105 attacks); (**b**) leopards ($n$ = 96 attacks); (**c**) lions ($n$ = 35 attacks); (**d**) cheetahs ($n$ = 19 attacks); (**e**) wild dogs ($n$ = 44 attacks)

were perceived to have been initiated by the predator approaching the herd (rather than the herd stumbling upon a resting predator) in 95% of 19 cheetah attacks, 85% of 40 wild dog attacks, 91% of 11 hyaena attacks, 65% of 17 lion attacks and 65% of 49 leopard attacks. When data were combined for the three primarily nocturnal species (leopards, lions and hyaenas) there was a non-significant trend suggesting that a smaller proportion of attacks were initiated by predators in the hot hours in the middle of the day, with predators approaching herds on 75% of 4 attacks occurring between 0600 h and 0900 h, 76% of 25 attacks occurring between 0900 h and 1200 h, 44% of 18 attacks occurring between 1200 h and 1500 h, and 76% of 29 attacks occurring between 1500 h and 1900 h ($\chi^2 = 6.28$, $df = 3$, $P = 0.099$). There was no such trend for the diurnal predators (cheetahs and wild dogs, $\chi^2 = 3.51$, $df = 3$, $P = 0.32$).

The number of livestock killed per attack also varied between predators (Table 2). When attacking herds grazing by day, wild dogs killed more sheep and goats per attack than did leopards, cheetahs or hyaenas (Kruskal–Wallis test, excluding two lion attacks, $H_{44,36,17,10} = 21.00$, $P < 0.001$), and also injured more animals ($H_{44,36,17,10} = 18.46$, $P < 0.001$). In contrast, there was a near-significant trend suggesting that wild dogs attacking grazing herds killed fewer cattle per attack than did lions or leopards ($H_{15,8,7} = 5.94$, $P = 0.051$), though there was no effect on the number of cattle injured ($H_{15,8,7} = 4.31$, $P = 0.116$). When attacking herds enclosed in bomas at night, hyaenas killed more sheep and goats per attack than did leopards (one lion attack excluded, Mann–Whitney $U$ test: $U_{86,44} = 2264.5$, $P = 0.030$), though there was no difference in the number of sheep and goats injured ($U_{86,44} = 1987.5$, $P = 0.471$), nor was there any difference between hyaenas and lions in the number of cattle killed (one leopard attack excluded, $U_{16,8} = 76$, $P = 0.376$) or injured ($U_{16,8} = 69.5$, $P = 0.634$) per attack on livestock inside bomas.

## Characteristics of livestock husbandry

Ninety-seven percent of 502 grazing herds (cases and controls combined) for which data were available were accompanied by herders. The average grazing herd was accompanied by 2.1 ± 1.9 SD herders (range 0–19): 0.6 ± 1.0 men, 0.1 ± 0.4 women, and 1.3 ± 1.2 children. Thirty-seven percent of 505 herds included cattle, 76% included sheep or goats, 9% included donkeys and 3% included camels. The average herd comprised 82.6 ± 73.4 SD individual animals (range 2–400): 11.8 ± 29.6 adult cattle, 2.0 ± 4.4 calves, 68.3 ± 75.4 sheep and goats, 0.3 ± 1.4 donkeys, and 0.7 ± 3.9 camels. Twenty-four percent of 502 grazing herds were accompanied by one or more domestic dogs, with an average of 1.3 ± 0.5 (range 1–3) dogs per accompanied herd.

Of 491 bomas examined (cases and controls combined), 446 (91%) were constructed of thornbrush, 27 (5%) were built from solid poles or stone, 12 (2%) were made of wire, and six (1%) were "open" bomas with no physical wall. The average thornbrush boma had 2.4 ± 1.7 SD gates (range 1–12). Cattle were present at 62% of 477 bomas with 54.1 ± 76.6 SD (range 1–603) adult cattle and 9.5 ± 12.4 SD (range 0–83) calves present. Seventy percent of 89 cattle herds for which data were available included one or more adult bulls. Sheep or goats were present at 86% of 477 bomas with 144.1 ± 189.9 (range 4–1300) individuals present. The average boma was occupied by 11.3 ± 8.2 SD people: 2.3 ± 2.0 men, 2.6 ± 2.2 women, and 6.4 ± 5.5 children. Domestic dogs were present at 71% of 484 bomas, with an average of

**Table 2** Numbers of livestock killed and injured on predator attacks

| Predator | Cattle | | | Sheep & goats | | | Camels | | | Donkeys | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *n* | Killed | Injured | *n* | Killed | Injured | *n* | Killed | Injured | *n* | Killed | Injured |
| Leopard | | | | | | | | | | | | |
| Herd | 8 | 1.9 ± 1.5 (1–5) | 0.1 ± 0.4 (0–1) | 45 | 2.1 ± 2.3 (0–12) | 0.2 ± 0.6 (0–2) | 0 | – | – | 1 | 2 ± 0 | 0 |
| Boma | 1 | 1 | 0 | 44 | 1.4 ± 1.2 (1–16) | 0.2 ± 0.4 (0–2) | 0 | – | – | 0 | – | – |
| Lion | | | | | | | | | | | | |
| Herd | 15 | 1.3 ± 1.1 (0–5) | 0.3 ± 0.6 (0–2) | 3 | 1.7 ± 0.6 (1–2) | 0.3 ± 0.6 (0–1) | 4 | 1 ± 0 (1–1) | 0.5 ± 0.6 (0–1) | 0 | – | – |
| Boma | 16 | 1.3 ± 0.4 (1–2) | 0.2 ± 0.4 (0–1) | 1 | 1 | 1 | 0 | – | – | 1 | 1 | 0 |
| Cheetah | | | | | | | | | | | | |
| Herd | 0 | – | – | 19 | 1.3 ± 0.7 (1–4) | 0.1 ± 0.3 (0–1) | 0 | – | – | 0 | – | – |
| Boma | 0 | – | – | 0 | – | – | 0 | – | – | 0 | – | – |
| Hyaena | | | | | | | | | | | | |
| Herd | 2 | 1.0 ± 0 (1–1) | 0 | 11 | 1.6 ± 1.9 (0–7) | 0.3 ± 0.5 (0–1) | 0 | – | – | 0 | – | – |
| Boma | 8 | 1.0 ± 0.8 (0–2) | 0.4 ± 0.7 (0–2) | 86 | 2.5 ± 4.0 (0–33) | 0.5 ± 3.0 (0–28) | 0 | – | – | 2 | 2.5 ± 2.1 (1–4) | 0 ± 0 |
| Wild dog | | | | | | | | | | | | |
| Herd | 7 | 0.7 ± 0.5 (0–1) | 0.7 ± 0.8 (0–2) | 38 | 4.1 ± 3.9 (0–16) | 1.0 ± 1.2 (0–4) | 0 | – | – | 0 | – | – |
| Boma | 0 | – | – | 0 | – | – | 0 | – | – | 0 | – | – |

For each predator species, prey species, and attack type (on herds grazing by day, or enclosed in bomas at night), *n* denotes the sample size of attacks for which full data were available, and other columns give the numbers of animals killed or injured (as mean ± SD (range))

$2.0 \pm 1.3$ dogs per boma. Fires were left burning outside 22% of 481 bomas, and scarecrows were present at 44% of 483 bomas with an average of $2.4 \pm 1.5$ scarecrows per boma. Only 6% of 483 bomas reported having a gun.

## Predictors of predator attacks on herds grazing during the daytime

Across all species of predator and livestock prey, the probability of depredation was lowest for smaller herds, that were accompanied by one or more domestic dogs, and grazed in more open habitat (Table 1). Sensitivity analyses showed that the fit of the model was reduced by substituting the number of herdsmen for the presence of herd dogs, with which dogs' presence was intercorrelated (overall model deviance 292.7, $df = 5$, compared with 280.8, $df = 5$).

Analysis of attacks by different predator species on their most common domestic prey revealed marked variation in which husbandry features were most effective. Results for leopards were similar to those for all predators (perhaps because leopard attacks were most common, Table 2); multivariate analysis ($n = 39$ matched sets) revealed that leopard attacks were more likely for sheep and goat herds that were unaccompanied by herd dogs (odds ratio 0.091, 95% CI 0.02–0.45, $\chi^2 = 8.63$, $df = 1$, $P = 0.003$), and those that grazed in more dense habitat (open & light bush vs. dense & very dense bush; odds ratio 7.33, 95% CI 1.22–43.94, $\chi^2 = 4.76$, $df = 1$, $P = 0.029$). There were no statistically significant predictors of lion attacks, although an association with dense habitat approached significance (odds ratio 6.75, 95% CI 0.77–59.35, $\chi^2 = 2.97$, $df = 1$, $P = 0.085$, $n = 22$ matched sets). There were likewise no significant predictors of cheetah attacks (for which only limited data were available), although a non-significant trend suggested that attacks might be more common in sheep and goat herds unaccompanied by domestic dogs (odds ratio 0.28, 95% CI 0.06–1.38, $\chi^2 = 2.44$, $df = 1$, $P = 0.118$, $n = 17$ matched sets). Attacks by wild dogs were the only ones for which effects of herder characteristics were detectable; wild dogs were more likely to attack sheep and goat herds accompanied by larger numbers of child herders (odds ratio 2.125, 95% CI 1.003–4.50, $\chi^2 = 3.87$, $df = 1$, $P = 0.049$, $n = 35$ matched sets), as well as those grazing in less open habitat (open & light bush vs. dense & very dense bush; odds ratio 3.95, 95% CI 1.15–13.61, $\chi^2 = 4.73$, $df = 1$, $P = 0.030$). In contrast with the findings for other species, there was a non-significant trend suggesting that sheep and goat herds accompanied by domestic dogs might be *more* likely to experience attacks by wild dogs (odds ratio after adjusting for effects of habitat and child herders 4.01 95% CI 0.86–18.62, $\chi^2 = 3.15$, $df = 1$, $P = 0.076$). The sample size for hyaena attacks on sheep and goats was very small (only 11 matched sets) and there were no significant predictors of attack risk. Sensitivity analyses revealed no evidence that any of the effects detected were generated by intercorrelations among possible explanatory variables.

Pairwise comparisons of the habitat density recorded at attack sites, and in overall areas grazed, revealed that leopard attacks tended to occur when herds entered dense bush (Wilcoxon signed rank test $P = 0.034$), as did lion attacks (Wilcoxon signed rank test $P = 0.034$). There were no such significant effects of habitat density for attacks by cheetahs, hyaenas or wild dogs (Wilcoxon signed rank tests, $P$ values all $>0.15$), nor were there effects of terrain for any species of predator ($P$ values all $>0.25$).

Predictors of predator attacks on herds enclosed in bomas at night

When data were pooled for all predator species, the type of boma construction (thornbrush, solid, wire or open) did not influence the probability of attack ($\chi^2 = 5.07$, $df = 3$, $P = 0.167$, $n = 244$ matched sets). Considering only thornbrush bomas, the most common type, Table 3 shows that the probability of attack was influenced by features of boma construction (the transparency of the boma wall, and the number of gates) as well as by deterrents present at the boma (men, and domestic dogs). Unexpectedly, the number of scarecrows, a widely-used deterrent, was associated with an increased risk of attack. Sensitivity analyses revealed no evidence that these effects were generated by intercorrelations among possible explanatory variables.

As for daytime attacks on herds, multivariate analyses revealed marked variation in the husbandry characteristics most effective at preventing boma attacks by different predator species on their most common domestic prey. There was no significant effect of the type of boma construction for any species, so analyses considered only thornbrush bomas, the most common type. The only significant predictor of leopard attacks on sheep and goat herds was the number of scarecrows present at the boma (odds ratio 1.54, 95% CI 1.001–2.36, $\chi^2 = 3.87$, $df = 1$, $P = 0.049$, $n = 35$ matched sets). The only significant predictor of lion attacks on cattle herds was the total number of people present at the boma, with attacks more likely where human activity was lower (odds ratio 0.84, 95% CI 0.71–0.99, $\chi^2 = 4.21$, $df = 1$, $P = 0.040$, $n = 31$ matched sets). The probability of hyaena attack on sheep and goat herds was greatest at bomas with thin walls (odds ratio 0.99, 95% CI 0.97–1.00, $\chi^2 = 5.25$, $df = 1$, $P = 0.022$, $n = 95$ matched sets), with larger numbers of gates (odds ratio 1.39, 95% CI 1.03–1.87, $\chi^2 = 4.61$, $df = 1$, $P = 0.032$), and where domestic dogs were absent (odds ratio 0.30, 95% CI 0.13–0.72, $\chi^2 = 7.38$, $df = 1$, $P = 0.007$). Sensitivity analysis suggested that, in this analysis, the transparency of the boma walls could be substituted for their thickness (odds ratio 1.10, 95% CI 1.03–1.17, $\chi^2 = 9.14$, $df = 1$, $P = 0.003$). In this case, however, the effect of number of gates became non-significant (odds ratio after adjusting for boma transparency and domestic dogs 1.25, 95% CI 0.93–1.67, $\chi^2 = 2.21$, $df = 1$, $P = 0.137$) and, after dropping this covariate, the overall model had (non-significantly) greater deviance than the original model incorporating significant effects of wall thickness, gates and domestic dogs (difference in deviance = 1.81, $df = 1$, $P = 0.178$). There was no evidence that effects detected for leopards or lions were influenced by intercorrelations among possible explanatory variables.

**Table 3** Predictors of the probability of attack, by any predator species, on herds enclosed in thornbrush bomas at night, based on conditional logistic regression analysis of 178 matched case–control sets

| Variable | Odds Ratio (95% CI) | $\chi^2$ | *df* | *P* |
|---|---|---|---|---|
| Number of boma gates | 1.402 (1.119–1.756) | 8.63 | 1 | 0.003 |
| Transparency of boma wall | 1.039 (1.005–1.075) | 4.94 | 1 | 0.026 |
| Number of scarecrows | 1.451 (1.157–1.820) | 10.34 | 1 | 0.001 |
| Domestic dogs | | | | |
| present vs. absent | 0.412 (0.223–0.759) | 8.11 | 1 | 0.004 |
| Number of men | 0.764 (0.615–0.949) | 5.9 | 1 | 0.015 |

## Discussion

Our results confirm that, in our study area, predator attacks on livestock are, to some extent at least, preventable without resorting to lethal control. This raises the possibility that at least some of the carnivore species may be sustainably conserved on community lands in other areas. Various aspects of livestock husbandry, including boma design, herding practices, and deterrents, were effective in reducing the probability of predator attack. Since killing of wild carnivores is associated with livestock predation on both commercial (Ogada et al. 2003) and community (Romañach et al. in review) lands, such measures almost certainly reduced the level of lethal control carried out. These methods are therefore likely to be valuable not only in reducing predators' impacts on local people's livelihoods, but also in conserving wild carnivores, both locally and more widely.

Our study area was characterised by very attentive livestock husbandry (e.g. 97% of herds were accompanied by herders), in comparison with other parts of Africa, western Europe, North and South America, where traditional livestock husbandry practices have typically been abandoned (Breitenmoser et al. 2005). There are probably multiple reasons for the retention of this traditional husbandry, but one key factor appears to be the widespread risk of stock theft which commits farmers to guard their herds carefully even in the absence of predators (Frank et al. 2005).

As mentioned briefly in the *Methods* section, the distribution of investigated attacks shown in Figs. 1 and 2 does not necessarily reflect the actual distribution of attacks, since observers did not cover the whole area, were not able to investigate all attacks, and because one pair of observers was employed specifically to collect data in an area suffering chronic livestock depredation by wild dogs. Nevertheless, Figs. 1 and 2 suggest a non-random distribution of attacks by different predators. Wild dog attacks appear concentrated in the north-western part of the study area; reasons for this are discussed in detail elsewhere (Woodroffe et al. 2005a) but probably reflect severe depletion of wild prey in this area. Figures 1 and 2 also indicate that most of the investigated lion attacks occurred on or near commercial ranches, even though observers were working primarily on community land. This probably reflects lions' marked preference for commercial ranches (Frank et al. 2005), perhaps because wild prey are more abundant there (Khaemba et al. 2001).

The numbers of attacks investigated likewise give only a very approximate picture of each predator species' impact on local people's livelihoods. This impact will be influenced not only by the frequency of attacks, but also by the numbers of animals killed or injured on each attack. The latter varies substantially between species, with wild dogs particularly likely to kill multiple animals when attacking grazing herds, and hyaenas particularly likely to make multiple kills inside bomas (Table 1). Since our analyses did not take into account the age, sex, or reproductive state of each animal killed, we did not quantify the impact of depredation on local systems of livestock production (Mizutani et al. 2005).

Our findings are broadly comparable with those of previous studies (Kruuk 1980; Ogada et al. 2003), showing that herding practices and boma construction can greatly reduce the probabilities of livestock loss. However, our case–control approach allowed us to more precisely quantify the relative impacts of different husbandry factors and should be helpful in indicating improvements that could reduce livestock losses to predators. For example, analyses indicate that having a domestic dog accompanying a herd reduces the risk of attack by 63% (Table 1), yet only 24% of herds were so accompanied even though dogs were present at 71% of bomas. Likewise, we found that each gate in a boma wall increases the likelihood of attack by 40% (Table 3), yet the average boma had 2.4 gates. These sorts of findings are helpful because they allows farmers (and conservation managers) to make informed decisions about optimal livestock husbandry, taking into account, for example, that a more densely constructed boma wall will provide more effective protection for livestock (and hence lead to fewer predators being killed), but will also be more labour-intensive to construct (and involve greater offtake from slowly-growing native trees, Okello et al. 2001).

While there is considerable local knowledge and experience concerning effective livestock husbandry, the quantitative approach taken in this study revealed two results that were somewhat surprising, namely that attack probability was higher for (i) bomas with more scarecrows; and (ii) herds accompanied by more child herders. Concurrent findings in line with expectations—for example that predation events were more likely to occur in dense bush, or that domestic dogs help to deter attacks—suggest that these counter-intuitive findings should not be dismissed as anomalous. The detrimental effect of scarecrows was particularly marked for leopards although, after adjusting for the significant effects reported above, non-significant trends for lions ($P = 0.137$) and hyaenas ($P = 0.127$) were in the same direction. This unintended effect of scarecrows might perhaps reflect attraction to a visual cue (cloth moving in the wind)—although similar moving flags have been shown to deter wolves from attacking livestock (Musiani et al. 2003). While the detrimental effect of multiple child herders was unforeseen, community members had an immediate explanation for this findings: lone herd boys are likely to be more attentive to their flocks than those with companions to talk or play with.

Our results demonstrate clear benefits of having domestic dogs both at bomas and accompanying grazing herds (Tables 1, 3). It should be noted that the dogs involved are not selectively bred for guarding livestock, nor do they actively chase predators away; their main role is to alert people to predators' presence. It is perhaps not surprising that domestic dogs reduce livestock depredation, and, by extension, reduce the numbers of predators killed by livestock farmers. This finding is important, however, because domestic dogs also have negative consequences for predator conservation: they carry infectious diseases that have the potential to substantially reduce the viability of wild carnivore populations (Cleaveland and Dye 1995; Laurenson et al. 1998; Roelke-Parker et al. 1996), and are also widely used for hunting wild prey. While, from a disease perspective, control of domestic dog populations might be desirable (Laurenson et al. 2004), our findings suggest that benefits to carnivore conservation achieved by reduced disease risks might be countered by increased retaliatory killing associated with livestock depredation. This reinforces the idea that—outside protected areas at least—vaccination (rather than control) of domestic dog populations is a more sustainable solution to disease threats for wild carnivores (Laurenson et al. 2004). These benefits of domestic dogs are widely recognised by local people: interviews conducted at 562 bomas revealed that 49% of interviewees wanted more dogs at their boma, compared with 42% wanting to keep the same number and just 9% wanting fewer (R. Woodroffe unpubl. data). The possibly (though not statistically significantly) detrimental effects of domestic dogs on livestock predation by wild dogs are perhaps unsurprising; there are several anecdotal reports of wild dogs being attracted to domestic dogs (R. Woodroffe unpubl. data; Butynski 1974).

The different husbandry practices that appear effective against different predator species influence the extent to which our overall findings may be generally applicable. Since attacks by leopards and hyaenas dominated our dataset, effects on these species will have strong effects on the overall results presented in Tables 1 and 3; hence findings for the particular species may be more appropriate for applying to other areas with different predator problems. For example, in the majority of community areas studied, the principal predators of livestock were leopards and hyaenas (Figs. 1, 2), suggesting that the most effective husbandry approaches would involve ensuring that domestic dogs accompany grazing herds as well as staying at bomas at night, building bomas with thick walls and the minimum number of gates (ideally reinforced to further reduce losses), and removing scarecrows from bomas. In the north-west of our study area, however, wild dogs were the principal predator of livestock. Here, therefore, the most important improvements to livestock husbandry would be to avoid assigning herding duties to groups of children, and perhaps also to discourage domestic dogs from accompanying herds. These differences illustrate how local conditions need to be taken into account in extrapolating our findings to other areas where predator communities may differ.

In conclusion, our study indicates that relatively small improvements to livestock husbandry have the capacity to substantially reduce depredation on livestock by wild carnivores and, hence, to reduce both predator impacts on rural people's livelihoods and lethal control of species of conservation concern. Similar approaches would presumably also be effective in other parts of Africa, or for similar species elsewhere. However, whether such approaches would be adopted in other areas depends on multiple factors including local herding traditions, access to materials to construct bomas, the availability of education and alternative employment for potential herders, and opportunities for generating income from predator conservation (through tourism or trophy hunting) as well as from livestock farming. Moreover, preventing wild carnivores from killing livestock will only contribute to their conservation if alternative, wild, prey are available to them. For species such as wild dogs and cheetahs, which can survive in areas of comparatively low prey density (Durant 1998; Mills and Gorman 1997), the maintenance of traditional livestock husbandry (perhaps combined with control of domestic dog diseases) may be sufficient to allow populations to persist in pastoralist community lands (Woodroffe et al. 2005a). In contrast, evidence suggests that lions may require higher densities of wild prey (Frank et al. 2005), indicating that improvements to livestock husbandry will not allow lion populations to recover in community lands in the absence of measures to promote conservation of their prey.

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