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Evaluating support for rangeland-restoration practices by rural Somalis: an unlikely win-win for local livelihoods and hirola antelope?

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Beatragus hunteri; elephant; endangered species; habitat degradation; rangeland; restoration; tree encroachment; antelope.

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Abstract

In developing countries, governments often lack the authority and resources to implement conservation outside of protected areas. In such situations, the integration of conservation with local livelihoods is crucial to species recovery and reintroduction efforts. The hirola *Beatragus hunteri* is the world's most endangered antelope, with a population of <500 individuals that is restricted to <5% of its historical geographic range on the Kenya–Somali border. Long-term hirola declines have been attributed to a combination of disease and rangeland degradation. Tree encroachment—driven by some combination of extirpation of elephants, overgrazing by livestock, and perhaps fire suppression—is at least partly responsible for habitat loss and the decline of contemporary populations. Through interviews in local communities across the hirola's current range, we identified socially acceptable strategies for habitat restoration and hirola recovery. We used classification and regression trees, conditional inference trees, and generalized linear models to identify sociodemographic predictors of support for range-restoration strategies. Locals supported efforts to conserve elephants (which kill trees and thus facilitate grass growth), seed and fertilize grass, and remove trees, but were opposed to livestock reduction. Locals were ambivalent toward controlled burns and soil ripping (a practice through which soil is broken up to prevent compaction). Livestock ownership and years of residency were key predictors of locals' perceptions toward rangeland-restoration practices. Locals owning few livestock were more supportive of elephant conservation, and seeding and fertilization of grass, while longer term residents were more supportive of livestock reduction but were less supportive of elephant conservation. Ultimately, wildlife conservation outside protected areas requires long-term, community-based efforts that are compatible with human livelihoods. We recommend elephant conservation, grass seeding and fertilization, manual tree removal and resting range from livestock both to enhance the potential for hirola recovery and to build positive rapport with local communities in the geographic range of this critically endangered species.

Introduction

In semi-arid rangelands, overgrazing, fire suppression and climate change degrade forage bases, thereby threatening both wildlife populations and pastoral livelihoods (Wilcox & Murphy, 1985; Turner & Corlett, 1996; Schrott, With & King, 2005; Angassa & Oba, 2008; Hanke *et al.*, 2014). This is especially so in East African rangelands that historically housed a staggering diversity of wildlife alongside pastoralists (Angassa & Oba, 2008; Bhola *et al.*, 2012). Here, human–wildlife coexistence can sometimes involve benefits of wildlife to livestock and vice versa (Georgiadis *et al.*, 2007; Augustine *et al.*, 2011; Odadi *et al.*, 2011; Allan *et al.*, 2017). However, this coexistence is precarious, and can be threatened by increasing livestock densities that degrade wildlife habitat and cause to wildlife populations to decline (Western, Russell & Cuthill, 2009a; Western, Groom & Worden, 2009*b*; Ogutu *et al.*, 2011).

Restoring habitat for wildlife also has the potential to improve forage for livestock, thereby creating a means through which communities can both actively engage in and benefit from conservation. In turn, local opinions and perceptions can benefit conservation tremendously (Infield, 1988; Holmes, 2007; Larijani & Yeshodhara, 2008; Campbell, Sayer & Walker, 2010), such that conservation efforts often are most effective when led by locals (e.g. Lepp & Holland, 2006; Sebele, 2010; Ingram, Redford & Watson, 2012). Despite the apparent recognition of the importance of local involvement, authorities often fail to take into account the diversity and motivation of community interests (Pimbert & Pretty, 1997; Kiss, 2004), thereby generating hostility between local communities and the government agencies responsible for wildlife conservation and management (Holmern, Nyahongo & Røskaft, 2007; Hazzah, Borgerhoff-Mulder & Frank, 2009; Redpath *et al.*, 2013).

With these challenges in mind, we sought to quantify community attitudes toward rangeland-restoration practices for livestock and hirola *Beatragus hunteri*. The hirola is the world's most endangered antelope (IUCN, 2008), restricted to 1200 km^2 on the Kenya–Somali border. The extent of the hirola's range within Somalia is unclear; the distribution of hirola has historically been mentioned in the context of both Kenya and Somalia (Andanje, 2002). Although they have never been common, hirola have dwindled from ca. 13 000 individuals in 1970 to <500 individuals currently (Probert *et al.*, 2015). Remaining populations occur almost solely on pastoral lands with no formal protection, while the single protected area that exists within the hirola's native range (Arawale National Reserve) lacks adequate support from both the Kenyan government and the international conservation community. Much of the hirola's historical range occurred in semi-arid grasslands, which were inhabitated by nomadic people and wildlife. However, colonial policies led to a shift from nomadism to sedentary pastoralism by encouraging settlements around boreholes and other fixed infrastructure (Niamir-Fuller & Turner, 1999; Boone, 2005). Increasing livestock numbers across Garissa County and other parts of Kenya have coincided with declining wildlife populations (Ogutu *et al.*, 2016). In Garissa County and elsewhere in eastern Kenya (see Ford, Fryxell & Sinclair, 2016), these trends were associated with human population growth, increasing numbers of livestock, increased frequency of drought and elephant extirpation, subsequently triggering the loss of herbaceous biomass and replaced with bare soil or woody cover leading to degradation of forage supply for grazing species like hirola (Ali *et al.*, 2017, 2018). Since the mid-1980s, tree cover throughout the hirola's geographic range has increased >250% (Ali *et al.*, 2017).

Such landscape change has made it more profitable for locals to shift from (grass-eating) cattle *Bos indicus* production to (tree/shrub-eating) goat *Capra hircus* and camel *Camelus dromedarius* production. In sub-Saharan Africa and across the continent, tree encroachment has been linked directly to a release from browsing caused by megafaunal declines, particularly elephants (Riginos, 2009; Goheen *et al.*, 2013; Daskin, Stalmans & Pringle, 2016) as well as many other factors such as overgrazing, fire suppression and climate change (Mitchard & Flintrop, 2013; O'Connor, Puttick & Hoffman, 2014; Stevens *et al.*, 2017). Currently, and although elephant populations in eastern Kenya seem to be recovering, they are far below the ca. 5000 individuals that inhabited this region in the 1970s (Ottichilo, Kufwafwa & Stelfox, 1987; Butynski, 2000; Thouless *et al.*, 2016). Indeed, in a recent study on hirola movement and habitat selection, tree encroachment was the ultimate driver of hirola habitat availability, more so than access to water or proximity to people (Ali *et al.*, 2017). Critically, this study also demonstrated that habitat availability for hirola has declined by 75% between 1984 and 2012 (Ali *et al.*, 2017).

In 2012, and in an attempt to curtail further hirola declines, the Ishaqbini Community Conservancy, the Kenya Wildlife Service and the Northern Rangelands Trust established a 25 km^2 livestock-free and predator-proof sanctuary to breed hirola and then reintroduce them to wide swathes of their historic range in eastern Kenya. To the extent that tree encroachment was (and continues to be) responsible for low numbers of hirola, the success of this reintroduction effort likely hinges on rangeland restoration and thus the support, perspectives, knowledge, and participation of local communities.

The goals of our research were to: (1) identify socially acceptable, potential solutions for rangeland restoration; and (2) assess predictors of social acceptance for these rangeland-restoration practices by local communities. We identified the following practices as potential solutions for rangeland restoration, all of which have been demonstrated to enhance grass growth, reduce tree cover, or both in sub-Saharan savannas: manual removal of trees (Riginos, 2015); core-area resting of range – which is restricting grazing by livestock away from some range areas during the wet season (also 'core' areas) to allow regrowth and later grazing of livestock during the dry season (O'Connor *et al.*, 2010); livestock reduction (Odadi *et al.*, 2011); controlled or 'prescribed' burns (Sensenig, Demment & Laca, 2010); soil ripping – a form of tillage involving breaking of compacted soil surface manually using machinery or hand tools (Kinyua *et al.*, 2010); seeding and fertilization (Kinyua *et al.*, 2010); and elephant conservation (as a means through which to reverse tree encroachment; Duffy *et al.*, 2002; Goheen & Palmer, 2010). We show that pastoralist communities in eastern Kenya are supportive of several of these rangeland-restoration practices, which could improve the quality of hirola habitat alongside local livelihoods.

Materials and methods

Study area

We conducted our study in Ijara (latitude 1°36′S, longitude 40°32′E) and Fafi (latitude: -0°25′ S, longitude: 40°13′E) subcounties of Garissa County in eastern Kenya. Communities rely on livestock production, and pastoralism has been practiced in the region for hundreds of years. Livestock herds are composed of goats, cattle, camels and donkeys (*Equus asinus*). Most households strive to have large cattle herds representing wealth to the Somali pastoralist and this has often resulted in declining forage availability. Somalis in eastern Kenya like elsewhere in the Horn of Africa are spatially clustered through nomadic clan system albeit with same culture, language and religion (Tilahun *et al.*, 2016). Here, pastoralists comprise two Somali subtribes: the Abudwaq in Fafi and the Abdalla in Ijara, collectively referred to as the Talamoge Ogadens.

Our study area lies between 40 m and 250 m above sea level and is underlain by well-drained sandy soils. Rainfall is bimodal, with the long rainy season (locally referred to as *Guu*) occurring in April to June and the short rainy season (locally referred to as *Deir*) occurring from November to December. Two punctuated dry periods occur between the wet seasons: the short dry season in January–March (locally referred to as *Jilal*) and the long dry season which occurs from July to October (locally referred to as *Hagaa*). The mean annual rainfall ranges from 350 mm in Fafi to 550 mm in Ijara (Bunderson, 1979, 1981). The preferred habitat of hirola occurs on open grassland in the 400–550 mm rainfall zone in both subcounties (Bunderson, 1981; Ali *et al.*, 2017). Average annual temperatures in the region range from 2l to 30°C (Muchena, 1987). The most common ungulates in the area include the reticulated giraffe *Giraffa camelopardalis reticulata*, gerenuk *Litocranius walleri*, lesser kudu *Tragelaphus imberbis*, waterbuck *Kobus ellipsyprimnus* and Kirk's dik-dik *Madoqua kirkii*. Large carnivores in the region include lions *Panthera leo,* cheetahs *Acinonyx jubatus*, spotted hyenas *Crocuta crocuta* and African wild dogs *Lycaon pictus*; Ali *et al.* (2017, 2018).

Survey design

From 2013 to 2014, we conducted surveys using a semi-structured questionnaire (Liu *et al.*, 2011; Okello *et al.*, 2011; Table 1). Prior to administering the surveys, we subjected the questionnaires to expert review with the Kenya Wildlife Service and pilot testing with communities using copies translated into the local Somali language ($n = 80$ pilot-tested respondents). Where understanding of the specific questions was difficult, it was explained further by the principal investigator or a trained field assistant by use of photographs and other illustrations.

Across the two subcounties, we sampled a total of 10 villages (mean distance between sampled villages = 28.0 km ± 9.0 SE): Gababa, Hara, Korisa, Masalani and Qotile in Ijara, and Aliimitch, Bura, Galmagala, Garasweno and Mansabubu in Fafi (Fig. 1). We selected these villages because they represent the largest semi-permanent settlements within the hirola's geographic range (Kenya National Bureau of Statistics, 2009). Within each village, we sampled in proportion to the number of households, such that atleast 20% of households were sampled in each village. We defined households as members of the same family in which a single individual (mother or father) is regarded as the head of the household (Kideghesho, Røskaft & Kaltenborn, 2007). We ensured that each respondent belonged to a unique household, and thus surveyed only a single respondent per household for a total of 131 households across the 10 villages (range = 10–16 households per village). This level of sampling intensity is comparable to that of other studies on human attitudes toward wildlife conservation (e.g. Lindsey *et al.*, 2006; Harihar, Ghosh-Harihar & MacMillan, 2014; Rakotomamonjy *et al.*, 2015).

Table 1 Questions posed to Somali pastoralists in semi-structured questionnaires

Which of the following restoration practices will you accept for range improvement for hirola and livestock?	Response
Manual removal of trees	1 Strongly disagree
	2 Disagree
	3 Neutral or undecided
	4 Agree
	5 Strongly agree
Core-area resting	1 Strongly disagree
	2 Disagree
	3 Neutral or undecided
	4 Agree
	5 Strongly agree
Livestock reduction	1 Strongly disagree
	2 Disagree
	3 Neutral or undecided
	4 Agree
	5 Strongly agree
Controlled burns	1 Strongly disagree
	2 Disagree
	3 Neutral or undecided
	4 Agree
	5 Strongly agree
Soil ripping (i.e. soil disking)	1 Strongly disagree
	2 Disagree
	3 Neutral or undecided
	4 Agree
	5 Strongly agree
Seeding and fertilization	1 Strongly disagree
	2 Disagree
	3 Neutral or undecided
	4 Agree
	5 Strongly agree
Elephant conservation	1 Strongly disagree
	2 Disagree
	3 Neutral or undecided
	4 Agree
	5 Strongly agree

To encourage participation in our surveys, respondents were not asked to indicate their names. We trained one local per village to administer the questionnaires in each of the villages. We recorded the following sociodemographic (predictor) variables associated with each respondent: gender, age, level of education (no formal education, primary and

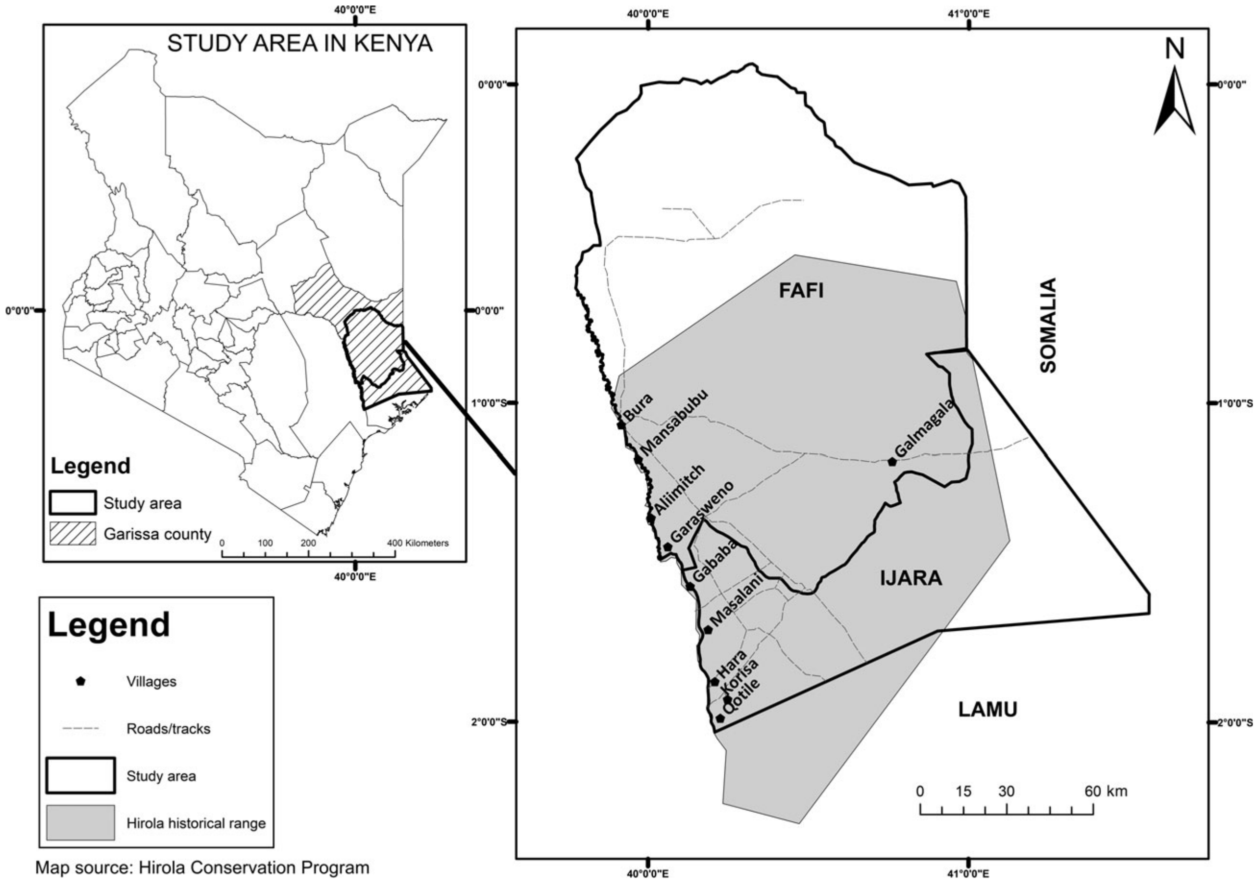

Figure 1 Communities in Ijara and Fafi subcounties in Garissa County, Kenya, and the historical geographic range of hirola (estimated from a minimum convex polygon based on a 1963 hirola distribution in Kenya).

high school), years of residency in the village and livestock wealth (the total number of livestock owned by the household).

Before administering questionnaires, we operationally defined the seven rangeland-restoration practices to individuals as follows:

- *Manual removal of trees*: the physical cutting, uprooting or breaking of branches in attempt to restore grassland at scales of hundreds of hectares.
- *Core-area resting of rangeland*: the cessation of livestock grazing across hundreds of hectares (i.e. 'core' areas) during the wet season to allow the regrowth of grasses, that then can be grazed by livestock during the dry season.
- *Livestock reduction*: the voluntary sale or butchering of 20% of individual livestock in a respondent's herd. These 20% could be any combination of goats, sheep and cattle.
- *Controlled burns*: the prescribed burning of tree-encroached areas at scales of hundreds of hectares.
- *Soil ripping*: a type of tillage in which compacted soil is broken open manually (but not removed) at scales of hundreds of hectares.
- *Seeding and fertilization*: the planting of native grass seeds alongside fertilizer (manure) at scales of hundreds of hectares.
- *Elephant conservation*: community-based protection of elephants (in the form of antipoaching squads and enhanced communication between villages) to encourage elephant herds to reside on community lands.

Data analysis

To analyze responses from questionnaires, we used a classification and regression tree (CART) approach, using the *rpart* package in R version 3.03 (Therneau & Atkinson, 2010). We used CARTs to examine sociodemographic predictors of acceptance for each of the proposed rangeland-restoration practices. CARTs can be used for the analysis of numeric and non-numeric response data with missing values, as well as nonlinear datasets (De'ath & Fabricius, 2000). CARTs also allow for complex interactions among covariates with fewer specifications, thus making it possible to identify predictors underlying social acceptance of rangeland-restoration practices (Sutton, 2005). Further, and unlike multiple regression, CARTs accounts for multicollinearity through best-split criteria and bias minimization in selection of predictor variables (Kim & Loh, 2011).

To help with interpretation of CART output, we employed a splitting rule function using the *rattle* package in R version

3.03 (Williams, 2009; R Development Core Team, 2014), which utilizes a squared residual minimization algorithm (Timofeev, 2004). The algorithm computes and minimizes the sum of variances for corresponding left and right nodes and stops when the number of observations in each of the two nodes does not exceed a predefined required minimum. To validate each CART, we used the relative error, calculated by $1–R^2$, and obtained the complexity parameter (*cp*) for each of the seven CART models (i.e. one for each rangeland-restoration practice). The cross-validation procedure penalizes (prunes off) any split in the model that does not improve the fit by *cp*, which results in selection of 'optimal' regression trees.

Our CART models do not provide predictions with probabilistic levels or confidence intervals (Yohannes & Webb, 1999), which is of interest in our study. To complement our efforts with CART, we developed a conditional inference tree (CIT) approach using the *party* package in R version 3.03 (Hothorn, Hornik & Zeileis, 2006; R Development Core Team, 2014). Conditional inference trees reduce biases in predictor selection, thus enabling selection of predictors with the most possible splits or missing values (Strobl *et al.*, 2008). In addition, conditional inference trees make it possible to compute levels of significance and provide *P*-values (Hothorn *et al.*, 2006).

Finally, we used generalized linear models (GLMs) to model predictors of answers to survey questions. GLMs are less prone to overfitting and generate easily interpreted regression coefficients, which can be problematic for CARTs and CITs (Evans & Cushman, 2009). These questions addressed how sociodemographic predictors influenced answers with a discrete value ('Strongly Agree', 'Agree', 'Neutral/Undecided', 'Disagree', 'Strongly Disagree'). We combined 'Strongly Agree' and 'Agree' into a single category ('Agree'), and 'Strongly Disagree' and 'Disagree' into a single category ('Disagree'). To examine relationships between acceptance of rangeland-restoration practices and sociodemographic predictors in our CART, CIT and GLM models, we visually inspected plots from the model outputs in addition to assessing measures of goodness-of-fit (through coefficients, residuals, variance and deviance (Arentze & Timmermans, 2004)). We also identified the most important sociodemographic predictors of acceptance for each rangeland-restoration practice using mean square errors and *P*-values.

Results

In order of agreement, participants were most supportive of elephant conservation (86.0%, with livestock wealth explaining 26.4% of the variance), manual removal of trees (85.5%, with livestock wealth explaining 30.7% of the variance), grass seeding and fertilization (72.5%, with livestock wealth explaining 19.0% of the variance) and core-area resting (56.8%, with education explaining 27.8% of the variance; Table 2, Table S1). In contrast, participants were less supportive of voluntary reduction of livestock (37.4%, with age explaining 30.5% of the variance), soil ripping (39.0%, with livestock wealth explaining 21.1% of the variance) and controlled burns (43.5%, with livestock wealth explaining 23.1% of the variance; Table 2, Table S1, Fig. 2).

We present the CARTs illustrating sociodemographic predictors for attitudes toward elephant conservation (Fig. 3a) and livestock reduction (Fig. 3b) that represent the rangeland-restoration practices toward which respondents were most and least supportive, respectively. Livestock wealth was the primary predictor of respondents' attitudes toward elephant conservation: support for elephant conservation was strongest for households owning <150 head of livestock. Age was the most important predictor of locals' attitudes toward livestock reduction, as respondents ≥50 years old were more supportive of voluntary reductions in livestock. A summary of the CART output is presented in Table 2, and the remaining five CARTs are appended in the supplementary material (Figs. S1–S5). The remaining two CITs associated with statistically significant *P*-values (for core-area resting, and for seeding and fertilization) are appended in the supplementary material (Figs. S3 and S4).

Livestock wealth was (1) the most important sociodemographic predictor of attitudes toward five of the seven rangeland-restoration practices (soil ripping, controlled burns, manual removal of trees, grass seeding and fertilization, and elephant conservation; Table 2); and (2) significantly and negatively related to support for soil ripping, grass seeding and fertilization, and elephant conservation (Table 3). The level of formal education was the most important social-demographic predictor explaining attitudes toward core-area resting: respondents lacking formal education did not support core-area resting (Table 2 and Table 3). Gender of the household head was not a statistically significant predictor for acceptance toward any of the rangeland-restoration practices. Results from CITs were congruent with those of CARTs (Fig. 4), with livestock wealth ($P = 0.004$) and years of residency ($P = 0.002$) as the primary determinants for acceptance of elephant conservation, and age the most important determinant for acceptance of livestock reduction ($P = 0.039$).

Discussion

We explored attitudes of pastoralists toward seven rangeland-restoration practices, all of which have been demonstrated previously to enhance range quality. Over 75% of the hirola's range has experienced tree encroachment, likely caused by some combination of elephant extirpation, overgrazing by livestock and fire suppression (Ali *et al.*, 2017). Historically, elephants encouraged grass growth through the reduction of trees, thereby maintaining grasslands (Laws, 1970; Coverdale *et al.*, 2016). Small population sizes of hirola have coincided with tree encroachment, and the few hirola that persist in eastern Kenya strongly avoid woody cover (Ali *et al.*, 2017). In addition to its detrimental impact on hirola, this widespread conversion of grassland to shrubland has negatively impacted the livelihoods of pastoralists in eastern Kenya (Ali, personal observation). Consequently, the majority of pastoralists in our study area are supportive of rangeland restoration in general,

Table 2 Summary of CART output. Rangeland-restoration practices are in ascending order of agreement from respondents (i.e. livestock reduction was the least-supported practice while elephant conservation was the most-supported practice). CART, classification and regression tree

Range-restoration Practice	Sociodemographic importance (most to least agreement)
Livestock reduction	• Age • Livestock wealth • Length of residency • Gender • Education
Soil ripping	• Livestock wealth • Length of residency • Age • Gender • Education
Controlled burns	• Livestock wealth • Length of residency • Age • Education • Gender
Core-area resting	• Education • Length of residency • Livestock wealth • Age • Gender
Seeding and fertilization	• Livestock wealth • Gender • Age • Education • Length of residency
Manual removal of trees	• Livestock wealth • Length of residency • Education • Age • Gender
Elephant conservation	• Livestock wealth • Length of residency • Education • Age • Gender

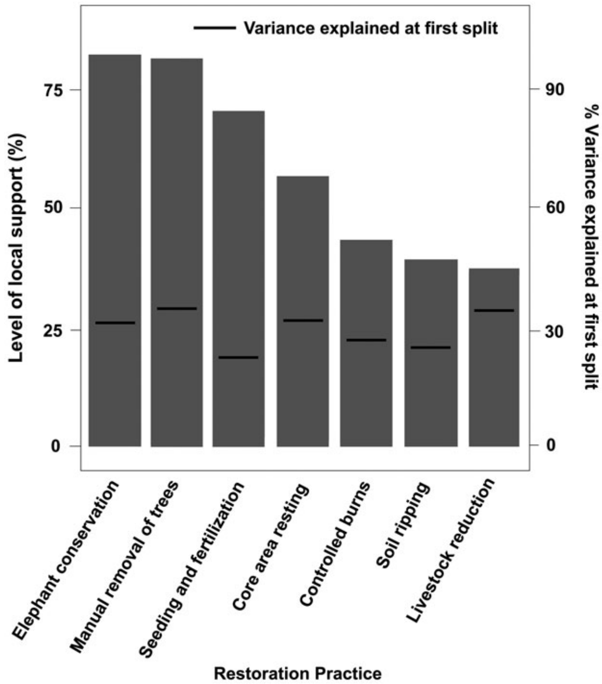

Figure 2 Showing the level of local support for each of the rangeland-restoration practices and the percent variance explained at the first split (summary of CART model) in order of the most supported to the least (i.e. elephant conservation, manual removal of trees, seeding and fertilization, core-area resting, control burns, soil ripping and livestock reduction). CART, classification and regression tree.

and elephant conservation, grass seeding and fertilization, manual removal of trees and core-area resting in particular. This level of support for rangeland restoration by the majority of individuals in our study conforms with others from this region, linking wildlife conservation and human livelihoods (Boyd *et al.*, 1999; Homewood & Rodgers, 2004; Young, Palmer & Gadd, 2005; Western, Waithaka & Kamanga, 2015).

Our findings are aligned with those of a recent study in southern Kenya in which the majority of pastoralists supported the conservation of elephants in community rangelands (Browne-Nuñez, Jacobson & Vaske, 2013). While we acknowledge that the high level of enforcement associated with elephant conservation outside of formally protected areas would be immense, we believe that any future attempts to restore rangeland would be well-served to also protect newly recolonizing elephant herds *in situ* within Ijara and Fafi subcounties. After an absence of nearly three decades (Ali *et al.*, 2017), elephants recently have begun to recolonize Ijara and Fafi subcounties naturally, although they persist only in low numbers and typically pass through this region as they move between Boni National Reserve to the east and Tsavo National Park to the southwest. Integration of community activities and elephant conservation has been successful elsewhere in Kenya (e.g. Kuriyan, 2002), and we recommend that government agencies and non-government organizations afford every protection possible to bolster plummeting elephant numbers and as a potential means to restore habitat for hirola. In Ijara and Fafi, communities expressed strong support for elephant conservation because of (1) a perceived link between the presence of elephants and profitable levels of cattle production in the 1960s and 1970s (which likely are a cause and an effect, respectively, of open-grassland habitat); and (2) ecosystem services provided by elephants (e.g. seed dispersal, excavation and maintenance of watering holes). Interestingly, none of the individuals we surveyed invoked economic gains from tourism as a rationale for conserving elephants.

We are encouraged by the fact that a large fraction of pastoralists were supportive of grass seeding and fertilization for rangeland restoration. The acceptance of seeding and fertilization conforms with its demonstrated potential as a tool in both wildlife conservation and poverty reduction (Kinyua *et al.*, 2010; Mganga *et al.*, 2015). Additionally, manual removal of

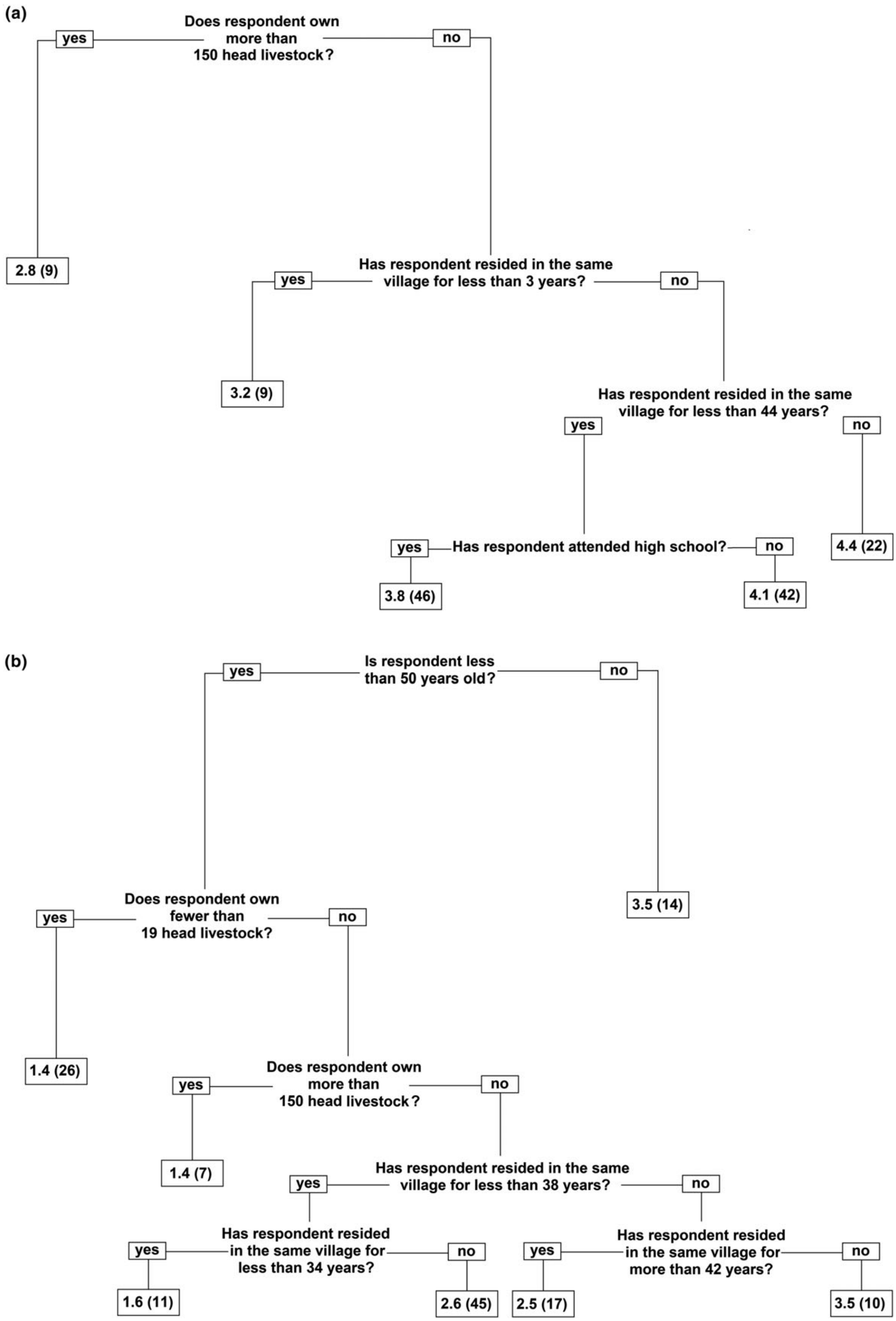
(a)
Does respondent own more than 150 head livestock?
yes
no
2.8 (9)
Has respondent resided in the same village for less than 3 years?
yes
no
3.2 (9)
Has respondent resided in the same village for less than 44 years?
yes
no
Has respondent attended high school?
yes
no
3.8 (46)
4.1 (42)
4.4 (22)
(b)
Is respondent less than 50 years old?
yes
no
3.5 (14)
Does respondent own fewer than 19 head livestock?
yes
no
1.4 (26)
Does respondent own more than 150 head livestock?
yes
no
1.4 (7)
Has respondent resided in the same village for less than 38 years?
yes
no
Has respondent resided in the same village for less than 34 years?
yes
no
1.6 (11)
2.6 (45)
Has respondent resided in the same village for more than 42 years?
yes
no
2.5 (17)
3.5 (10)

Figure 3 Optimal CART models for responses to the questions (a) 'Do you support elephant conservation as a strategy to improve range quality?'; and (b) 'Do you support reducing the number of livestock you own to improve range quality?' Predictor variables are defined at each corresponding branch split. Terminal nodes represent the mean response (ranging from 1 to 5, where one represents the strongest level of disagreement, and five represents the strongest level of agreement); for each terminal node, numbers of respondents are included in parentheses. Branch lengths are proportional to the amount of variance explained by the predictor variable at the split. For example, the group most supportive of elephant conservation are individuals owning less than 150 head of livestock who have resided in the same village for more than 44 years (22 individuals with a mean acceptance score of 4.4), while the group least supportive of elephant conservation (mean acceptance score of 2.8) are the nine individuals who own more than 150 head of livestock. CART, classification and regression tree.

Table 3 Regression coefficients (slopes) and associated *P*-values of sociodemographic predictors for rangeland-restoration practices as obtained from GLMs. *P*-values < 0.10 are reported; *P*-values < 0.05 are underlined. Slope estimates are given in parentheses

	Livestock reduction	Soil ripping	Controlled burning	Core-area resting	Manual removal of trees	Seeding and fertilization	Elephant conservation
Age							
Agree	0.07 (0.01)	–	–	–	–	–	–
Disagree	0.02 (−0.01)	–	–	–	–	–	–
Gender							
Agree							
M	–	–	–	–	–	–	–
F	–	–	–	–	–	–	–
Disagree							
M	–	–	–	–	–	–	–
F	–	–	–	–	–	–	–
Level of education							
Agree							
P	–	–	–	–	–	–	–
H	–	–	–	–	–	–	–
N	–	–	–	0.02 (−0.48)	–	–	–
Disagree							
P	–	–	–	–	–	–	–
H	–	–	–	–	–	–	–
N	–	–	–	0.08 (0.34)	–	–	–
Livestock wealth							
Agree	–	0.05 (−0.005)	–	–	–	0.0004 (−0.001)	0.002 (−0.001)
Disagree	–	–	–	–	–	0.0006 (0.001)	0.0001 (0.001)
Years of residency							
Agree	0.05 (−0.001)	–	–	0.07 (−0.01)	–	–	0.003 (0.005)
Disagree	0.07 (0.005)	–	–	–	–	–	0.03 (−0.004)

M = Male, F = Female, P = Primary school, H = High school, N = No formal education.

trees was strongly supported by locals and may be another option to facilitate rangeland restoration. The long-term persistence of hirola on communal lands may very well hinge on active habitat management such as manual removal of trees, which may provide local employment and provisioning of charcoal for households (Mwampamba *et al.*, 2013). Finally, by exploiting the same areas at different points in time, core-area resting holds potential as a means through which hirola, other grazing wildlife, and livestock may coexist (see also Augustine *et al.*, 2011; Odadi *et al.*, 2011).

In many parts of Africa, overgrazing by livestock has triggered rangeland degradation where pastoralism is the dominant land-use (e.g. Dodd, 1994; Wessels *et al.*, 2007; Hanke *et al.*, 2014). Perhaps not surprisingly, participants in our surveys were least supportive of voluntary reductions in livestock among potential rangeland-restoration practices. Although livestock wealth is a measure of individual status in Somali society, years of residency was the only sociodemographic predictor strongly associated with support for livestock reduction.

A major challenge for the future is ensuring that livestock owners do not simply increase livestock numbers in light of improved range, leading to a classic Tragedy of the Commons (Hardin, 1968). Since livestock consume forage that otherwise could be utilized by hirola, hirola conservation hinges ultimately on a level of local restraint: some critical fraction of restored rangeland must be made available as food and habitat for hirola (Swallow & Bromley, 1995; Hackel, 1999). Such long-term, sustainable yields for livestock, hirola, and other wildlife necessitate (1) well-defined, widely recognized boundaries around rangelands associated with communities within the hirola's range, with exclusion of outside parties; (2) rules for the provision of grazing lands to individuals within communities, coupled with sanctions for those who violate such rules; and (3) participatory decision-making, in which

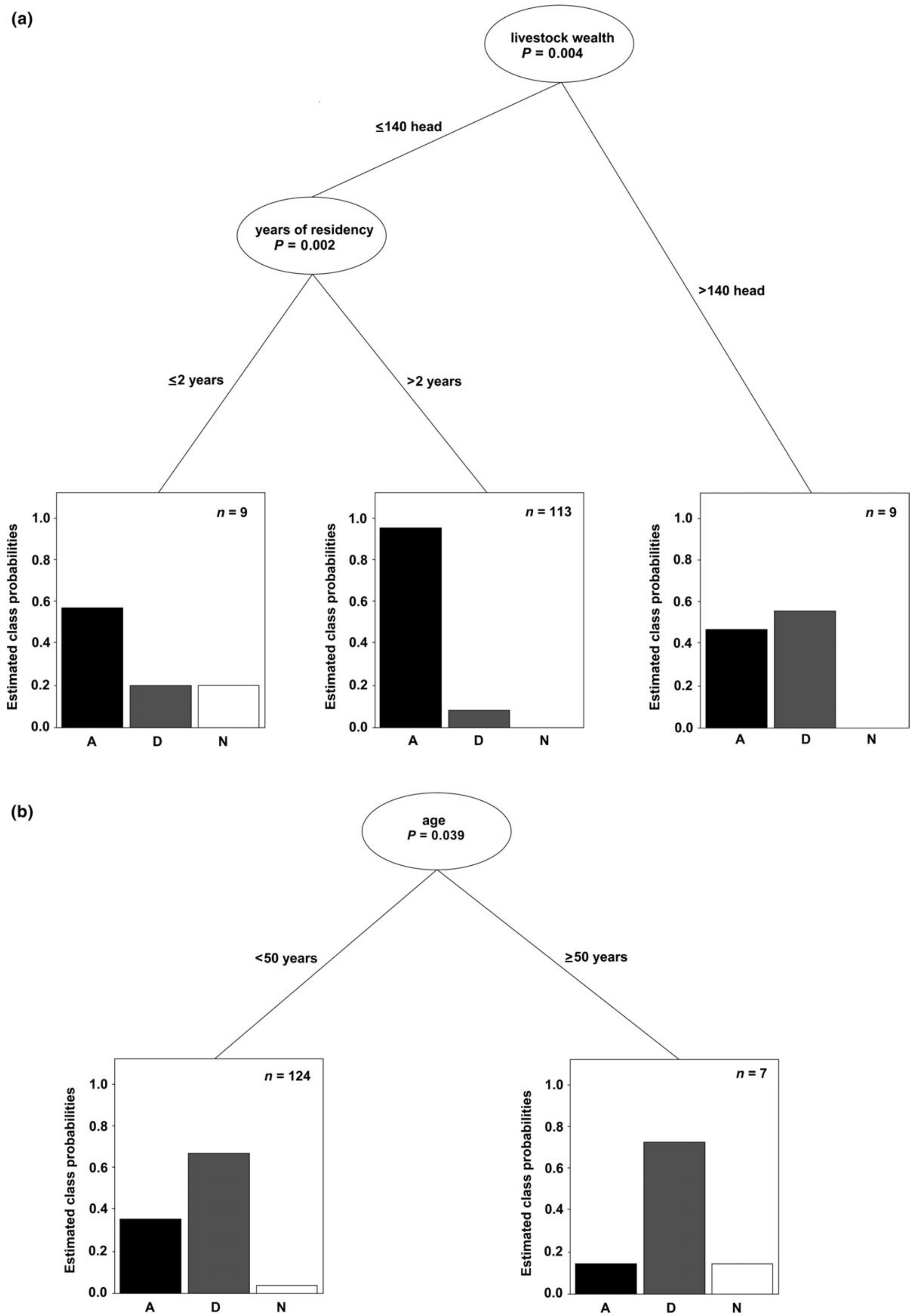
(a)
livestock wealth
P = 0.004
≤140 head
>140 head
years of residency
P = 0.002
≤2 years
>2 years
n = 9
n = 113
n = 9
Estimated class probabilities
1.0
0.8
0.6
0.4
0.2
0.0
A
D
N
(b)
age
P = 0.039
<50 years
≥50 years
n = 124
n = 7

Figure 4 Conditional inference trees depicting the estimated proportions and statistical significance of sociodemographic predictors for the questions (a) 'Do you support elephant conservation as a strategy to improve range quality?'; and (b) 'Do you support reducing the number of livestock you own to improve range quality?' The prefixes A stand for Agree (those responding 'Strongly agree' or 'Agree' to the question), D for Disagree (those responding 'Strongly disagree' or 'Disagree') and N for Neutral (those responding 'Neutral' or 'Undecided').

individuals are encouraged to determine #1 and #2 independently of higher level authorities (Ostrom, 1990). Ultimately, implementation of these principles requires strong, prominent leadership through community elders coupled who, in turn, have strong public support (Kothari, Camill & Brown, 2013; Hazzah *et al.*, 2014; see also Gutiérrez, Hilborn & Defeo, 2011).

Human–wildlife conflict often constrains opportunities for habitat restoration, species reintroductions, and other endeavors central to wildlife conservation. We have demonstrated that pastoralists in eastern Kenya are supportive of several rangeland-restoration practices, which could improve hirola habitat alongside local livelihoods. Implementation of these practices and, ultimately, the persistence of hirola depends on the willingness of communities to enact these measures.

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Supporting information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Figure S1. Optimal CART model for the question 'Do you support controlled burning as a strategy to improve range quality?' Predictor variables are defined at each corresponding branch split.

Figure S2. Optimal CART model for the question 'Do you support manual removal of trees as a strategy to improve range quality?'.

Figure S3. (A) Optimal CART model for the question 'Do you support rotational grazing as a strategy to improve range quality?'. (B) Conditional inference tree depicting the estimated probabilities and statistical significance of a social-demographic predictor for the same question.

Figure S4. (A) Optimal CART model for the question 'Do you support reseeding and fertilization as a strategy to improve range quality?'. (B) Conditional inference tree depicting the estimated probabilities and statistical significance of a sociodemographic predictor for the same question.

Figure S5. Optimal CART model for the question 'Do you support soil ripping as a strategy to improve range quality?'.

Table S1. Response frequencies to questions on range-restoration solutions for improving hirola habitat in Ijara and Fafi subcounties (n = 131 respondents). Rangeland-restoration practices are ordered from least supported (Livestock reduction) to most supported (Elephant conservation).