Journal for Nature Conservation 88 (2025) 127035

Contents lists available at ScienceDirect

Journal for Nature Conservation

journal homepage: www.elsevier.com/locate/jnc

# Socioeconomic predictors of pastoralist tolerance towards large carnivores in northern Tanzania

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ARTICLE INFO

*Keywords:*
Human-carnivore conflict
Human-carnivore coexistence
Tolerance
Human dimensions of wildlife
Attitudes
Human-wildlife interactions
Hazard acceptance model
Risk perceptions

ABSTRACT

Human-carnivore interactions can negatively affect wildlife and people, particularly in pastoral areas where herding communities depend on livestock for livelihood and well-being. The success of large carnivore conservation initiatives in such regions largely hinges on the extent to which people are willing to share landscapes with carnivores. Tolerance for predatory wildlife, and the array of tangible and intangible factors that shape it, is thus of central importance for promoting human-carnivore coexistence. Based on questionnaire surveys ($n$ = 424), this paper identifies socioeconomic predictors of pastoralist tolerance towards two species of large carnivores in the Tarangire ecosystem of northern Tanzania. Informed in part by theory on the Hazard Acceptance Model and Wildlife Tolerance Model, we used mixed effect binomial regression models to assess the effects of perceived monetary costs, conservation importance, hidden impacts on well-being, and attitudes about species on people's tolerance levels for sharing landscapes with leopards (*Panthera pardus*) and spotted hyenas (*Crocuta crocuta*). Pastoralist tolerance for hyenas and leopards was influenced by the magnitude of livestock losses experienced, frequency of carnivore-induced sleep disturbances, individually held attitudes, and the perceived importance of carnivore conservation. Notably, tolerance for hyenas and leopards declined only when perceived impacts rose from moderate to severe levels suggesting that herders are willing to absorb some of the minor costs of coexistence. Based on these findings, we conclude that regional conservation initiatives and wildlife governance institutions should address herder concerns about the risks engendered by large carnivores to ensure that the hazards posed by dangerous wildlife remain lower than people's thresholds of tolerability.

## 1. Introduction

### 1.1. Background to research problem

Interactions between humans and large carnivores represent a pressing global issue with significant implications for wildlife and the well-being of local communities. From a human point of view, large carnivores can threaten safety and livelihoods, particularly those that depend on herding livestock (Raycraft, 2023, 2024a,b). In terms of wildlife population persistence, large carnivores require connected landscapes to thrive, making them vulnerable to habitat loss, economic intensification, and land use change (López-Bao et al., 2017; Wolf and Ripple, 2017). One of the most pressing elements of the human-carnivore interface is that predatory species are often persecuted if they pose direct threats to livestock, pets, or human security, highlighting the need to consider the perspectives of people who share landscapes with carnivores (Kissui, 2008; Bruskotter et al., 2017; Boronyak, Jacobs, and Wallach, 2020).

A holistic framework for understanding human-carnivore interactions is offered by the concept of coexistence, commonly defined as a dynamic, co-adaptive state in which people and wildlife share landscapes in ways that maintain mutually tolerable levels of risk (Carter and Linnell, 2016). This conditional state is shaped by social-ecological context and often underpinned by reciprocal relationality – recognizing the mutual responsiveness and interdependence between people and wildlife in sustaining acceptable levels of risk. The concept of coexistence has gained prominence in both social and conservation sciences as a practical and adaptive approach to framing human-wildlife (and human–human) relationships and is now a central theme in conservation discourse (Krauss et al., 2025; IUCN, 2023; Pooley et al., 2021). Over the past decade, this perspective has led to a paradigm shift in how human-wildlife interactions are conceptualized – placing greater

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https://doi.org/10.1016/j.jnc.2025.127035
Received 27 February 2025; Received in revised form 20 July 2025; Accepted 20 July 2025
Available online 21 July 2025

emphasis on how people who share landscapes with large carnivores perceive and experience these species (Puan and Mah, 2023). This shift has been accompanied by a growing body of literature providing recommendations on how to promote coexistence in practice (Borrini et al., 2013). Understanding the human dimensions of these interactions, including sustainable risk perception thresholds and economic trade-offs, is essential for developing effective coexistence strategies.

People's tolerance for sharing environments with large carnivores is particularly important in this regard and demands attention to the perceived costs and benefits of carnivore conservation for people (Kansky and Kidd, 2024; Martin and Cole Burton, 2022; Dorresteijn et al., 2014). Socioeconomic costs and threats to cultural land-use practices brought about by human-carnivore interactions are especially relevant for place-based societies—such as Maasai pastoralists of East Africa—for whom the ability to carry out traditional livelihood practices on community lands is tightly interwoven with cultural integrity (Bell et al., 2025). Livestock losses are significant for pastoral communities beyond their direct economic consequences for households given the social capital they generate in the context of exchange, rituals, sociality, and food security (Galaty, 1982). These sociocultural outcomes of livestock depredation are consequential in and of themselves from an environmental justice standpoint and also have the potential to undermine the prospects of coexistence by corroding people's tolerance for carnivores (Slagle et al., 2022).

### 1.2. Operationalizing tolerance

In the context of human-wildlife interactions, tolerance refers to the willingness of people to endure the ongoing presence of wildlife despite perceived or realized risks and challenges that wildlife co-occurrence and encounters create (Inskip et al., 2016; Expósito-Granados et al., 2019; Kansky et al., 2021). Carter and Linnell (2016) emphasize that tolerance is not just passive acceptance but rather an active process of co-adaptation that minimizes negative interactions and underpins coexistence. It entails people refraining from taking negative actions such as poaching, retaliatory killings, or habitat destruction to ensure long-term persistence of wildlife populations. Similarly, Bruskotter and Wilson (2014) conceptualize tolerance as a threshold indicating how much impact people are willing to absorb before support for wildlife erodes. Tolerance thus encompasses both reluctant endurance and proactive engagement, enabling humans and wildlife to persist and thrive on shared landscapes.

Definitions of tolerance can comprise both attitudinal dimensions (e.g., fear, aversion, or opposition to a species) and behavioral expressions (e.g., lethal responses or resistance to conservation) (Marchini et al., 2023; Kansky and Kidd, 2024). We maintain that tolerance is more than an attitudinal disposition, but a potential determinant of behaviour (Slagle and Bruskotter,019; Bruskotter and Wilson, 2014). Thus, a semantic distinction we make in the context of our analysis is between "attitudes," which we define as evaluative assessments of a particular species, and "tolerance" as the willingness to accept the presence of wildlife despite perceived risks (Bruskotter and Wilson, 2014). Tolerance exists along a spectrum, wherein varying degrees could be manifest, for instance, in tolerant behaviours like guardianship, stewardship, or adoption of habitat protection strategies, and in intolerant behaviours like retaliatory killing, deliberate antagonism, or resistance to conservation, notwithstanding social and political institutional frameworks of governance. In this manner, tolerance is foundational to coexistence because it holds potential to affect real-world decisions in ways that abstract opinions may not. Even when views towards carnivores are negative, high tolerance—owing to core beliefs or minimal perceived costs—can still lead to non-lethal responses and proactive coexistence. In practical and holistic terms, tolerance involves recognizing the ecological and social value of wildlife, adopting strategies to reduce negative interactions, and fostering supportive attitudes towards wildlife protection initiatives. This framing is essential for developing effective conservation strategies that promote wildlife population persistence and safeguard human well-being. We elaborate on our conceptualization of tolerance in Section 2.3.

### 1.3. Theoretical approach

Despite its widespread use, the phrase "human-wildlife conflict" often lacks the nuance and precision needed to represent the complexities of human–carnivore interactions and their influence on tolerance (IUCN, 2023; Peterson et al., 2010). Through their behavioral traits and ecologies, large carnivores sometimes pose threats to human well-being (Nyhus, 2016). Such risks can be interpreted as hazards and analyzed in the context of people's interpretations of the benefits and risks associated with their interactions with wildlife (Slagle et al., 2022; Ascher et al., 2012; Slagle and Bruskotter, 2019; Kansky et al., 2016). Though direct material consequences of such interactions are indeed consequential, it is people's perceptions of risks and benefits associated with these encounters that ultimately shape the extent to which they are willing to accept the presence of hazards posed by predatory wildlife. Generally speaking, higher perceptions of risk tend to predict lower levels of acceptance (Zajac et al., 2012), while increased perceptions of benefits tend to correlate with higher levels of acceptance of wildlife (Carter et al., 2012). Such dynamics are often referred to in studies of wildlife tolerance as the Hazard Acceptance Model.

Couched within the Hazard Acceptance Model is a particular theoretical framing forwarded by Kansky et al. (2016, 2021) called the Wildlife Tolerance Model that evaluates the predictive effect of a series of tangible and intangible perceived costs and benefits of wildlife on people's levels of tolerance. Though once assumed to be a straightforward converse relationship (i.e. as perceived benefits rise, so does acceptance and vice versa for perceived risks), recent scholarship by Kansky and Kidd (2024) and others suggests that an array of other human factors may bear on people's experiences of tolerance.

Recent quantitative studies have explored associations between people's attitudes (defined here as "evaluative judgements" following Kansky and Kidd, 2024) and tolerance towards carnivores and a range of socioeconomic and ecological variables (Gebo, Takele, and Shibru, 2022). Local attitudes have been shown to be influenced by the frequency of carnivore attacks (Janeiro-Otero et al., 2023), demographic factors such as age, gender, and education (Ostermann-Miyashita et al., 2023; Koziarski, Kissui, and Kiffner, 2016; Gebo, Takele, and Shibru, 2022), years of residence in "conflict" areas, and knowledge about carnivores (Mkonyi et al., 2017c). For instance, many Indigenous cultures around the world incorporate guiding principles of environmental stewardship and reciprocal relationships with land, water, and non-human beings, which shape their approaches to ecosystem interactions and management (Teixidor-Toneu et al., 2025). Among the Maasai, cultural beliefs, values, and practices shape environmental stewardship and relationality with wildlife, including large carnivores, through customary livestock grazing systems, coexistence strategies, and an ontology that recognizes predators as integral to the landscape (Dheer et al., 2021; Goldman et al., 2010). Attitudes are also likely shaped by how carnivore ecology is communicated at the community-level, either formally through the media or informally through social networks (Arbieu et al., 2021).

In the context of tolerance more precisely, conventional academic wisdom is that tangible economic costs corrode tolerance for carnivores, though some research complicates this perspective (Dickman, 2010; Kansky et al., 2016, Kansky et al., 2021). Recent studies suggest that the perceived costs of carnivores may be overemphasized in the literature in terms of their causal effects on attitudes and tolerance in relation to other contributors (Jacobsen et al., 2021; Inskip et al., 2016; Merz et al., 2023). Of particular significance here, Kansky and Kidd (2024) found that monetary costs of carnivores may only be of indirect importance when contextualized in relation to the intangible costs and benefits of wildlife. Intangible social factors like environmental values and feelings

of empathy seem to play a significant role (Kansky and Kidd 2024; Jacobsen et al., 2021; Lagendijk and Gusset 2008), as do cultural beliefs (information considered true by groups of people) (Ghosal and Kjosavik 2015), attitudes towards species (Bruskotter and Wilson 2014; Slagle and Bruskotter 2019), awareness of carnivore population trends, perceptions of risk (Inskip et al., 2016), and perceptions of wildlife governance institutions (Merz et al., 2023).

In contribution to this discourse, this paper assesses socioeconomic predictors of people's tolerance for large carnivores in the Tarangire ecosystem of northern Tanzania. We use an analytical approach derived in part from Kansky et al.'s (2016, 2021) Wildlife Tolerance Model to assess the effects of perceived tangible monetary costs, intangible effects on human well-being, intangible conservation benefits, and intangible attitudes on people's tolerance towards spotted hyenas (*Crocuta crocuta*) and leopards (*Panthera pardus*), two large carnivore species frequently involved in negative interactions with local people in northern Tanzania. We discuss our findings in the context of theoretical literature on tolerance towards wildlife and conclude by offering management recommendations for the benefit of local communities and regional conservation efforts.

## 2. Methods

### 2.1. Study area

Field research was carried out in the Tarangire ecosystem of northern Tanzania (Fig. 1). The Tarangire ecosystem is a semi-arid landscape that supports a diversity of wildlife, including numerous species of large mammals (Vallin et al., 2025). Though the landscape spans about 25,000 km$^2$, only a small portion of this total area is circumscribed by Tarangire National Park in the central part of the ecosystem (Kiffner et al., 2022a). The park provides dry season habitat for wildlife, but since its boundary is unfenced, large mammals disperse outside the park into neighbouring village communities seasonally to access nutrient-rich areas outside the park (Bond et al., 2022; Raycraft et al., 2024). During the dry season, they return to the park to access forage and permanent water sources like the Tarangire River (Lohay et al., 2022). Rainfall in the Tarangire ecosystem follows a bimodal pattern with most concentrated between November to January and March to May with an annual mean of around 656 mm (Foley and Faust, 2010). Lowland areas receive as little as 250 mm, while certain mountain forests receive up to 850 mm on average per year (Prins and Loth, 1988). The ecosystem supports numerous large (>15 kg body mass) carnivore and mesocarnivore species including black-backed jackal (*Lupulella mesomelas*), African wild dog (*Lycaon pictus*), cheetah (*Acinonyx jubatus*), leopard (*Panthera pardus*), striped hyena (*Hyaena hyaena*), spotted hyena (*Crocuta crocuta*), and lion (*Panthera leo*) (Kiffner et al., 2022b). Based on previous ethnographic research with local livestock herders, we decided to focus our human-carnivore interaction analysis on tolerance towards leopards and spotted hyenas due to reports of frequent negative interactions with these species. Hyenas, in particular, kill the most livestock of any carnivore species in the Tarangire ecosystem (Kissui et al., 2022; Raycraft, 2024a; Raycraft, 2024b; Mkonyi et al., 2017a).

The five study villages—Oldonyo, Lolkisale, Nafco, Lengoolwa, and Lemooti—were selected since they surround Lolkisale mountain where local herders reported regular interactions with hyenas and leopards (Raycraft, 2024a; Raycraft, 2024b). Lolkisale mountain is part of village land and is used primarily for dry season livestock grazing, though parts of the forested area have been designated as a village land forest reserve (Mwakalukwa et al., 2023). The five villages are members of Randilen Wildlife Management Area, a community-based conservation model in Tanzania that involves demarcating some parts of village land as reserved areas for wildlife conservation and tourism, and certain areas for local land use practices necessary for subsistence livelihoods (Fig. 1).

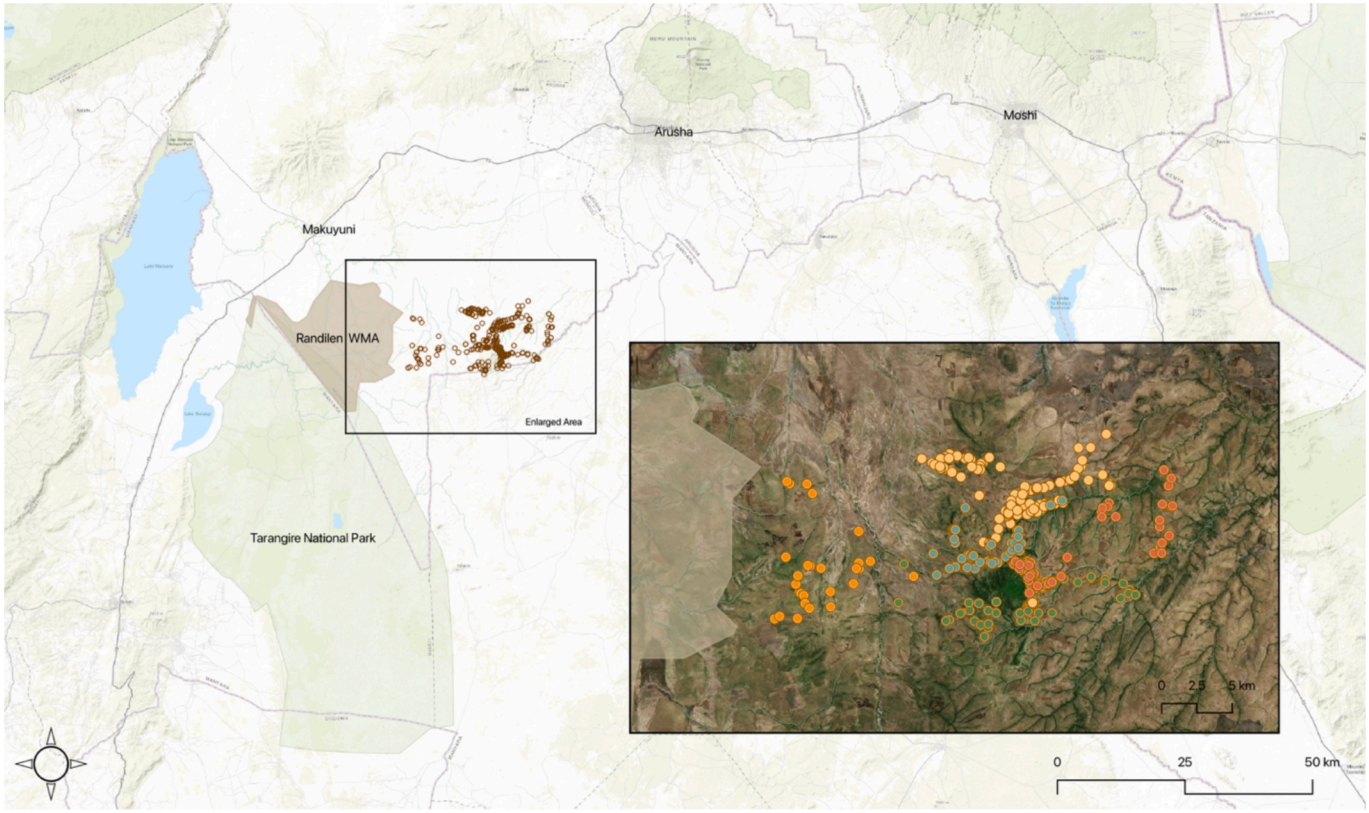


**Fig. 1.** Map of study area in the Tarangire ecosystem of northern Tanzania. The reserved area of Randilen Wildlife Management Area (RWMA) (beige polygon, left side of inlay) lies west of the homesteads (coloured circles) where questionnaire surveys were administered in 2020 ($n$ = 424) across five RWMA member villages: Lemooti (orange), Lengoolwa (pale blue), Lolkisale (pink), Nafco (yellow), and Oldonyo (green). Satellite and basemap source: ESRI.

A portion of safari tourism revenue is shared with WMA member villages and community members are permitted to cultivate crops within their villages and graze livestock seasonally inside the WMA in accordance with a multiple use zoning scheme (Raycraft, 2022b, 2025).

The study villages are primarily inhabited by Kisongo Maasai pastoralists and Arusha Maasai agropastoralists (Raycraft, 2022a). The Kisongo Maasai are herders who maintain a pastoral mode of production through customary range management institutions including rotational livestock grazing, an age-set system, section-and-clan-based forms of territoriality, and ethnic reciprocity. The Kisongo keep cattle, goats and sheep and likely moved into the study area around 200 years ago. Over the past forty years, they have diversified their livelihoods to include wage labour and cultivation of maize and beans, though they still consider themselves Maasai pastoralists (Homewood et al., 2009; McCabe et al., 2014; Sachedina and Trench, 2009; Trench et al., 2009). The Arusha share a common language with the Kisongo (*Maa*) and the same age-set system but settled the area in the 1950s–1960s after expanding westward from the fertile slopes of Mount Meru (Bluwstein, 2017; Igoe, 2010). They practice a combination of crop cultivation and animal husbandry (cattle, goats and sheep), but lean more heavily towards sedentarized agriculture than the Kisongo. Both groups could be considered agropastoralists in this ethnographic context, and their families are drawn together through patterns of intermarriage, clan affiliations, and friendship.

### 2.2. Data collection

Ethical reviews for the conduct of research with human subjects were provided by McGill University (479–0419) and the University of Alberta (Pro00130079). Permits for carrying out research in Tanzania were provided by the Tanzania Commission for Science and Technology (2019-426-NA-2019-299) and the Tanzania Wildlife Research Institute (CST00000398-2024-2024-00240). Informed consent was obtained prior to conducting the research and the privacy rights of research subjects were maintained throughout the research process in accordance with ethical protocols. A questionnaire survey was designed, pre-tested, and administered halfway through a year of ethnographic fieldwork (2019–2020) in collaboration with local livestock herders. Questions were close-ended and included demographic questions followed by a series of Likert-like questions about attitudes and tolerance towards each carnivore species (Table 1). To sample households, we used stratified random sampling. We numbered male-headed ($n$ = 1366) and female-headed ($n$ = 245) households across the five villages and used a random number generator to randomly select proportionately weighted samples from each sub-village. Proportionate weightings from each sub-village stratum were not exact but were fairly representative of differences in population sizes across the study villages. In total, we sampled 220 male household heads and 134 female household heads. To compensate for gender discrepancy due to higher numbers of male-headed households in this cultural context, we additionally surveyed the senior wife of every second male-headed household until the sample was reasonably gender balanced ($n$ = 70). While our approach resulted in an overrepresentation of the sampled number of female-headed households as compared to the ratio of sampled male-headed households, our objective with this study was not to provide a descriptive overview of the study population but to assess the effects of socioeconomic factors on people's levels of tolerance. We thus considered it important for our total sample to be reasonably gender balanced. Our total sample size was 424 people. Table S1 (Supplementary Information) displays the socioeconomic demographics of the sampled population.

### 2.3. Hypothesized predictors of tolerance

A collection of social, economic, and political factors have been shown to influence tolerance for wildlife (Expósito-Granados et al., 2019; Inskip et al., 2016; Kansky et al., 2021). Drawing from Kansky et al. (2016), Kansky et al. (2021), Kansky and Kidd (2024) and Usman et al. (2023), and knowledge of the local social-ecological context, we focused our analysis on the predictive effects of both tangible and intangible costs and benefits of leopards and hyenas on people's tolerance for sharing landscapes with each species. We assessed tangible costs, quantified here in terms of perceived economic impacts of carnivore predation on livestock production. Notably, livestock losses are tangible measures of costs but also carry great intangible cultural significance in Maasai society for the social capital they generate for exchange, reputation, and accessibility of ritual participation. Thus, our framework of variables does not fit neatly into a tangible/intangible binary. Based on participant observation and emplaced ethnographic fieldwork in the study villages, which involved staying in people's homesteads for months prior to questionnaire design, we observed significant carnivore-induced disruptions to people's sleep patterns. We sought to quantify the impact that these sleep disturbances had on people's tolerance, a variable that could be framed following Kansky et al.'s (2016, 2021) Wildlife Tolerance Model as an intangible cost of carnivores, or following the conceptualization of Barua et al. (2013) and Mayberry et al. (2017) as a "hidden" cost of wildlife on human well-being. Similarly to livestock losses, disturbed sleep is difficult to classify through an intangible/tangible binary, as sleep reductions in turn affect daytime livelihood activities with economic bearing on people's material well-being, suggesting that they could also be conceptualized as a tangible cost.

In the same fashion as documented by Usman et al. (2023), preliminary interviews and pilot assessments of the questionnaire revealed that people did not perceive tangible benefits from either leopards or hyenas. As such, we decided to focus on the intangible benefits of each species in terms of their perceived conservation importance. We further

**Table 1**
Surrogate definitions, survey questions, original response options, and bucketed variable categories for social predictive factors used in mixed effect binomial regression models for assessing predictors of tolerance. Reference levels of categorical predictors, against which other levels are compared, are marked with an asterisk.

| Variable Surrogate Definition | Survey Question | Survey Response Options | Bucketed Variable Answers |
|---|---|---|---|
| Tolerance *(response variable) | Are you happy living with hyenas/leopards? | 1 = I am happy living with hyenas/leopards; 2 = I am okay living with hyenas/leopards if they do not disturb me or my livestock; 3 = I want hyenas/leopards eradicated | tolerant (1 and 2), intolerant (3) |
| Perceived conservation benefit (intangible) | Do you think conservation of hyenas/leopards is important? | 1 = yes, 2 = no | yes*, no |
| Attitude towards species (intangible) | Do you like hyenas/leopards? | 1 = strongly like; 2 = like a little; 3 = neutral; 4 = dislike a little; 5 = strongly dislike | like (1 and 2), neutral (3)*, dislike (4 and 5) |
| Perceived magnitude of economic losses (tangible) | Perceived impact of hyenas/leopards on livestock production (past 12 months) | 1 = no problem; 2 = small problem; 3 = medium-sized problem; 4 = big problem | low-moderate (1–3)*, high (4) |
| Perceived impacts on well-being (intangible) | How much do hyenas/leopards affect your sleep at night? | 1 = none; 2 = they sometimes disturb my sleep; 3 = they often disturb my sleep; 4 = they always prevent me from sleeping | none (1), sometimes (2 and 3)*, always (3) |

wanted to explore relationships between people's attitudes towards each species—ranging from loathing (strongly dislike; *Siwapendi kabisa*) to adoration (Strongly like; *nawapenda kabisa*)—and their tolerance for sharing landscapes with them.

In sum, we focused on (1) tangible (and intangible) monetary costs, measured in terms of perceived magnitude of carnivore predation influence on livestock production (2) intangible (and tangible) hidden effects on human well-being, quantified in terms of reported sleep disturbances caused by each species, (3) intangible benefits in the form of perceived conservation importance of the species, and (4) intangible dispositions as manifest in people's attitudes towards each species (Table 1).

Although our survey included several questions that relate to our definition of tolerance—such as, "do you think there are too many leopards/hyenas?"—which speaks to tolerable or intolerable assessments of carnivore population demographics, we chose a single direct metric for defining tolerance: "are you happy living with leopards/hyenas?" Among our predictor variables, people's attitudes—which reflect the culmination of societal and individual influences, such as socio-economic structures, social norms, and lived experiences—were represented as a general affinity for leopards/hyenas by the question, "do you like leopards/hyenas?" and were included as a singular predictor in the tolerance models. Questions were designed either based on 3 to 5-point Likert-adapted ordinal scales or as binary categorical responses (Table 1).

Importantly, tolerance is not a binary state but exists along a dynamic continuum of willingness to coexist, ranging from total acceptance to an active desire for carnivore eradication. As with all subjective social measures, tolerance is difficult to quantify without reducing complexity and defaulting to reductionism. Psychosocial phenomena should not be uncritically reduced to a binary form of representation without recognition of the dynamics within which they are situated. While we acknowledge that tolerance is a fine-grained spectrum that must be contextualized in terms of nuanced and complex psychosocial realities that challenge rigid categorization, our survey instrument used an ordinal scale to classify people's views as (1) completely tolerant, (2) conditionally tolerant, and (3) completely intolerant (Table 1). Complete tolerance was defined as instances where people were fully content with the state of their interactions with carnivores and were willing to share landscapes with them without any changes to the current situation. This was written as "I am happy living with hyenas/leopards" on the survey instrument and was contextualized in greater depth orally during administration. Conditional tolerance was contingent on reductions in perceived risks to people's livelihoods, safety, and well-being ("I am happy living with hyenas/leopards if they do not disturb me or my livestock"). Complete intolerance was signaled by a total unwillingness to share landscapes with carnivores and a desire for local eradication ("I want all hyenas/leopards eradicated"). Though we recognize that tolerance is a complex continuum that is not wholly represented by our typology, we maintain that these thresholds likely have direct bearing on the prospects of human-wildlife coexistence.

### 2.4. Data analysis

During descriptive analysis, we observed that an extremely low number of respondents (<1%) expressed complete tolerance for leopards or hyenas (Fig. 3), which limited the suitability of ordinal models due to distributional imbalance. As such, we grouped complete and conditional tolerance into a single category (Table 1). While this reclassification approach reduced a psychosocial gradient to a binary representation, we argue it was warranted both statistically and conceptually—given our central interest in distinguishing between a willingness to share landscapes with carnivores and a desire for local extirpation—and aligned with our core interest in understanding the underlying state of coexistence from a human standpoint.

We subsequently modelled the relative strength of social variables in predicting human tolerance for hyenas and leopards using a set of mixed effect binomial regression models. We investigated whether attitudes towards each species, perceived conservation benefits, perceived economic losses or impacts on personal well-being (i.e. sleep disturbance) influenced the likelihood that participants found sharing landscapes with leopards and hyenas to be tolerable. In order to control for the degrees of freedom given to our models, we also grouped some other survey responses into broader categories (Table 1). For instance, we reclassified the perceived economic impact variable into a binary format to address wide confidence intervals resulting from low intolerance case representation in lower severity categories. This binary transformation reclassification improved model interpretability and statistical robustness. While this strategy loses some information and nuance within complex social dimensions, we strategically bucketed answers in a manner that holds practical significance and that amalgamated options that had an extremely low number of responses.

To assess the factors influencing tolerance towards hyenas and leopards, we fitted generalized linear mixed models using the glmer() function from the lme4 package in R. A random intercept for Village was included to account for unobserved contextual effects like potential spatial clustering of responses within geographic locations. The models used a binomial distribution with a logit link function (i.e. mixed effect binomial regression models). Collinearity diagnostics indicated no problematic multicollinearity among predictors in either model (all GVIFs $< 2$; all pairwise correlations $r < 0.7$), supporting the retention of all variables (see Supplementary Tables S2 and S3). In our results section, we present Beta (β) coefficients, which represent the change in log-odds of the outcome—in this case, moving from tolerant to intolerant—for each unit increase in a given predictor variable. When exponentiated, β yields the odds ratio (OR), which quantifies 'effect size' by indicating how the odds of intolerance change across predictor levels. In practical terms, it speaks to how likely individuals within a predictor grouping are to express intolerance towards hyenas or leopards—in other words, how the odds of the outcome change across levels. Odds ratios intuitively convey the magnitude and direction of predictor effects. For example, an OR of 3 indicates the odds of intolerance are three times higher, while an OR of 0.25 means they are four times lower.

Candidate models were constructed and evaluated using the MuMIn package in R (version 4.4.1) to assess the relative strength of alternative predictor subsets in explaining tolerance towards large carnivores in the Tarangire ecosystem (Table 2). Our candidate models included one that exclusively examined personal impacts of carnivores (economic and personal well-being), one that looked exclusively at attitudes (i.e., conservation perspectives and personal attitudes) and a combined model that incorporated both sets of causal factors. The best performing models were identified using Akaike's Information Criterion (AICc) score (lowest score was associated with the best model fit) and normalized AICc weights.

## 3. Results

### 3.1. Tolerance levels across study area

People's tolerance towards hyenas and leopards varied across the study villages. The variance of the village-level random intercepts was 0.819 (SD = 0.905) in the hyena model, indicating moderate between-

**Table 2**
Predictor variables for each candidate model.

| Candidate model | Predictor variables |
|---|---|
| Model 1 (m1) | Perceived Conservation Benefits + Attitudes + Economic + Well-being |
| Model 2 (m2) | Economic + Well-being |
| Model 3 (m3) | Conservation Benefits + Attitudes |

village variation in baseline tolerance. In contrast, the variance in the leopard model was 0.000 (SD = 0.000), suggesting negligible village-to-village heterogeneity after accounting for fixed effects. While the variance of village-level random intercepts in the leopard model was very minimal ($\sigma = 0.00076$), we retained the random effect because our data is nested by village and its inclusion accounts for potential non-independence among respondents. This outcome further supports that most between-village differences were captured by fixed effects and aligns the modeling structure with that used in the hyena model, supporting a consistent comparative framework. Descriptive overviews of people's reported tolerance levels by species and study village are displayed in Figs. 2 and 3.

### 3.2. Model selection for predictors of tolerance

For both carnivore species, the models that best explained variability in the data were those which contained both subsets of predictive variables indicating that a combination of factors related to perceived economic impacts, intangible conservation benefits, intangible effects on well-being, and attitudes towards species contributed to whether or not people were tolerant of hyenas and leopards in the Tarangire ecosystem (Tables 2–4).

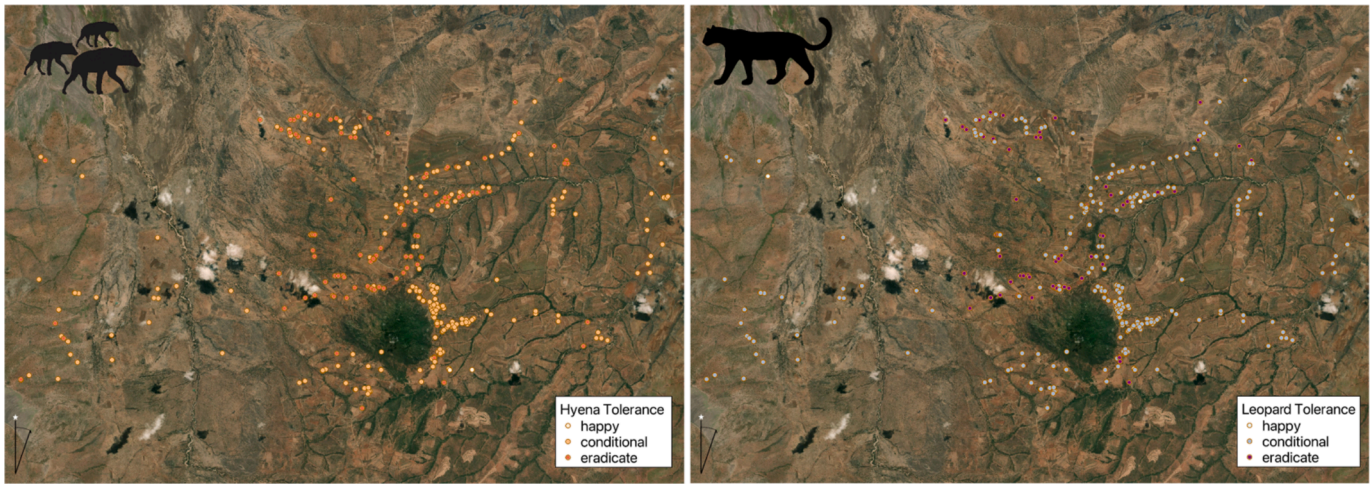


**Fig. 2.** Spatial representation of participant responses to the question, "Are you happy living with hyenas/leopards?" Responses were categorized as follows: (1) "happy" = I am happy living with hyenas/leopards without any changes to the current situation [i.e. complete tolerance], (2) "conditional" = I am okay living with hyenas/leopards as long as they do not disturb me or my livestock [i.e. conditional tolerance], and (3) "eradicate" = I want hyenas/leopards eradicated [i.e. complete intolerance]. The distribution of responses reflects varying levels of tolerance towards large carnivores across Randilen Wildlife Management Area member villages. Satellite and basemap source: ESRI.

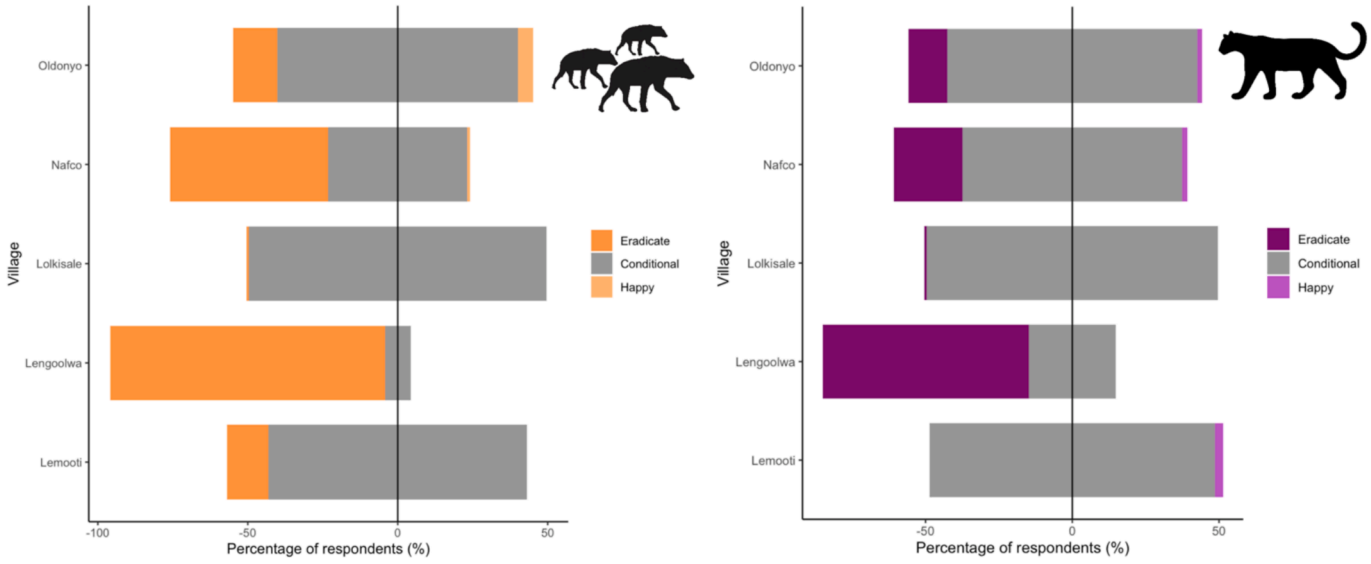


**Fig. 3.** Comparison of survey results on tolerance disaggregated by species and study village. Surveys were administered in 2020 across five member villages of Randilen Wildlife Management Area. Bars represent proportions of responses ($n = 424$). Happy = "I am happy living with hyenas/leopards without any changes to the current situation" [ i.e. complete tolerance]; Okay = "I am okay living with hyenas/leopards if they do not disturb me or my livestock" [i.e. conditional tolerance]; Eradicate = "I want all hyenas/leopards eradicated" [ i.e. complete intolerance].

**Table 3**
AICc model comparison results for hyena tolerance mixed effect binomial regression model.

| Hyena Tolerance Candidate Model | Intercept | df | log likelihood | AICc | delta | weight |
|---|---|---|---|---|---|---|
| Hyena Model 1 (hm1) | −4.01 | 8 | −138.09 | 292.53 | 0.00 | 1 |
| Hyena Model 3 (hm3) | −2.82 | 5 | −149.35 | 308.85 | 16.32 | 0 |
| Hyena Model 2 (hm2) | −2.09 | 5 | −150.65 | 311.44 | 18.91 | 0 |

**Table 4**
AICc model comparison results for leopard tolerance mixed effect binomial regression model.

| Leopard Tolerance Candidate Model | Intercept | df | log likelihood | AICc | delta | weight |
|---|---|---|---|---|---|---|
| Leopard Model 1 (lm1) | −6.85 | 8 | −99.32 | 214.99 | 0.00 | 1 |
| Leopard Model 3 (lm3) | −4.52 | 5 | −133.96 | 278.06 | 63.07 | 0 |
| Leopard Model 2 (lm2) | −3.23 | 5 | −135.56 | 281.27 | 66.28 | 0 |

### 3.3. General trends

Marginal effects on the probability scale, derived from mixed effect binomial regression models, are displayed in Fig. 4. Odds ratios are shown in Fig. 5. In general, for both hyenas and leopards, people who did not view conservation as beneficial were more likely to express intolerance (Fig. 4a and e). Measures of pastoralist attitudes revealed that disliking hyenas and leopards sharply increased predicted intolerance consistently across both models (Fig. 4c and g). Perceptions of costs—comparing those who reported low to moderate impacts versus those who perceived high levels of livestock losses from hyenas/leopards—also correlated with people's reported tolerance level. Higher economic loss perceptions were associated with greater predicted intolerance in both cases, with narrow confidence intervals suggesting strong predictive confidence (Fig. 4b and f). In terms of personal intangible effects on well-being (i.e. sleep deprivation), individuals whose sleep was continuously disrupted by hyenas or leopards on a daily basis showed the highest probabilities of intolerance across all metrics examined herein (Fig. 4d and h).

### 3.4. Tolerance towards hyenas

In the case of hyenas, those who did not perceive hyena conservation as beneficial were approximately five times more likely to be intolerant of hyenas and express the opinion that they would like to see hyenas eradicated, compared to those who saw conservation value (Table 5; Fig. 4). Regarding attitudes, there was no indication that individuals who had neutral opinions and those who liked hyenas differed in their tolerance, however, people who disliked hyenas were more than three times more likely to be intolerant relative to those who held neutral attitudes (Table 5; Fig. 5).

Those who perceived hyenas to have a high impact on livestock production were more than twice as likely to express intolerance as compared to those who perceived moderate or less impact. Respondents who reported always losing daily sleep due to hyenas were more than five times as likely (OR = 5.76) to express intolerance towards hyenas,

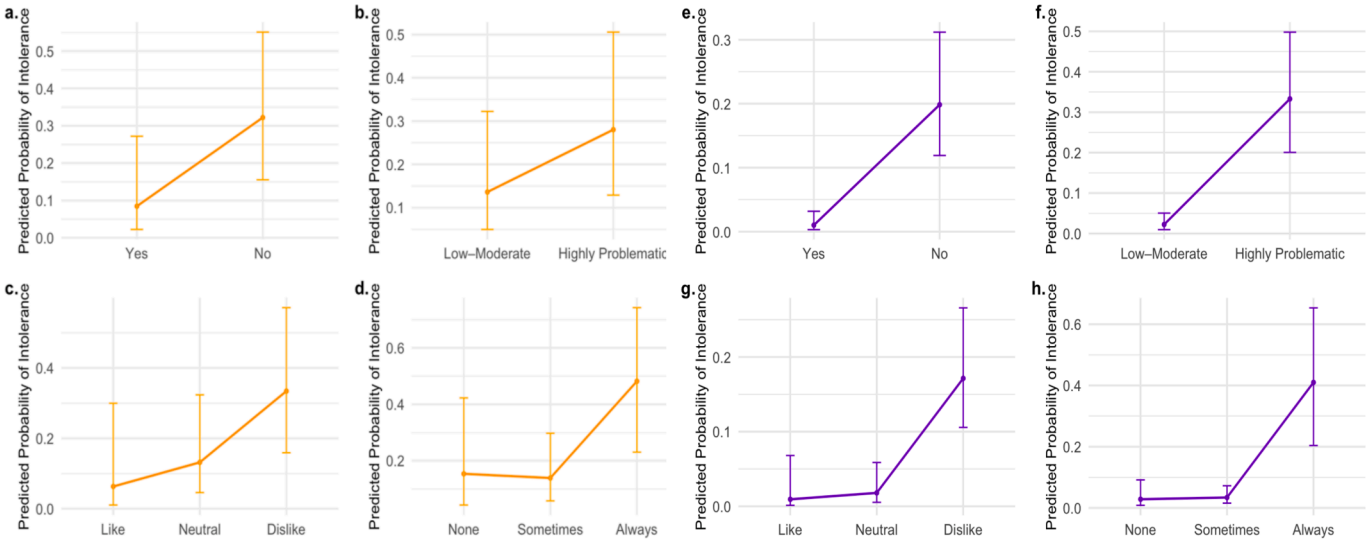


**Fig. 4.** Predicted probabilities of intolerance towards hyena (left orange; a-d) and leopard (right violet; e-h) at each level of categorical predictor, holding other variables constant. Results were derived from mixed effect binomial regression models. Error bars represent 95% confidence intervals. For hyenas, individuals who did not perceive conservation benefits (a), reported highly problematic economic losses (b), expressed dislike for the species (c), or experienced consistent sleep disruption (d) were significantly more likely to exhibit intolerance. For leopards, directionality mirrored hyena model trends. Intolerance was elevated among respondents who did not perceive conservation value (e), faced highly problematic losses (f), disliked leopards (g), or experienced frequent sleep disruptions (h).

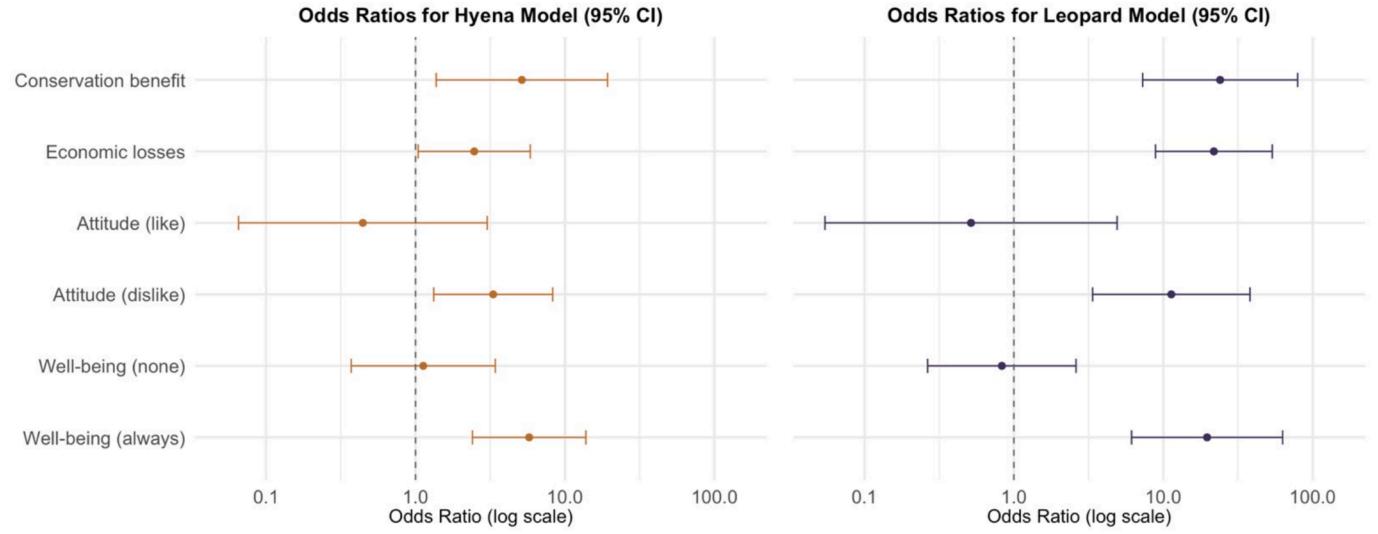


**Fig. 5.** Odds ratios with 95% confidence intervals for predictors of human tolerance towards hyenas (orange) and leopards (navy) based on mixed effect binomial regression models. Odds ratios greater than one indicate increased odds of intolerance associated with the predictor, while values less than one indicate decreased odds. Predictors included perceived conservation benefit, economic losses (from livestock depredation), attitudes, and reported sleep disturbance (i.e. hidden impact on well-being).

**Table 5**
Results of best fit model for human tolerance towards hyenas in five RWMA member villages within the Tarangire ecosystem.

| Coefficients (hm1) | ß (estimate) | exp(ß) | SE | p-value |
|---|---|---|---|---|
| Intercept | −4.01 | 0.02 | 0.87 | <0.01* |
| Conservation (no) | 1.64 | 5.14 | 0.67 | 0.02* |
| Problem level (big) | 0.90 | 2.47 | 0.44 | 0.04* |
| Attitudes (like) | −0.81 | 0.44 | 0.98 | 0.41 |
| Attitudes (dislike) | 1.20 | 3.31 | 0.47 | 0.01* |
| Sleep Impacts (none) | 0.12 | 1.13 | 0.57 | 0.83 |
| Sleep Impacts (always) | 1.75 | 5.76 | 0.45 | <0.01* |

compared to those who experienced sleep disturbances only sometimes or often. Interestingly, those who reported no sleep impacts did not significantly differ in their likelihood of expressing intolerance relative to the reference group ($p = 0.83$; Table 5).

### 3.5. Tolerance towards leopards

Leopard model results mirrored those of hyenas in terms of significant predictors but differed somewhat in the magnitude of effect sizes. Individuals who did not consider leopard conservation important were 24 times more likely to want to see the species eradicated from the region ($p < 0.01$; Table 6). In terms of attitudes, respondents who disliked leopards were significantly more likely to be intolerant, with odds more than 11 times higher than those with neutral attitudes ($OR = 11.31$, $p < 0.01$; Table 6), while those who liked or felt neutral towards them showed similar degrees of tolerance (Table 6; Fig. 5).

**Table 6**
Results of best fit model for human tolerance towards leopards in five RWMA member villages within the Tarangire ecosystem.

| Coefficients (lm1) | ß (estimate) | exp(ß) | SE | p-value |
|---|---|---|---|---|
| Intercept | −6.85 | 0.00 | 0.89 | <0.01* |
| Conservation (no) | 3.18 | 24.00 | 0.61 | <0.01* |
| Problem level (big) | 3.08 | 21.79 | 0.46 | <0.01* |
| Attitudes (like) | −0.66 | 0.52 | 1.15 | 0.57 |
| Attitudes (dislike) | 2.43 | 11.31 | 0.62 | <0.01* |
| Sleep Impacts (none) | −0.19 | 0.83 | 0.58 | 0.75 |
| Sleep Impacts (always) | 2.98 | 19.63 | 0.60 | <0.01* |

When perceived impacts of leopards on livestock production increased from moderate to severe, intolerance rose sharply with a large effect size ($OR = 21.79$; Table 6). Individuals who reported moderate or less livestock production impact from leopards had a low predicted probability of intolerance (less than 5 %), while those who perceived leopards as highly problematic in this regard showed a predicted intolerance probability of approximately 35 %, holding other variables constant. Regarding well-being, sleep-related impacts showed a notable pattern: respondents who always lost daily sleep due to leopards were nearly 20 times more likely to be intolerant ($\exp(\beta) = 19.63$, $p < 0.01$). Conversely, those who experienced no sleep impacts did not differ significantly in their tolerance levels compared to those with moderate sleep disturbances ($p = 0.75$) (Fig. 5).

## 4. Discussion

### 4.1. Tolerance, coexistence, and carnivore conservation

Our approach, drawing on social science data, suggests opportunities for long-term resource sharing between humans and large carnivores in the Tarangire ecosystem of northern Tanzania. The major factors that affected people's tolerance for carnivores were the social and economic costs of livestock depredation and the impacts of carnivores on human well-being in the form of reduced sleep quality. We repeatedly observed that moderate impacts—such as occasional sleep disruption or neutral attitudes—were generally associated with tolerance, with baseline measures similar to low impact levels. However, trends of increased intolerance emerged when impacts escalated to their highest levels (e.g., persistent sleep disruption or strong dislike), suggesting that tolerance may hold until a perceived threshold of severity is crossed at the household level (Tables 5 and 6).

Unsurprisingly, those who experienced major livestock predation by large carnivores over the past year were much less tolerant than those with only moderate or minor losses. This result aligns with other recent studies, like Kichloo et al. (2024), who reported that frequent livestock predation by leopards in the Indian Himalayas led to negative perceptions and attitudes due to the economic losses incurred. Notably, in our study, tolerance for hyenas and leopards declined only when perceived costs escalated from moderate to severe (problem levels), with intolerance linked to the highest recorded economic losses from livestock predation in the past 12 months. Tolerance levels did not decline when

livestock predation rose from none to minor or minor to moderate, suggesting that preventative measures that protect against major livestock losses could make a considerable impact in helping maintain herder tolerance for large carnivores. A key interpretation of these findings is that pastoralists in the Tarangire ecosystem seem willing to tolerate moderate levels of risk, which is particularly noteworthy in the context of coexistence. This suggests that herders are willing to absorb some of the minor costs of sharing landscapes with carnivores, provided that governance institutions and formal policies help ensure that the hazards posed by large carnivores remain below people's threshold of tolerability. Thus, it is crucial that wildlife governance institutions help reduce major risks, bearing in mind the willingness of herders to accept minor to moderate ones.

The effect size between those with moderate and major livestock losses—a 22-fold decrease in tolerance in the case of leopards—was striking. This finding is especially consequential considering the high levels of livestock depredation across the study villages (Raycraft, 2024b; Kissui et al., 2022). Notably, in northern Tanzania, even when the majority of livestock predation events are perpetrated by spotted hyenas, retaliatory human actions often target lions and other species of higher conservation concern (Kissui et al., 2019; Nicholson et al., 2024). Thus, leopards—with an IUCN status of vulnerable and decreasing (Stein et al., 2024)—may be especially vulnerable to retaliation in the Tarangire ecosystem owing to their own impacts in conjunction with peripheral negative attitudes perpetuated by hyena predation.

These findings clearly point to the importance of reducing the direct economic costs of large carnivores on the local livestock economy as a crucial point of intervention to promote coexistence in this social-ecological context. Community members are economically dependent on their livestock and consider them culturally integral for their well-being and way of life. Conservation outreach initiatives that focus only on educating local herders about the environmental benefits of carnivores—specifically to improve negative attitudes, which were also found here to be a predictor of tolerance—will likely have limited success if the direct costs to people's livelihoods (inclusive of cultural implications of livestock deaths) are not concurrently addressed. Qualitative insights from community members reveal that they consider livestock depredation to be the most significant factor that currently undermines human-carnivore coexistence and this ought to be noted alongside our quantitative findings as well. Importantly, herder experiences of carnivore attacks do not exist in a vacuum and converge with other stressors that bear on their everyday lives including the regular threats of droughts and livestock disease (cf. Kissui, 2008). Thus, the hazards posed by carnivores in this social-ecological context compound existing environmental stressors and increase people's perceptions of risk.

Relatedly, the strong relationship between the effects of carnivores on people's sleep quality and their tolerance for sharing landscapes shows the importance of reducing the "hidden" impacts of carnivores on people's well-being (Barua et al., 2013; Mayberry et al., 2017). Sleep deprivation resulting from human-wildlife interactions can cause tremendous peripheral damage to individual and societal well-being, manifesting in the forms of exhaustion and inability to productively complete daytime tasks, loss of income potential, and, for children, decreasing school attendance and academic performance (Frank et al., 2019; King, 2010). Thus, sleep quality may exacerbate economic losses, which are already highly influential in dictating tolerance. Conservation initiatives aimed at improving homestead fencing may serve to reduce livestock predation and the impacts of carnivores on human well-being, simultaneously amplifying increases in tolerance and associatively fostering coexistence. This recommendation aligns with existing studies that found notable reductions in livestock predation by large carnivores through the provision of fortified homestead fencing (Grau et al., 2025; Mkonyi et al., 2017b; Kissui et al., 2019; Lichtenfeld et al., 2015; Sutton et al., 2017; Wakoli et al., 2023). Recent research also suggests that fortified perimeter fencing may deter hyenas and leopards from visiting homesteads in the Tarangire ecosystem (Bell and Raycraft, 2025). Several applied research measures (e.g. fencing subsidies from the Tarangire Lion Project) and civil society initiatives (e.g. "living fences" by Tanzania People and Wildlife) have made considerable headway in this regard and have shown great promise. Thus far, however, such contributions are unevenly distributed geographically due to economic constraints and more assistance to households is needed in the study villages described here.

Notably, people who experienced no sleep impacts from leopards and hyenas did not significantly differ in their tolerance levels from those who reported moderate impacts. However, predicated intolerance probabilities were approximately 45 % and 40 % for hyenas and leopards respectively for those who described daily sleep disturbances as occurring "*always*" (Fig. 4d and h). This suggests that ongoing and severe sleep loss may be a stronger trigger for intolerance than the total absence of sleep disruption is for promoting tolerance (Fig. 5). This finding aligns with existing research on the Hazard Acceptance Model, suggesting a threshold of acceptance whereby people are willing to absorb moderate impacts from carnivores on their well-being until these intangible costs reach an intolerable level. Fortified homesteads would help greatly in this regard to ensure that sleep disturbances engendered by approaching carnivores at night are not unsustainably frequent.

### 4.2. Methodological considerations

It is important to note that our study used herder perceptions of carnivore impacts on livestock production as a means of assessing the tangible costs of carnivores. There is a growing body of research showing that communities may exaggerate reports of livestock depredation as a means of communicating frustrations about conservation inequities to wildlife authorities (Gillingham and Lee, 2003; Kissui et al., 2022). Since our study did not include direct monetary costs and used instead people's perceptions of the impacts of carnivores on the livestock economy, the potential dissonance between subjective interpretation and material reality must be acknowledged here. At the same time, since our main interest was in examining tolerance towards wildlife—an inherently subjective psychosocial phenomenon—we maintain that assessing herder perceptions in this context is methodologically sound because it represents people's lived experiences of perceived economic costs. If people perceive the economic costs of carnivores to be major, then this measure is of direct consequence for our model of tolerance. This stance aligns with recent literature on the Hazard Acceptance Model, which highlights the importance of risk perceptions rather than the objective nature of interactions. As Slagle et al. (2022:2) write, "although describing acceptance in terms of risk and benefit implies a considered and rational cost/benefit approach to managing a carnivore species, in reality, it is the human perceptions of these risks and benefits that matter… and these perceptions are not always objectively accurate." Furthermore, the IUCN Species Survival Commission's human-wildlife conflict and coexistence specialist group defines negative interactions with wildlife in terms of "struggles that emerge when the presence or behaviour of wildlife poses actual or perceived, direct and recurring threats to human interests or needs" (IUCN 2023:3). Thus, we maintain that the perceived costs of carnivores are likely as important as objective monetary measures in the context of tolerance towards wildlife.

Another methodological consideration in our study is that we administered questionnaire surveys to households about both hyenas and leopards together. Respondents were first asked the series of questions about hyenas and then, shortly after, the questions about leopards. It is thus possible that people's responses about hyenas were informing their views about leopards, suggesting potential cross-pollination of influence in people's views from one species to the other. Other studies from the Tarangire ecosystem indeed suggest that negative perceptions of one species may colour people's tolerance towards others. Kissui (2008), for instance, found that lions were disproportionately affected

by people's negative experiences of hyena predation. Similarly, Hoffmann et al. (2024) noted in their study that people's perceptions of carnivores had to be contextualized in relation to their lived experiences of living with elephants. Thus, there is potential for people's perceptions of one species to influence their views on others, and people's survey responses should not be taken uncritically as totally independent assessments by species.

Finally, as stated in the methods section, tolerance is not a binary measure and our attempt to re-bucket responses likely does not encapsulate the complexity of this psychosocial phenomenon. While we focused on key thresholds of tolerance in an attempt to identify the levels of perceived risk that people deemed to be acceptable for sharing landscapes with large carnivores (cf. Slagle and Bruskotter, 2019), future research may benefit from evaluating tolerance on a fine-grained ordinal scale to better encapsulate the real-world gradient that characterizes subjective human phenomena like tolerance.

### 4.3. Conclusions and management recommendations

Our results emphasize the need for conservation education and outreach initiatives that help communities realize the benefits of large carnivore conservation. The fact that perceptions of conservation importance influenced people's degrees of tolerance for carnivores implies that there is a willingness to undergo some individual discomforts if there is a feeling that carnivores have benefits that people can either directly or indirectly profit from (i.e. Nature's Contributions to People[1]; Díaz et al., 2018). Maasai pastoralists' willingness to coexist with carnivores, as long as risks remain at tolerable levels, is embodied in the holistic concept of *Enaboisho*, meaning "coming together." *Enaboisho* as described by Maasai elders, represents the deep-rooted unity between Maasai people, the land, and wildlife, grounded in mutual respect. It underscores the interconnectedness of humans and nature, emphasizing balance, and shared responsibility in sustaining coexistence (Teixidor-Toneu et al., 2025; Bell et al., 2025). It could also speak to local interest in collaborating with wildlife authorities if community livelihood and well-being concerns are integrated in conservation practice (Carter and Linnell, 2016; Redpath et al., 2013).

The finding that individuals who did not consider hyena and leopard conservation important were more likely (i.e. five and 24 times more respectively) to be intolerant towards carnivores shows how pressing this issue is. Meaningful community engagement, through multi-directional pathways of knowledge co-creation and application, is needed (Mishra et al., 2017). For effective wildlife co-management, conservation initiatives must clearly communicate—or ideally co-develop and decipher—tangible benefits to community members while addressing their concerns about the economic, social, and cultural costs of coexisting with carnivores.

Our findings highlight the importance of incorporating community perspectives in human-carnivore interaction research and looking beyond mitigation that is solely focused on technical fixes to "conflict" resolution. Policymakers should prioritize incorporating community concerns into decision-making processes to ensure equitable, socially just and sustainable outcomes (Treves et al., 2006). The strong link between negative attitudes about carnivores and intolerance for sharing ecological resources with them highlights the need for formation of ethical engagement spaces where conservationists and communities can exchange perspectives and co-develop effective management strategies (Ermine, 2007). Hopefully, our work contributes to improved understanding of why local herders sometimes express intolerance towards large carnivores in the Tarangire ecosystem. Addressing their concerns, and the specific tangible and intangible factors affecting their views, could represent a possible pathway to coexistence.

[1] Nature's Contributions to People (NCP), introduced in the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) conceptual framework, expands on the ecosystem services concept from the 2005 Millennium Ecosystem Assessment by incorporating social, cultural, and spiritual dimensions of human-nature relationships. NCP promotes diverse knowledge systems, including Indigenous and local perspectives, to enhance environmental decision-making and sustainable policies, as seen in IPBES Global and Regional Assessments.

## Funding sources

Research was supported by a series of grants and fellowships from the Social Sciences and Humanities Research Council of Canada (SSHRC) including the "Institutional Canopy of Conservation" project, the "People, Livestock, and Carnivores" Insight Development Project (430-2025-01388), an Explore grant, a Vanier Canada Graduate Scholarship (Raycraft), a Michael Smith Foreign Study Supplement, and a SSHRC Doctoral Award (Bell). Fieldwork was also enabled by the Canadian Anthropology Society through a Salisbury Award (Raycraft) and internal grants from the University of Lethbridge and the Prentice Institute for Global Population and Economy. Article processing charges for open access publishing were covered by the University of Lethbridge library through an institutional agreement with Elsevier.

## CRediT authorship contribution statement

**Justin Raycraft:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization. **Elicia Bell:** Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Formal analysis, Data curation.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Acknowledgements

We express gratitude to Edwin Maingo Ole for his field assistance and sincerely thank the local communities for collaborating on this project. We are also thankful to TAWIRI, COSTECH, and government authorities for providing permits to conduct research in Tanzania.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jnc.2025.127035.

## Data availability

The data that has been used is confidential.

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