



## RESEARCH ARTICLE

# Livelihood and Season Determine Human-Carnivore Conflict Around Zakouma National Park, Chad

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**Received:** 21 October 2025 | **Revised:** 17 December 2025 | **Accepted:** 24 December 2025

**Keywords:** depredation | hyaena | leopard | lion | mitigation | nomad

## ABSTRACT

Transhumant pastoralists and their livestock spend the dry season in the floodplains around Zakouma National Park, Chad, where resident people practice mixed farming. We used interview data from 146 households to investigate the differences between these user groups in terms of vulnerability to depredation, attitudes and impact on conservation. Predation by spotted hyaena and disease were the major causes of livestock loss for both cattle and small ruminants, followed by lion depredation and theft. We found that seasonality and livelihood interact in shaping depredation patterns, with the presence of nomads in the dry season attenuating the pressure of depredation on the livestock of resident people, who become more vulnerable in the wet season, when nomads are not present and more wildlife stays outside the Park. Local mitigation techniques were not effective, and 98% of all households suffered hyaena attacks. Only solid enclosures, which were employed uniquely by some villages, mitigated lion depredation. Attitudes varied between groups, with nomads more likely to turn to retaliation in case of depredation. For coexistence, there is a need to differentiate between different resource users with different needs and different attitudes.

## 1 | Introduction

Large carnivores appear to be expanding in temperate regions where animal husbandry has been industrialised and where rural areas are rewilded (Chapron et al. 2015; Ripple et al. 2014). In most of rural Africa, in contrast and despite rapid urbanisation, land use is intensified, driven by a growth in human population size and rising local and global demand for resources. As a result, the range and numbers of many species of large carnivores are declining, with iconic species listed on the IUCN Red List either as Endangered (African wild dog *Lycaon pictus*) (Woodroffe and Sillero-Zubiri 2020) or as Vulnerable (cheetah *Acinonyx jubatus*, lion *Panthera leo* and leopard *P. pardus*) (Durant et al. 2024; Nicholson et al. 2023; Stein et al. 2025). Declines are particularly steep in West and Central Africa (Bauer et al. 2015; Craigie et al. 2010), where management

effectiveness is limited by state fragility, resource scarcity and a low potential for tourism (Bauer et al. 2022; Lhoest et al. 2022; Scholte et al. 2022).

One of the main threats to large carnivores is retaliatory killing in response to depredation of livestock (Bauer et al. 2022). In West and Central Africa, large carnivores are largely confined to Protected Areas, and human conflict with large carnivores is often the most pressing management issue for their persistence. In some protected areas, management is not effective at keeping livestock out, and large carnivores have ranges that expand beyond protected area boundaries, so the issue is often both inside and outside protected areas (Scholte et al. 2022).

Coexistence is the sustainable dynamic state where human and wildlife populations actively share landscapes, co-adapting over

time to mitigate conflicts and ensure tolerable levels of risk (Carter and Linnell 2016; König et al. 2020; Pooley et al. 2021). It requires more than mitigation of conflict and increasing tolerance, and involves more than costs and benefits (Brenner and Metcalf 2020; Kansky et al. 2021). Tolerance is based on perception and can vary based on demographic characteristics such as gender, age, ethnicity, religion and past experiences (Bhatia et al. 2017; Newsom et al. 2025). These concepts are crucial in understanding the illegal killing of carnivores, and offer clues towards management aimed at reducing anthropogenic carnivore mortality (Carter et al. 2017; IUCN 2023).

Many studies have tried to quantify livestock damage, either in absolute numbers, in proportion to the size of the owner's herd or in financial terms. Annual losses of 3.35%, 4.5%, 5% and 8% for all livestock were reported in Omo Valley, south Ethiopia (Wereta et al. n.d.), Serengeti National Park, Tanzania (Holmern et al. 2007), Gokwe community lands, Zimbabwe (Butler 2000) and in communal conservancies in northeast Namibia (Verschuere et al. 2020), respectively. Graham et al. (2005) reported worldwide losses to predation ranging from 0.02% to 2.6% of livestock per year. Quantifying depredation is a time-consuming activity that suffers from several biases and may be inappropriate where livestock is culturally seen as more than a commodity (e.g., as family or as an indicator of status) or inadvertently raises expectations (Ibbett and St John 2024). In the present paper we have taken a different approach and have followed the IUCN guidelines (IUCN 2023) to focus on more meaningful metrics that are informative for the drivers of conflict.

One approach is to use comparative data, for example comparing the impacts of different large carnivore species. In Kenya, Bauer et al. (2017) found that a lion conservation programme was actually spending more money on spotted hyaena. This has been found in many studies; out of total depredation, spotted hyaena was responsible for 70% in the Tarangire ecosystem (Mkonyi et al. 2017), for 58% in the Maasai steppe (Kissui et al. 2019), for 41% in the Amboseli ecosystem (Muriuki et al. 2017) and for 57% in Bale Mountains in Ethiopia (Atickem et al. 2010). Exceptions do exist: in Westgate Community Conservancy, leopards were the main culprit (51%), followed by spotted hyaenas (35%), lions (13%) and wild dogs (1%) (Mitchell et al. 2019). Any study of depredation would therefore do well to include all large carnivore species and compare them.

Disease is often found to cause more livestock mortality than depredation (Ashish et al. 2022; Farhadinia et al. 2017; Kissui 2008), and this can have an effect on attitudes and tolerance towards predators as it increases economic instability (Ashish et al. 2022). In two Ethiopian sites, Gebresenbet, Baraki, et al. (2018) found that depredation by lions, spotted hyaenas and leopards led to very different attitudes, with intent to retaliatory killing related to depredation in Gambella but not in Kafa. With the influx of pastoralists in Central Africa (Aebischer et al. 2020), parameters such as these must also be measured in Zakouma National Park.

In the present paper we use interview data to address three research questions. First, we investigate how nomadic pastoralists differ from sedentary agropastoralists with respect to depredation, attitudes and impacts on conservation. Secondly, we examine

the difference between causes of livestock mortality in terms of their impacts on people's livelihoods. Finally, we examine the differences between depredation patterns of lions, spotted hyaenas and leopards and how these interact with mitigation practices to shape attitudes towards large carnivores. We discuss our findings in a context of increased management capacity to address human wildlife conflict and identify how interventions should differentiate between resource user groups in trying to promote coexistence.

## 2 | Material and Methods

### 2.1 | Study Area

Zakouma National Park (NP), situated in the Sudano-Sahelian region of southeastern Chad, is a 3054 km<sup>2</sup> protected area established in 1963. Unfenced, it is surrounded on all sides by the 20,950 km<sup>2</sup> Bahr Salamat Faunal Reserve, established in 1964 (Figure 1). In collaboration with the government of Chad, African Parks has managed Zakouma NP and its immediate surroundings since 2010, and in 2017 the mandate was extended to the entire Bahr Salamat Faunal Reserve (African Parks 2023).

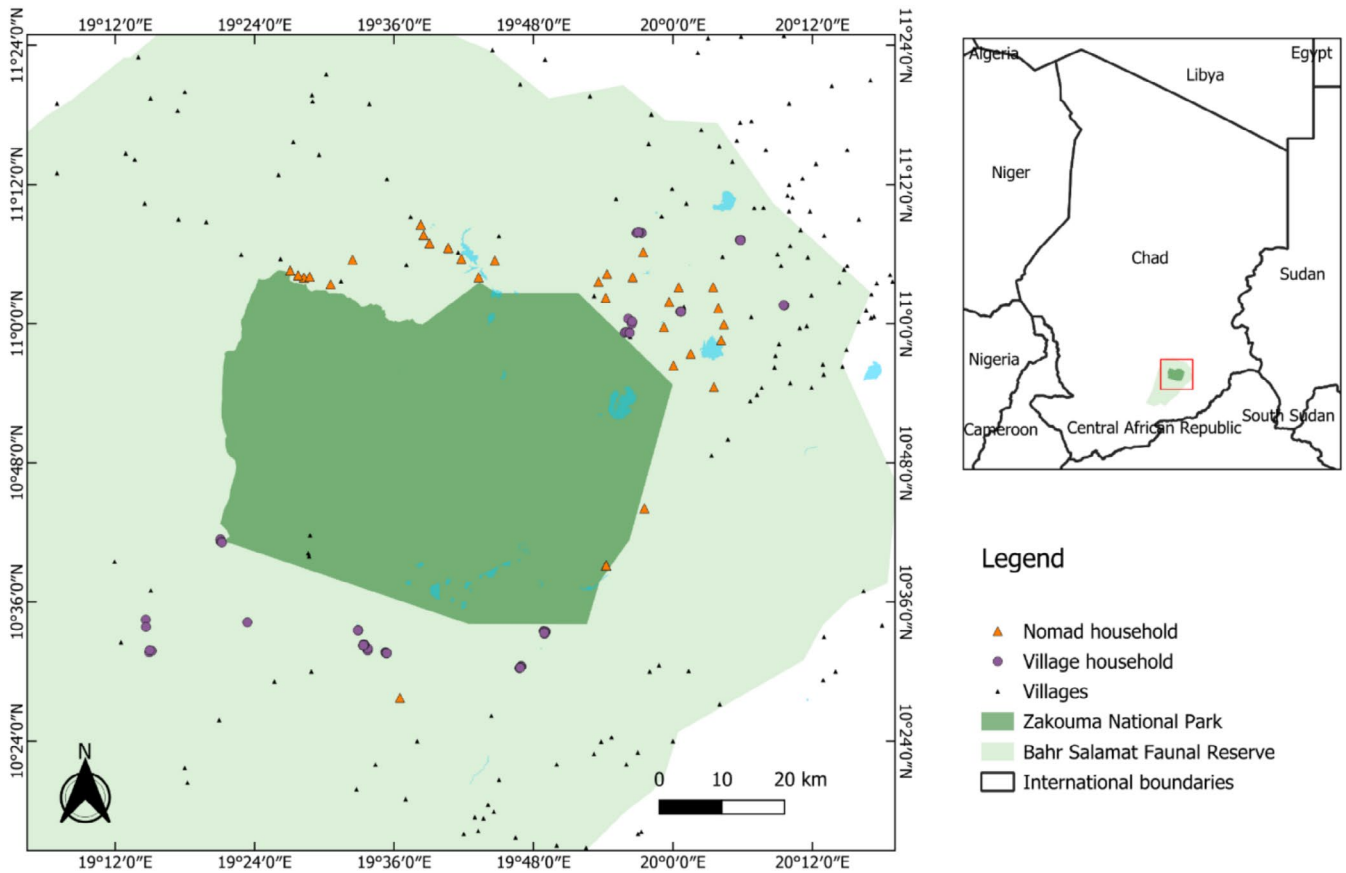
Human activities in the region include both permanent settlements with livestock and agriculture, as well as seasonal transhumant herders with cattle and camel herds. These nomadic people, mainly from Arabic origins, spend the dry season in the south of Chad or in the Central African Republic to then move back to the north of Chad with the wet season. A 'ferrick' is a temporary nomad camp that is composed of several tents for one or more households.

Zakouma NP is home to various species, including lion, leopard, spotted hyaena (*Crocuta crocuta*), savanna elephant (*Loxodonta africana*), buffalo (*Syncerus caffer*), giraffe (*Giraffa camelopardalis*), roan antelope (*Hippotragus equinus*), hartebeest (*Alcelaphus buselaphus*), tiang (*Damaliscus lunatus*), waterbuck (*Kobus ellipsiprymnus*) and olive baboon (*Papio anubis*), as well as smaller herbivores and carnivores. Side striped jackal (*Lupulella adusta*) and African wolf (*Canis lupaster*) are both present in the area, but people do not distinguish between them in the field; we therefore analyse them together and refer to them as jackal/wolf. Many of these species extend their ranges, either permanently or seasonally, in the surrounding faunal reserve (Clark et al. 2023; Fraticelli et al. 2025).

Rainfall in the area mainly occurs between June and October, with the first rains starting in April. Rains in the first 2 months fill local pools and feed grass which attracts wildlife from Zakouma NP onto community land. Rainfall gradually leads to flooding, at which point nomadic pastoralists move further away but villagers and their livestock stay. The rainy season is followed by a cool dry season until February, and then a hot dry season, during which surface water is only available in a few permanent waterholes on the eastern side of the park.

### 2.2 | Data Collection

We carried out semi-structured interviews in the Bahr Salamat Faunal Reserve within 25 km from the border of Zakouma NP,



**FIGURE 1** | Study area in and around Zakouma National Park and location of interviews for nomad households (triangles) and village households (circles).

with the head of the household and, depending on availability, up to 4 other members of the household, including women. We always first approached the local chief to describe the work and get permission and then proceeded with randomly selected respondents. For the nomad pastoralists, the interviewer travelled to the areas where they usually stationed and randomly selected groups to interview, also with the head of household and up to 4 other members of the same household.

The questionnaire was divided into four sections: socioeconomic status of the household, opinions and attitudes towards conservation, human-wildlife conflict, techniques of conflict mitigation. Wealth status was based on self-assessment of the household: if they could buy all necessary and save money (rich), buy all necessary but not able to save money (medium), had to deprive themselves in order to live and/or be able to pay off debts (poor). Questionnaires were administered using KoboCollect, a tool of the KoboToolbox for data collection, on a smartphone. An image board with the species mentioned in the questionnaires was also available to allow respondents to identify the species.

Prior to the interview, the interviewer explained the objectives of the study and gave an overview of the topics, and the participants were asked to orally consent to the interview. If no consent was given, the interview would not be carried out, but this situation was not encountered. All interviewees were over 18 years of age. Data were immediately anonymized and stored in the

KoboToolbox secure servers, accessible only to the researchers. Under the partnership agreement between Africa Parks and the Government of Chad, the GZE management has the authorization to carry out research studies, including interviews with the local populations.

Interviews in the villages were carried out in July, August and September 2021, while interviews with the nomads in the ferriek were carried out earlier in the season the following year: May and June 2022.

### 2.3 | Data Analysis

Data was mapped with QGIS (QGIS Development Team 2024) and all analyses were carried out in R (R Core Team 2024).

Socioeconomic variables were analysed using descriptive statistics. We used nonparametric Fisher's Exact Test to determine differences in responses between groups for each categorical variable and Wilcoxon rank-sum test for continuous variables.

Identification skill of the respondents was calculated as the proportion of species they recognised among the 8 carnivores in the survey (lion, leopard, cheetah, caracal (*Caracal caracal*), serval (*Leptailurus serval*), spotted hyaena, striped hyaena and jackal/wolf). This was then compared across groups with the Wilcoxon rank-sum test.

Reported population trends and reported conflict trends are presented graphically and with percentages, and conflict trends between lifestyle groups were compared with Fisher's Exact Test.

Seasonality of conflict was compared with chi-squared tests for each species, then we used binomial logistic regression models using a generalised linear model (GLM) with a binomial error distribution to look at interactions between type of respondent and season of conflict reported for each species.

The importance of different causes of livestock loss was compared with pairwise Wilcoxon rank-sum test with Bonferroni correction, to control for Type I error due to multiple comparisons. We used mean local market price to calculate losses; 37 USD for sheep and goats and 238 USD for cattle, prices had a wide range based on body condition, but there was no difference in cost between village or nomad stock, so we used the same mean costs for stock of both groups (M. Haltebaye, pers. comm.). We tested for differences between causes using pairwise Wilcoxon rank-sum test with Bonferroni correction, to control for Type I error due to multiple comparisons.

To examine the effectiveness of mitigation practices, we fitted a binary logistic regression model using a generalised linear model (GLM) with a binomial error distribution and logit link function. The model was fitted using the `glm()` function. We then calculated the odds ratio (OR) and 95% confidence intervals for the explanatory variables, where an OR > 1 indicates that with the variable increases the probability of a predator attack, and OR < 1 indicates a protective factor, where the variable decreases the probability of a predator attack.

We compared the stated intention to kill a predator in retaliation between groups with a chi-squared test, while we analysed the association of stated intention to kill with loss of livestock with a Cochran-Armitage Test.

### 3 | Results

#### 3.1 | Respondents' Characteristics

We interviewed 186 respondents from 146 households; 91 households ( $1.1 \pm 0.4$  participants per household) from 14 villages and 55 nomad households ( $1.5 \pm 0.7$  participants per household). All household interviews involved at least one male respondent; in total, 82.8% of respondents were male. Age varied from 19 to 75 years ( $42.2 \pm 12.5$ ). Household size ranged from 1 to 35 people ( $9.6 \pm 5.7$ ). We asked the nomads for how many years they have been spending the season in this area, and responses ranged from a minimum of 10 years to a maximum of 54 ( $30.0 \pm 10.1$ ). Principal profession varied significantly between groups ( $p < 0.001$ ); all respondents from nomadic households were pastoralists, whereas respondents from the village households were mostly farmers (85%) with the other 15% including fishermen, teachers, students, drivers and tailors. The majority of respondents were in the medium wealth category, with no significant difference in wealth between villagers and nomads ( $p = 0.082$ ).

Most households owned livestock (100% of nomads and 82% of village households), with total number of livestock heads per

household ranging from 0 to 303; nomad households owned significantly more livestock ( $W = 4905.5$ ,  $p < 0.001$ ). The majority of households owned goats (78%), followed by donkeys (69%), sheep (47%), cattle (47%), horses (35%) and finally dromedaries (5%). Small ruminants were the most abundant group for both nomads and villagers (52% and 75% of total livestock, respectively), but nomads had a much stronger cattle-to-small ruminants ratio (0.83) compared to villagers (0.17).

Profession and type of interviewee (nomad/village) were closely linked; comparisons between nomads and villages are thus implicitly comparisons between nomadic pastoralists on one hand and other professions on the other.

#### 3.2 | Respondents Perception Towards Population Trends

Over 90% of households were able to recognise spotted hyaena, lion and striped hyaena; > 80% could recognise jackal/wolf, cheetah, serval and leopard, while only 27% of respondents recognised caracal, with no significant difference in carnivore identification skills between villagers and nomads ( $W = 1815$ ,  $p = 0.003$ ).

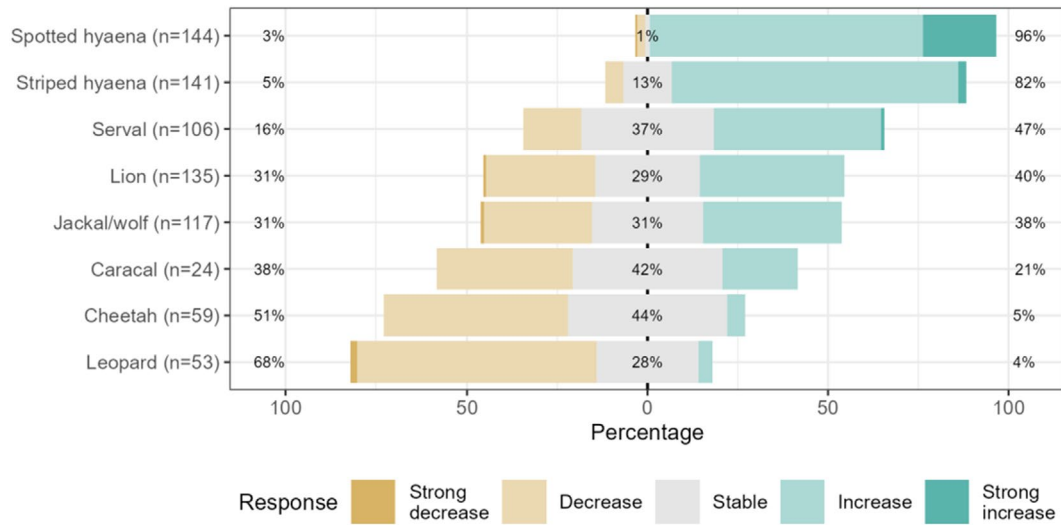
The species most frequently observed were spotted and striped hyaenas which were reported as being seen several times a month by 79% and 47% of the respondents, respectively. Lions were observed at least once a year by 85% of the respondents. The least observed were caracals (82% of the respondents never observed them), leopards (65% never observed) and cheetahs (59% never observed).

Most respondents, 95%, reported an increase in spotted hyaenas over the past 5 years, with 20% of them (all pastoralists) mentioning a strong increase. Apart from this, very few responses indicated a strong increase or strong decrease in carnivore populations. Cheetah and leopard were the only species where more respondents reported a decrease (21% and 25% of all respondents respectively) rather than stable or increasing (see Figure 2).

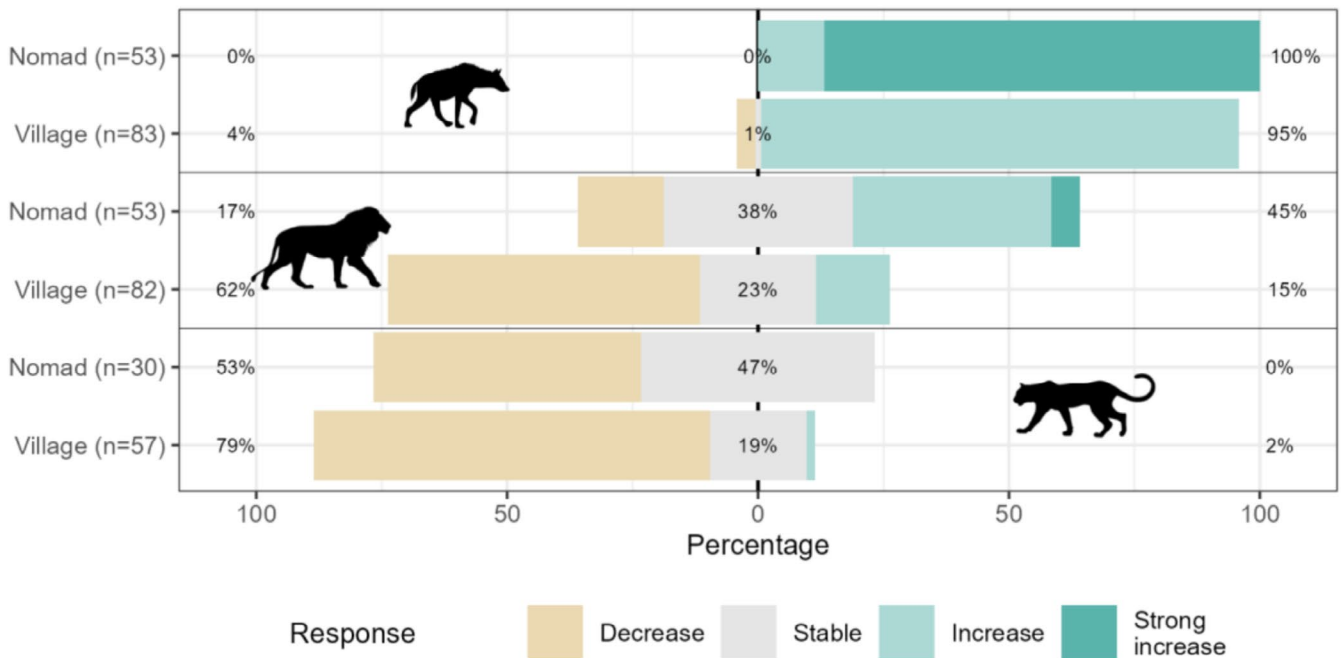
#### 3.3 | Factors Influencing Livestock Loss to Predators

Overall, respondents reported an increase in conflict over the past 5 years with spotted hyaenas, but a decrease of conflict with lions and leopards. In Figure 3 we report the perceived trend in conflict on a 5-point Likert scale. Both villagers and nomads reported an increase in conflict with spotted hyaenas (not significant difference between type of respondent;  $p = 0.388$ ). Conversely, there was a significant difference in reported trends between villagers and nomads when looking at lions ( $p < 0.001$ ) and leopards ( $p = 0.012$ ).

Overall, more conflict was reported for lions in the wet season compared to the dry season ( $\chi^2 = 13.88$ ,  $p < 0.001$ ) while there was no significant difference between seasons for leopard ( $\chi^2 = 0.63$ ,  $p = 0.428$ ) and spotted hyaena ( $\chi^2 = 0.26$ ,  $p = 0.610$ ), but these overall figures hide the interaction between season and type of respondent (Figure 4). The majority of respondents reported that conflict with spotted hyaenas was both in the dry



**FIGURE 2** | Trends of large carnivore population size over the past 5 years, according to village and nomad households around Zakouma National Park; the number of respondents for each species is given in the Y-axis legend.



**FIGURE 3** | Trends in conflict reported by villagers and nomads around Zakouma National Park, for spotted hyaena, lion and leopard. Number of respondents for each category included in parentheses.

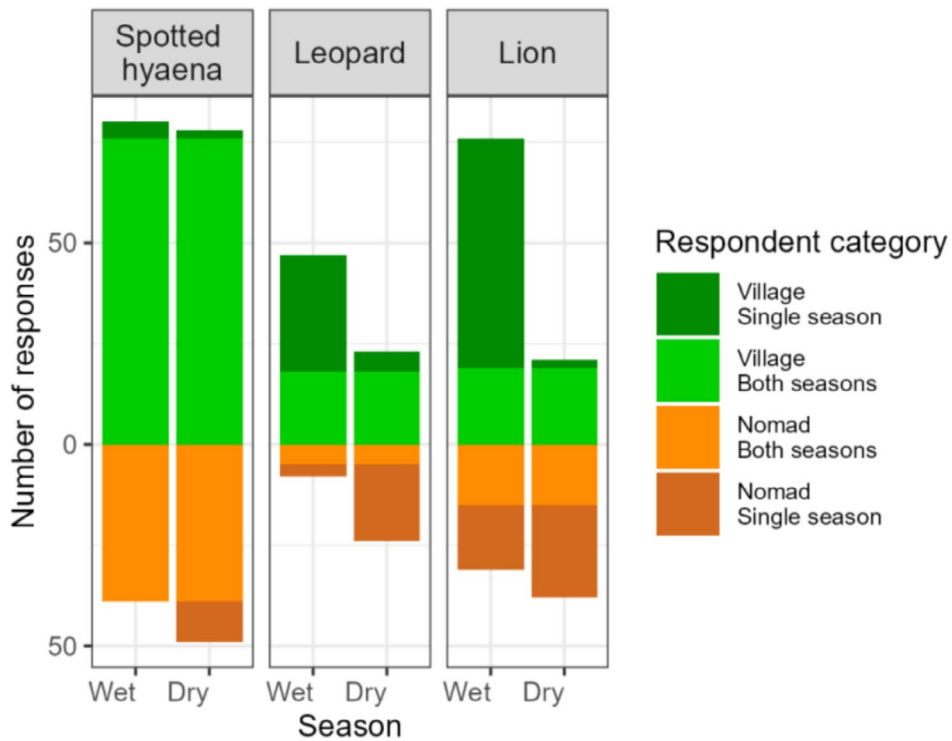
and wet season (80% of nomad and 93% of village respondents), with no significant difference between season or between type of respondent.

A binomial logistic regression examining seasonal variation in reported lion attacks revealed a significant interaction between season and household type ( $\beta = -5.20$ ,  $p < 0.001$ ), indicating that village households were substantially more likely to report attacks in the wet season but not in the dry season. No significant seasonal trend was observed among nomad households ( $\beta = 0.57$ ,  $p = 0.163$ ).

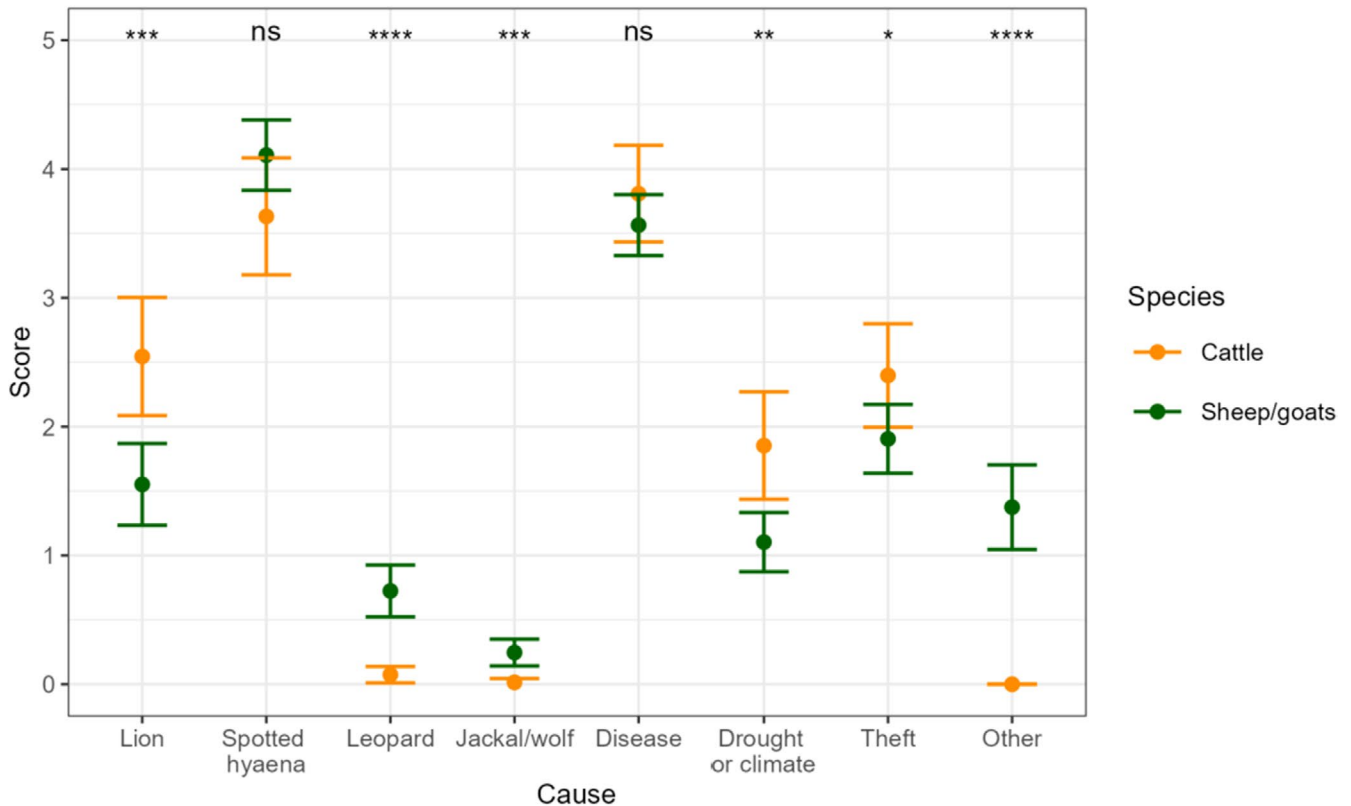
Logistic regression results for leopard attacks also revealed a strong interaction between household type and season ( $\beta = -5.42$ ,

$p < 0.001$ ). Among village households, reports were significantly more frequent in the wet season, while nomad households reported more attacks in the dry season ( $\beta = 2.94$ ,  $p < 0.001$ ). This suggests a contrasting seasonal pattern between the two groups.

Spotted hyaena predation was the major cause of loss for small ruminants, followed by disease ( $V = 2226$ , adj  $p < 0.001$ ), while for cattle these two causes ranked highest with no significant difference between them ( $V = 161$ , adj  $p \approx 1$ ). Within the cattle category, jackal/wolf, leopard and unspecified other causes ranked lowest with no significant differences among them. Lion predation, drought or other climate effects, and theft impacted cattle significantly more than small ruminants (Figure 5; see Table S1 for complete pairwise Wilcoxon rank-sum test results).



**FIGURE 4** | Seasonal distribution of conflict with spotted hyaena, lion and leopard according to villages (green) and nomads (orange), between wet season and dry season. Lighter colours indicate the respondents that report conflict in both seasons, while darker colours indicate the respondent reported conflict only in one season.



**FIGURE 5** | Importance of livestock loss causes for cattle and small ruminants (sheep and goats) for the past 3 years, ranked from 0 (not at all important) to 5 (very important cause), as reported by households owning the respective livestock species at the time of the survey. The error bars represent a 95% confidence interval. We indicate a significant difference between livestock species for each category at the top.

**TABLE 1** | Results of the binary logistic regression model for lion and leopard attacks, and guarding methods with odds ratio.

Variable	Estimate	Standard error	z	p	Odds ratio (95% CI)
<b>Lion</b>					
Intercept	-3.403	1.189	-2.862	0.004*	0.03 (0.003, 0.30)
Livestock numbers (log)	1.521	0.337	4.510	<0.001*	4.58 (2.52, 9.60)
[Distance from park (km)] <sup>2</sup>	-0.008	0.004	-2.217	0.027*	0.99 (0.98, 1.00)
Adult guard	-1.121	0.697	-1.607	0.108	0.33 (0.08, 1.24)
Dog	0.989	0.703	1.407	0.160	2.69 (0.71, 11.71)
Simple enclosure	-0.133	0.646	-0.206	0.837	0.88 (0.25, 3.19)
Solid enclosure	-1.842	0.783	-2.352	0.019*	0.16 (0.03, 0.68)
<b>Leopard</b>					
Intercept	-5.214	1.351	-3.860	<0.001*	0.01 (0.0003, 0.06)
Livestock numbers (log)	1.312	0.315	4.163	<0.001*	3.71 (2.11, 7.35)
Distance from park (km)	-0.126	0.051	-2.496	0.013*	0.88 (0.79, 0.97)
Adult guard	0.038	0.583	0.066	0.947	1.04 (0.32, 3.25)
Dog	0.119	0.568	0.210	0.834	1.13 (0.36, 3.40)
Simple enclosure	0.262	0.608	0.431	0.667	1.30 (0.40, 4.41)
Solid enclosure	0.906	0.806	1.125	0.261	2.48 (0.51, 12.74)

Note: \* indicates significant values.

Overall, spotted hyaena predation and disease were more economically impactful with no significant differences between them ( $V=3362$ , adj  $p=0.389$ ), followed by lion predation and theft together ( $V=3288$ , adj  $p\approx 1$ ), and then drought and climate. Predation by leopards or jackals/wolves was less economically impactful compared to all other causes.

Most respondents reported that their livestock had been attacked by spotted hyaenas (98%), whereas attacks by lions and leopards were reported by 48% and 24% of respondents, respectively. Only a single respondent reported his household having suffered an attack on a member of the household by a spotted hyaena.

### 3.4 | Effectiveness of Mitigation Measures

Because 98% of the household suffered attacks from spotted hyaenas, we were unable to model the effectiveness of guarding methods for this species, so this section only presents results for lion and leopard. None of the mitigation measures had a significant impact on leopard attacks when including livestock numbers and distance from the park as variables, while for lions only solid enclosure significantly decreased the probability of an attack (Table 1).

### 3.5 | Factors Influencing Carnivore Conservation Attitudes

When asked what they would do if a predator attacked their family or livestock, 30% of respondents said they would try to chase the predator off without killing or wounding it, while 13%

would actively try to wound or kill it. Few would call nearby administration (3%) or local authorities (13%).

Respondents in nomad households were significantly more likely to express willingness to hurt or kill predators ( $\chi^2=13.86$ ,  $p<0.005$ ) compared to village households. Respondents in households that reported predation events by lions or leopards were significantly more likely to express willingness to hurt or kill a predator (lion:  $p=0.018$ ; leopard:  $p=0.031$ ). Respondents with more loss of cattle or small ruminants had a significantly higher probability of wanting to kill lions (cattle:  $Z=-3.29$ ,  $p<0.001$ ; small ruminants:  $Z=-2.69$ ,  $p=0.007$ ). For spotted hyaena, loss of cattle did significantly increase stated willingness to kill ( $Z=-2.29$ ,  $p=0.022$ ), but losses to small ruminants did not. There was no significant influence from losses on stated willingness to kill leopard.

When asked why carnivores attack livestock, 63% of respondents said it is a natural behaviour and 12% said because livestock is easier to catch than wild prey. Some reported the lack of wild prey (20%), lack of space (5%) or increase in predator numbers (3%) in the park as the cause for carnivores to exit the park and look for livestock, and some acknowledged that the livestock (12%) or village/ferrick (3%) were too close to the park.

## 4 | Discussion

Studies based on questionnaires are prone to various sources of bias, including social desirability bias where respondents tend to give the answer that they think the interviewer is looking for (Leggett et al. 2003) and recall bias, when events in the

past are not remembered accurately. Here, the interviewer was an African Parks employee, and respondents may have avoided responding to certain questions truthfully, on one side to avoid self-incrimination, on the other to exaggerate their problems in the hope of receiving assistance. We attempted to mitigate these issues by explaining the aims of the study and assuring anonymity of records prior to each interview. Due to the permanent status of the villagers, compared to the seasonal nomads, some benefits tend to be biased towards the villagers (e.g., schools, clinics, jobs, etc.), thus this effect might be greater for one group compared to the other.

We evaluated the identification skills of the respondents for medium to large carnivores present in the area to ensure that the reported information was reliable and found that most respondents could correctly identify most carnivore species, with no difference in identification skills between nomads and villagers. Both spotted and striped hyaenas were reported as being seen several times per month by a large number of respondents and their populations were reported as increasing. Conflict with spotted hyaena was also reported as increasing by both villagers and nomads. Leopards were observed more rarely by the respondents, and most reported a decline in the population, which is consistent with the reported decline of leopard conflict. Responses about lions were also congruous: no clear trend on perceived population size or conflict, suggesting that these were stable.

Lions caused significantly more loss of cattle compared to small stock, while leopards and jackals/wolves killed more small stock. This reflects the preferred weight range of prey for these carnivores, with lions preferring prey between 190 and 550 kg (Hayward and Kerley 2005) and leopards between 10 and 40 kg (Hayward et al. 2006). Spotted hyaenas preferred a weight range of 56 to 182 kg (Hayward 2006) which is larger than small stock and smaller than adult cattle, but they are very adaptable animals; different studies have found them preying mostly on small ruminants (Kissui 2008; Mukeka et al. 2019) or mostly on cattle (Gueye et al. 2022). In our case, spotted hyaenas were considered one of the two most important causes of mortality for both cattle and small stock.

Disease is often found to be a major cause of livestock loss (Ashish et al. 2022; Farhadinia et al. 2017; Kissui 2008), and in our study, it was reported as one of the major causes of livestock loss, on par with spotted hyaena depredation. While hyaena depredation and disease were the highest causes of livestock loss for both cattle and small stock, lion depredation, theft and climate impacted cattle more than small ruminants, and depredation by leopard and jackal/wolf was more important for small stock. Cattle have a higher emotional and financial value than small ruminants (Craighead et al. 2021; Kissui 2008), thus loss of cattle is often found to be more impactful than loss of small ruminants even when the number of heads lost is lower (Kissui 2008). Due to the significant difference in cost between small ruminants (25–50 USD) and cattle (130–350 USD), hyaena and lion depredation have a disproportionate financial impact on cattle owners compared to small stock owners.

As with other areas in West and Central Africa (Bauer et al. 2010), attacks of wild carnivores on humans are rare, and

in our study only one household reported a non-lethal attack on a person by a spotted hyaena. A review of global large carnivore attacks on humans found significant differences in frequencies and circumstances of attacks on humans based on species, but also on local context, via different combinations of ecological, but also socio-economic factors (Bombieri et al. 2023). It identified lions and leopards as the main culprits in the African continent, but the dataset was limited to countries in East and southern Africa. Attacks on humans by hyaenas were reported, for example, in the Serengeti Ecosystem, Tanzania (Mbise 2021) and in Omo Valley, Ethiopia (Asfaw et al., in review), but lions were more dangerous.

Almost all households reported losses to spotted hyaenas which limited our ability to analyse variables that influenced spotted hyaena depredation; spotted hyaena depredation occurs irrespective of factors such as number of livestock or distance from the park. Leopards and lions, however, both showed a higher probability of attacking households with higher numbers of livestock and closer to the NP. An increase of livestock depredation with increase in herd size has been observed in other studies (Hemson et al. 2009; Van Bommel et al. 2007; Verschueren et al. 2020). Increased risk with proximity to protected area is recognised by some of the respondents in this study who reported that in their opinion the livestock was attacked because it was grazing too close to the park, and was reported by studies in other areas (Abade et al. 2014; Dickman et al. 2014; Kuiper et al. 2024). A difference in dependence from the park between predator species has also been found in other ecosystems such as the Serengeti, where lions and leopards were found closer to conservation areas, while spotted hyaenas were found in greater abundance further from protected areas (Craft et al. 2016). Spotted hyaenas are very adaptable in behaviour and coexistence with people and have benefitted from anthropogenic food subsidies in several areas (Craft et al. 2016; Yirga et al. 2012), making them less dependent on natural prey from protected areas.

Lack of dependence from the protected area of spotted hyaenas is also reflected in the seasonality of conflict. Predation from hyaenas and leopards was reported year-round, while lion conflict was reported significantly more in the wet season. However, contrasting seasonal patterns were observed for leopards and lions: where villagers reported significantly more conflict in the wet season with both species, nomads reported more conflict in the dry season, especially with lions. The patterns reported are partly associated with the seasonality of nomads in the area, who stay during the first 2 months of the rainy season, then progressively leave the area as it gets flooded. This is also the period when larger wildlife shifts out of Zakouma NP and into the surrounding community areas (Clark et al. 2023). Collar data show that at least some lions tend to follow prey movements, shifting their core zone from inside to outside park boundaries (Fraticeili et al. 2025), while our findings here suggest that spotted hyaenas are present in communal lands throughout the year. Possibly, in the dry season with less predators and more livestock, predation risk is diluted, and lions and leopards attack nomad livestock more as they have larger herds and settle on average closer to the park, with weaker enclosures, all significant factors increasing the probability of predator attacks. In contrast, for most of the wet season, only village livestock is available for depredation.

Smaller prey species, in the preferred weight class of leopards, mostly stay in the park throughout the year; we speculate that leopards are not pulled by migratory prey but pushed by the floods later on in the wet season. If leopards leave the park later than lions, the increase in abundance of leopards on community land would overlap less with nomad presence in the early wet season, which would explain why they reported less leopard depredation in the wet season.

In Narok County (Kenya) livestock depredation was strongly seasonal and dropped when migrating herbivores were in the area, while it increased in the wet season when migrants leave and resident ungulates disperse (Mukeka et al. 2019). Both in the Maasai Steppe and around Tarangire NP (Tanzania), most of the depredation incidents occurred in the wet and intermediate seasons, when wildlife moves outside of the park (Kissui 2008; Lichtenfeld et al. 2015). The same was also reported for Waza NP in Cameroon (Bauer and de Iongh 2005) and Niokolo Koba NP in Senegal, although the difference was low (Gueye et al. 2022). In Zimbabwe, the seasonal difference was apparent in attacks on cattle, but not for donkeys or goats, and it was speculated that it might depend on the seasonal differences in herding practices (Loveridge et al. 2017).

We did not find any evidence that the mitigation techniques employed by the households around Zakouma NP (e.g., active guarding, enclosures and dogs) reduced depredation by spotted hyaenas or leopards. Solid enclosures seem to be the only effective mitigation technique, but only for lions, while they have no effect on leopard or spotted hyaena depredation. It is worth noting that such reinforced structures are only used by villagers and not by the nomads. Similar results were also observed around Waza NP, where solid enclosures experienced significantly less predation than thorn enclosures (Tumenta et al. 2013). Other studies have also proven the effectiveness of fortified or double-layered enclosures compared to simple enclosures (Chaka et al. 2020), including evidence for a positive spillover effect of fortified enclosures (Lichtenfeld et al. 2015; Salerno et al. 2025). The lack of efficacy of other methods around Zakouma NP is possibly due to the lack of rigour in methods and the low quality of materials with which they are applied. For example, herding is often done by children and only part of the day and dogs are untrained.

As hyaena depredation usually occurs at night (Loveridge et al. 2017), introducing innovations to make enclosures predator-proof could minimise depredation by hyaenas and build up on the effect we observed where solid enclosures are effective against lion depredation in our study area. Fortified bomas could potentially mitigate the bulk of depredation losses but are technically more difficult for nomadic pastoralists. Note that innovations in mobile bomas from Zimbabwe have targeted pastoralists that are always or often in their project area (Sibanda et al. 2021), aware of the importance of their ranging patterns (Kuiper et al. 2015), but it might be difficult to adapt to a situation where pastoralists are only seasonally present, and with different groups between years.

Identifying mitigation practices that are effective and can be implemented by the nomadic pastoralists is especially important as our results show that nomads are more likely to want to kill a predator after an attack, compared to villagers. In particular, we

found a significant relationship between increased loss of livestock to lions and intention to retaliate, and this was also true for spotted hyaena attacks on cattle. Among Maasai pastoralists in Kenya, the probability of killing lions also increased with cattle lost to predators (Ontiri et al. 2019). In these cases, decreasing the rates of attacks, even if not able to completely prevent them, will likely reduce the possibility of retaliatory killing. But this is not always the case, as in the Kafa Highlands in Ethiopia a correlation was found between livestock loss and presumed reaction to leopard attacks but not for lions, and this was attributed to the higher tolerance of lions based on local culture (Gebresenbet, Bauer, et al. 2018).

We have identified groups by their source of livelihoods, but this is closely related to ethnicity, culture, language, land rights and mobility. Pastoralists are from various clans of Arab origins whose cultures are shaped by their (semi-)nomadic lifestyles. Attitudes are not only shaped by perceptions; there are important cultural dimensions. For our analysis, the pastoralist resource use pattern was the defining feature to serve as independent variable, but these dimensions need to be unpacked and taken into account in subsequent steps towards the promotion of coexistence.

Studies elsewhere in Africa have insisted on community-based solutions, but those communities are usually resident and with a degree of stewardship over the land and its resources (Dolrenry et al. 2016; Hazzah et al. 2009; Loveridge et al. 2017). Even if those communities are ethnically diverse and heterogeneous in their livelihood activities, they can be identified as stakeholders by protected area management. Examples include mobilising community members for hazing of lions (Petracca et al. 2019), community camera trapping, linking wildlife presence to tangible benefits (Dickman et al. 2025), and various other measures (Loveridge et al. 2017). These would work well with villages around Zakouma NP, but they are more difficult to implement with pastoralists that graze their livestock in the area for part of the year, and not necessarily every year. Our species identification results have shown that this group knows the ecology of the area very well and our damage assessment has shown substantial impacts from large carnivores on their livelihoods, but our analyses have also shown that their mitigation methods are ineffective and that they are more likely to resort to retaliatory killing. These results justify the creation of so-called ‘Tango-teams’, units that are specifically adapted to work with nomads (African Parks 2023). African Parks is gaining experience with this, and in 2023 Zakouma introduced the PeriFerrick teams, similar to the Tango teams (African Parks 2023), with members recruited among the nomads themselves. The PeriFerrick teams sensitise the nomads moving through the area to the risks of human-wildlife conflict, as well as the laws pertaining to the use of natural resources and the location of recognised transhumance corridors.

## 5 | Conclusion

This study compared the vulnerability to depredation and conservation attitudes of two user groups, sedentary agropastoralists and nomadic pastoralists, around Zakouma NP, Chad. We observed that livestock depredation patterns are shaped by the interaction between seasonality and livelihoods and that current

mitigation measures are not effective in protecting livestock from predators. Our study suggests that in order to mitigate human-wildlife conflict and improve coexistence, different approaches need to be implemented for the different user groups. Our data can be used as a baseline to evaluate effectiveness in the future.

## Acknowledgements

We would like to thank the Government of Chad for permission to carry out this research project. We also thank African Parks and the Greater Zakouma Ecosystem team for assisting this study with logistical and financial support and in particular Angela Gaylard for her suggestions and comments. We thank all the respondents of the questionnaire for sharing with us their time and knowledge.

## Conflicts of Interest

The authors declare no conflicts of interest.

## Data Availability Statement

The interview data that supports the findings of this study is available from African Parks upon reasonable request, but restrictions apply due to sensitivity reasons.

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### Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Table S1:** Statistics and significance values for pairwise comparisons between causes of livestock loss, within cattle or small ruminant groups, and between livestock species within each cause.