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Drivers of Human−wildlife interactions in a co-existence area: a case study of the Ngorongoro conservation area, Tanzania

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Abstract

Communities in Africa bordering national parks or protected areas commonly overlap with wildlife. However, it is unclear to what degree such overlaps result in interactions with wildlife. The Ngorongoro Conservation Area (NCA) was designated a multiple land-use conservation area in 1959. Maasai and Datoga pastoralists and Hadzabe hunter-gatherers reside with protected wildlife in NCA. The study was carried out in four Maasai villages within the NCA, including Kayapus, Endulen, Meshili, and Nainokanoka. A cross-sectional study was used to assess drivers of human−wildlife interactions using questionnaire surveys, focus group discussions, and field visits. A total of 396 households participated in the survey. The collected data were analysed using qualitative data analysis techniques and descriptive statistics such as frequencies and means. The habitat, which comprises water, pasture, shelter, and space, accounted for 100% of interactions, indicating that it is the primary driver of human−wildlife conflict. Other driving factors for human−wildlife interactions are the increase in wildlife, collections of firewood, domestic animals kept, and influence of community sleeping arrangements, searching for traditional medicines, and killing of lions for ritual purposes or defense. Large household sizes (36 family members) coupled with climate change have also driven and fuelled human−wildlife interactions. Challenges identified as threatening human−wildlife co-existence are injuries, deaths, disease transmission, and destruction of property. To mitigate human−wildlife conflicts, the following are recommended: the increase in boarding schools coupled with the increase in enrolment of students in boarding schools or providing reliable transport, distribution of tap water, increasing food assistance to the community living in poverty, controlling population increase through reallocation the population in other areas, introducing zero-grazing, using biogas, discouraging community sleeping arrangements, i.e., humans with calves in the same house, improving record-keeping of the wildlife attacks, provisional dissemination of research findings to the community.

Keywords Drivers · Human-wildlife co-existence · Interaction · Conflicts · Conservation Area

1 Introduction

Human−wildlife interaction has occurred in different social settings and environments worldwide [3, 11, 26, 44, 71]. Kaminski and Nitzschner [26] reported that human−wildlife interaction occurs in the zoo or the wild and that it is one of the features that still receives little attention. The increase in the human population, expansion of development, global

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climate change, and other environmental aspects put people and wildlife in competition for scarce resources [33, 53]. Hence, humans unavoidably interact with several animals in different environmental settings [3, 44]. The interacting animals, both domesticated and wild, are useful to humans as they are used for biomedical research, acquiring food, instruments for music, clothing, adornments, pets, and ingredients in curative preparation, for political, religious, and ritual purposes or for defense [1, 3, 15, 44]. Increased human−wildlife interaction leads to positive and negative consequences termed conflicts [11]. Frequently, human−wildlife interactions threaten human security or livestock, leading to overwhelming impacts. Ogada et al. [54] noted that human−wildlife interactions lead to conflicts that endanger human safety and health, resulting in exposure to injuries, deaths and the transmission of infectious diseases. Such an issue of devastating impacts could be a stumbling block for local wildlife and habitat conservation [65]. In Sub-Saharan Africa, human−wildlife interaction is a common phenomenon with negative consequences on local communities, as in Ethiopian protected areas where humans are affected by the interaction [34]. Likewise, in Tanzania, human−wildlife interaction has occurred in areas bordering protected areas (national parks, game reserves, game-controlled areas) or in the co-existence area, such as the Ngorongoro Conservation Area (NCA), with negative effects such as crop damage, loss of property, injuries, and deaths [32]. The NCA, established in 1959, is among the hot spot areas for human−wildlife interactions. It was designed to be the first multiple land-use conservation area in Tanzania where Maasai and Datoga pastoralists and Hadzabe hunter-gatherers reside [46]. Maasai together with their livestock roamed in NCA approximately 200 years ago. The Maasai pushed Datoga, who also resided within the NCA and remains as the minority in the southeast part of the NCA. The remaining ethnic group of the Hadzabe lives on the edge of the NCA by Lake Eyasi [2, 6, 28]. A provision of Maasai residency in the NCA is that they should maintain the traditional way of life that is beneficial to wildlife conservation [17, 46]. The NCA has high biodiversity and is inhabited by species known to be involved in human−wildlife interactions and conflicts. These include buffalos (*Syncerus caffer*), elephants (*Loxodonta africana*), leopards (*Panthera pardus*), lions (*Panthera leo*), wild dogs (*Lycaon pictus*), cheetahs (*Acinonyx jubatus*), and spotted hyenas (*Crocuta crocuta*). Herbivores such as elephants, buffalos, and carnivores, including lions, spotted hyenas, cheetahs, leopards, and wild dogs, are accountable for human−wildlife conflicts [72]. The natural landscape, diversity of African wildlife species, and rich archaeological resources make the NCA's scientific, ecological and cultural resources extraordinary [60]. The NCA has been a World Heritage Site since 1979 and an International Biosphere Reserve since 1981 [61]. Native Maasai have been sharing the area with wildlife for hundreds of years. However, they have lived under conservation policy since 1959 [46]. Maasai's long history of cohabitation with wildlife has resulted in interactions [46]. The Maasai can travel throughout the NCA without fear of predators. They also respect wildlife; however, regular conflicts happen when wild carnivores attack people or livestock through depredation due to the interactions [48]. URT [70] confirmed that 158 people in the NCA were attacked by wildlife due to interaction for five years (2015–2020), with a total of 21 human deaths. To better understand the nature and drivers of interaction, this study cataloged human−wildlife interactions within the NCA into direct and indirect interactions. In this study, the researchers intended to assess the main drivers of human−wildlife interactions, which could help define policies to minimize human−wildlife conflicts.

2 Materials and methods

2.1 Description of the study area

The study was conducted in the NCA in Tanzania, with a current population approaching 100,000 [37]. The NCA is the first multiple land-use conservation area in the world where Maasai pastoralists reside, with livestock keeping as their main economic activity [45, 46]. The study covered four villages of Kayapus, Endulen, Meshili, and Nainokanoka in the Ngorongoro District in the Arusha Region (Fig. 1). The rationale for selecting these villages was that the NCA has a healthy resident population of most species of wildlife [22, 57]. Additionally, there is human and wildlife contact in all these villages. NCAA [46] confirmed that Ngorongoro is the only wildlife reserve in the world where humans and wildlife co-exist i.e., human activities are taking place together with wildlife conservation. The NCA is situated 180 km west of Arusha city in northern Tanzania. The NCA is part of the Serengeti ecosystem and is the only place in the world inhabited by a larger density of animals [51]. It lies between Longitude 36° 1′ 38.7466″ and 36° 1.645776″ E and Latitude 3° 9′ 44.8399″ and 3° 9.747332′ S. It is bordered by the Serengeti National Park to the North, Maswa Game Reserve to the West, Loliondo Game Controlled Area to the north and urban and agricultural areas to the east and southern part [51].

The NCA covers an area of 8292 km^2 and can be divided into the Crater Highlands, Gol Mountains, Eyasi escarpment, and Salei plains [51, 57]. The Salei plains receive little rain, and as such, they are dry and dusty, which is blown from
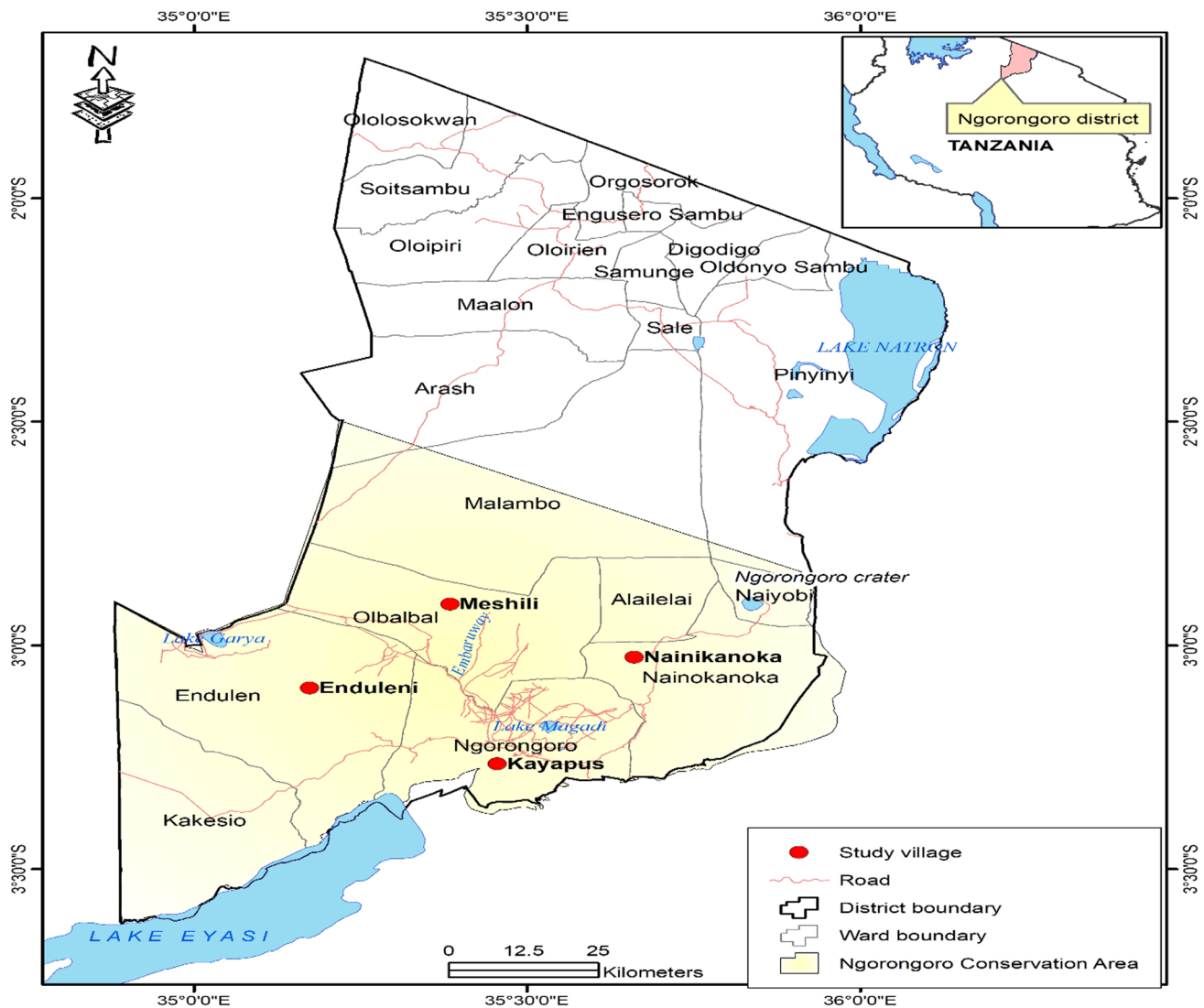
Fig. 1 The study area

volcanic ash. According to NCAA [46], dust has a high nutrient content of volcanic ash, which supports vegetation that enables mass herbivore migration to NCA.

2.2 Data collection

Different data collection methods and techniques were used. These included household surveys, focus group discussions (FGDs), field visits, and interviews with medical doctors, veterinarians, conservationists, villages, and ward officers in the NCA. Semi-structured questionnaires were administered to 396 heads of households using a simple random sampling method. The selection of a simple random sampling method is based on ensuring that the likelihood of any individual element in the population has an equal chance of being selected and representative, hence minimizing sampling biases [5]. However, non-probability sampling was also used to select key informants (KIs). KIs were those with knowledge about an idea, state, group, subject, or culture ready to share their viewpoints [5]. The KIs included medical doctors, veterinarians, conservationists, and village and ward officers. Field visits were made in the four villages to collect data independent of the feedback provided by villagers. As argued by Gans [19], a field visit is a pertinent systematic approach for describing events, behaviours, and artifacts in the social setting. Two focus group discussions (FGDs) were conducted in each village. Each group consisted of eight members from pastoralist communities. The relevance of FGD in the study is supported by Berg [4], who argues that FGD delivers detailed qualitative insights from a small group of

people concerning behaviour, past experience, perceptions, opinions, and suggestions. The criteria used to select members of FGDs included the duration of residence in the project area, sex, and the participant's age, whereby respondents who were over fifty years old were preferred because they could be in a better position to provide information. Sex was considered due to the structure of pastoralist societies and its impact on the type and frequency of contact with wildlife. Specific issues discussed during FGDs were the drivers, such as the increase in wild animals, human–wildlife interaction model, the influence of habitat on human–wildlife interaction, the influence of livestock on human–wildlife interaction, the influence of sleeping arrangements in human–wildlife interaction, the influence of traditional medicines on human–wildlife interaction, killing the predators and challenges related to human, livestock, and wildlife interaction. The data collected were mainly qualitative, thus necessitating the use of qualitative data analysis techniques and descriptive statistics such as frequencies and means. Descriptive statistics were derived using the Statistical Package for the Social Sciences (SPSS) for Windows, version 25.

3 Results and discussion

3.1 Education level of the respondents

Approximately 56.6% of the respondents had informal education represented by knowledge transmitted by elders, as indicated in Table 1. Informal education is a type of education that is acquired outside the structured school curriculum. As argued by IPRN [23], traditional knowledge is stored knowledge, practice, and belief with regard to the physical environment transmitted from generation to generation through stories, beliefs, and traditional songs. The provision of informal education in pastoralist communities is necessary for combating the harsh environment surrounding the area linked with drought, livestock rustling, the transmission of diseases, and poor provision of infrastructure. Chimah [9] and Mlekwa [40] note that informal education provides support in a challenging environment associated with diseases, drought, livestock rustling, and poor infrastructure. Conversely, the elders in the Maasai communities are unwilling to send children to school where they can acquire formal education. As a result, and as reported above, a large proportion of the community members possess informal education, i.e., 62.5% in Kayapus, 61.5% in Meshili, 58.7% in Endulen and 41.4% in Nainokanoka villages. The reason for this low education level is the unwillingness of the pastoralist communities to send their children to acquire formal education as it looks against their cultural and traditional lifestyles that are primarily nomadic. Thus, pastoral communities, regarded as mobile communities, are the most disadvantaged to formal education, requiring permanent settlement and hence low education in the NCA. Dyer [14] argues that the acquisition of formal education is significant, and concerns arise regarding compliance with the needs and support for the livelihood of pastoralists.

Table 1 Education level, Marital status, and Economic activities of the Respondents.
Source: Field data

Variable	Description	Village Name				
		Kayapus n = 82	Meshili n = 124	Endulen n = 118	Nainokanoka n = 72	Total n = 396
Education level	Informal	62.5	61.5	58.7	41.4	56.6
	Primary	24.0	24.0	31.2	39.1	29.3
	Secondary	9.4	12.5	5.5	19.5	11.4
	College	4.2	1.9	4.6	0.0	2.8
Marital status	Married	91.7	92.3	93.6	83.9	90.7
	Divorced	4.2	2.9	0.9	2.3	2.5
	Single	1.0	2.9	0.9	13.9	4.3
	Widow/Widower	1.0	1.9	4.6	0.0	2.0
	Separated	2.1	0.0	0.0	0.5	0.5
Economic activities	Livestock Keeping	97.1	99.0	97.2	97.7	97.7
	Business	1.0	1.9	0.0	2.3	1.3
	Formal employment	0.0	0.0	2.3	1.3	0.5
	Other (Tour guide)	0.0	1.0	0.9	0.0	0.5

Respondents (%)

Additionally, the vast generational knowledge of the pastoralists in managing their lives and livelihoods is another reason for the low acquisition of formal education in the NCA. Krätli [30]; Carr-Hill and Peart [8]; and Pesambili [55] also note that the culture, prevailing illiteracy and conservative lifestyle of pastoralists prevent the provision of formal education by governments. Furthermore, the marginalization of the pastoralist community due to inequality in the educational system between rural areas and urban areas, children of the rich families and the poor, females and males as opposed to Tanzania's education policy intending to promote equitable access to education for all segments of the population [68]. Likewise, the remoteness, distance, and widely scattered pastoralist communities in the NCA are stumbling blocks to acquiring formal education among pastoralists, thus the high rate of low educational attainment in the NCA. Krätli [30] and Krätli and Dyer [31] revealed that the inaccessibility of areas, nomadic pastoralists, and widespread coupled with a difficult environment challenged the provision of education. Lastly, the inadequate teachers due to the remoteness of the environment have contributed to education becoming low. Most teachers are unwilling to work in rural areas characterized by unfriendly environments, as in the case of the NCA. Most of the villages in the NCA are found in remote areas accompanied by a difficult and unreliable transport system, hence discouraging teachers from working under such circumstances. The absence of infrastructures such as roads, water, transport and information, electricity, and communications technology has created a shortage of teachers in rural areas [13].

Acquiring formal education in the NCA is not without the risk of being harmed by wildlife. The available student transport facility provided by the NCAA is unreliable and does not curtail the risk to students needing to travel to school.

Field observations revealed that students live far from schools and thus become exposed to dangerous wildlife, which in turn contributes to a negative local perception of wildlife.

The majority of respondents (90.7%) are married (Table 1). Marriage is compulsory in pastoralist communities, and girls are considered to be a source of income through bride prices. A higher bride price signifies the value of the girl in society. The study by Kipuri and Ridgewell [29] noted that bride prices signify importance, and women with higher bride prices are given more reverence than a simple commodity. Girls are married at the age of 13, which is considered a child, and it opposes girls' rights to enter into a marriage contract. According to Section. 2 of the Law of the Child Act (LCA), a child is defined as an infant who has not yet reached the age of eighteen years [41]. Under this age, the consent of marriage is vested in her parents or guardians, as it denies the freedom and rights of a child, and it is discriminatory. The law governing marriage in Tanzania stated in Sect. 13 of the LMA. Section 13 (1) puts the minimum age of marriage to be fifteen years for females and eighteen years for males. Based on the legal setting, a union involves a contract that requires a person's ability to contract. A child has no ability to enter a contract, and entrance into a marriage institution does not cease a person being a child. The international and regional laws on child rights as indicated under the Law of the Child Act, 2009, forbid people below the majority age to enter a marriage contract, and the Law of Marriage Act, 1971 (LMA) Act Sections 13 and 17 of Tanzania is unconstitutional [7, 41, 66]. However, the Court of Appeal of Tanzania specifies that the age of marriage for women is eighteen years [41]. Early marriage acts as a disincentive to formal education among girls. Girls and women are regarded as less capable than men, and the stereotype designates "*ditto*", which in the Maasai language means "child". This is also used to refer to wives. Early marriage also encourages bearing more children, which creates pressure on food production and land for settlement and in turn drives and intensifies human—wildlife interaction, leading to conflicts. Residents claimed to have experienced insufficient food aid, which the NCAA provides to feed families during the time of drought [39]. Cultivation to attain food self-sufficiency to meet the demand of population increase is not allowed, as it could create and drive human—wildlife interactions resulting in injuries and deaths. The growth of the human population, livestock, and wildlife might lead to competition for land, habitat destruction, indigenous conflict, and the spread of animal diseases [12].

3.2 Economic activities of the respondents

Almost all (97.7%) of the respondents keep livestock such as cattle, goats, sheep, donkeys, dogs, and cats as the main source of livelihood. Some (1.3%) are engaged in small-scale businesses such as shops, grain selling, buying, and selling of livestock, while 0.5% of the respondents are in the formal employment sector working as government and private sector employees and tour guides (Table 1). The livestock kept by the Maasai drives and increases the contact between humans and wildlife as they co-graze and cohabitate with humans. Predatory wildlife bouts on livestock, humans, and other wildlife make keeping livestock precarious. Agricultural activities are not allowed within the NCA, as it is unfriendly to wildlife. The practice could lead to increased contact, leading to conflicts between the community members and the wildlife. The search for honey by the community members in the NCA, which is sold in the nearby Karatu area to meet basic needs, has driven and increased interactions and conflicts with wildlife, leading to injuries and deaths. Similarly,

the preclusion of agriculture is linked with poverty, which is also perceived to have hindered the full participation of the communities in conservation, as the community is discontenting with the restrictions. Mkiramweni et al. [39] confirmed that residents in the NCA require food assistance during droughts. Food shortage during dry seasons is exacerbated by the restriction on agricultural activities in NCA to avoid human−wildlife conflict.

3.3 Household size in relation to human−wildlife interaction

The pastoralist maximum household size is 36, and the minimum is 1, with an average of 8.29 household members. This exceeds the Tanzania national average household size of 5. Large household size can be explained by the polygamy nature in pastoralist communities, which results in many children. This, on the other hand, is considered prestigious in pastoralist communities. A large household size leads to the demand for extensive land for settlement. The demand for land for settlement results in the depletion of natural resources, which in turn drives and increases human−wildlife interactions and conflicts leading to injuries and deaths. As argued by UNESCO/ICOMOS/IUCN [67] and Chubwa et al. [10], the rise of the human population together with livestock and resident wildlife could lead to a struggle for land, indigenous conflicts, and the spread of animal diseases.

It was observed during field visits that houses are scattered throughout the NCA, a situation that interferes with the conservation goals and the NCA General Management Plan, which aims at preserving multiple land-use systems to attain a balance between people and nature, conservation of biodiversity, and ecological integrity [47]. Houses also obstruct migratory routes to enter and exit the crater for wildlife in search of pasture. The blockage of wildlife corridors drives and increases interactions and conflicts between humans and wildlife, leading to injuries, deaths, and transmission of infectious diseases to humans and livestock. As reported by Jones et al. [25], human settlements, extraction of poles, and expansion of agricultural activities threaten wildlife corridors connecting Tarangire–Lake Manyara and Mikumi–Wami-Mbiki.

3.4 Increase of wild animals in the NCA

Almost all (93.7%) of the respondents reported a significant increase in wildlife in the NCA. Due to the strengthening of law enforcement by the NCAA to prevent illegal poaching for elephant ivory, bush meat, and lion killing for ritual purposes, which are locally known as "*Ola–mayio"* or for defense. On the other hand, the increase in wildlife in the NCA contributes to the involvement of the community in wildlife conservation. The integration of the community in wildlife conservation through the execution of laws regarding patrols within and outside the NCA is also among the factors for the increase in wildlife in the NCA. It was observed that the upsurge of wildlife in the NCA involves certain species, such as buffalo, wildebeest, zebra, elephants, and Grant gazelle, particularly outside the crater. The buffalo showed a stable increase from 1991 to 2018. The wildebeest has also been shown to be steady in 1995, and the increase is more prevalent subsequently. Other wildlife indicating the increase are the elephants, as observed in 2005, and an increase was observed again in 2014 with a record of 168 compared to 2000 with a record of 22 elephants. Lastly, a tremendous increase in Zebra was noted in 2000 and a double increase between 2001 and 2018 [64]. However, a decline in other wildlife species, such as the Thomson gazelle and giraffe, has been noted in the NCA. The trend of decline of Thomson gazelle occurred in both seasons, the dry and the wet seasons in the 1990s, and continued to fluctuate in 2000. A drastic decrease was further observed in giraffes, as almost fifty percent were lost in a period of eight to nine years [64]. Furthermore, it has been reported that NCA consists of a large number of mammalian communities, such as 0.9 million Thomson's gazelle, 1.3 million wildebeest, 0.6 million zebra and other species available in large numbers, including elephant, buffalo, hippopotamus, warthog, eland, black rhino and giraffe. It is also accompanied by a diversity of impressive predators, which include 3000 lions, 1000 leopards, 7500 hyenas, 225 cheetahs, and wild dogs [49]. The increase in wildlife has driven and intensified human−wildlife contacts and conflicts with the consequence of the destruction of properties, disease transmission (i.e., anthrax, rabies, and tuberculosis), injuries, and deaths. Furthermore, the introduction of the Kope Lion organization in the NCA with the intention of striving for sustainable human-lion co-existence with the application of research, the engagement of the community, and education and communication. The mission used is people, helping people, helping lions. The organization provides education starting from the grassroots by raising awareness among the Datooga, Hadzabe, and Maasai who deliberate NCA as their home. A close relationship between Kope Lion and the communities is established with discussions intending to reach viable solutions rather than killing lions in retaliation for the lost cattle or for ritual purposes. The organization employed men from the tribes known as "Ilchokut", which is referred to as Lion Guardians, with the roles of tracking and monitoring lions, cautioning the villagers sporadically about

the presence of lions in their area. Furthermore, it helps to find and recover any lost livestock and refurbishes fencing to keep herds safe at night. With the use of the Global Positioning System (GPS), they could track livestock-lion interactions, hence contributing to maintaining the lions in the NCA. Likewise, the incentive-based payment system executed by the NCAA for damage inflicted by wildlife on the community has contributed to the increase in wildlife. The incentive paid is in terms of money, and it is under the agreement between the NCAA and the affected person or relatives. As stated by NCAA [46, 49], the payment of incentives is done to improve the tolerance of the lions across the NCA. The tolerance of the Maasai communities towards wildlife has influenced the increase in wildlife, which in turn poses challenges to humans through direct confrontation with an outcome of injuries and deaths.

3.5 Trends of livestock heads in NCA 1960 to 2017

Between 1960 and 2017, livestock populations in NCA fluctuated (i.e., increasing and decreasing), as indicated in Table 2. Climate change resulting from drought is the main influencing factor for the increase and decrease in livestock. The analysis of livestock trends has been shown in the NCA as a limitation of ca. 125,000 Tropical Livestock Units (TLU) with major, radical declines in some years [2]. The drought that occurred in NCA in 2017 killed 78,490 heads of sheep, 77,389 heads of cattle, and 72,881 heads of goats with the devastation of the economy [50]. The devastation led to the total loss of livestock by 70% compared with the tallies of the preceding year [63]. Moreover, the impact of drought also killed cattle in Sinon, Sendui and Nainokanoka villages, with a great impact extending from 71 to 83% and 86%, respectively [63]. As a result of the effects of drought leading to the decline of herds, livestock keepers change from relying on cattle to small ruminants such as goats and sheep [24, 43]. Furthermore, the increase in poverty among families has also influenced the change from keeping cattle to small ruminants, which has reached to ca. 8% of the TLUs in the 1960s, to a maximum of 26% in the current era, with a climax in prosperity years and a drop during watersheds [36]. With the increase or decrease in livestock, which is the main source of food and income for pastoralists in NCA coupled with loss by predators as they co-graze, intensifying conflicts result in injuries, deaths and disease transmission, such as tuberculosis, anthrax and rabies.

Table 2 Shows the trends of livestock heads in NCA 1960 to 2017. Source: McCabe et al. (1992); NCAA, own data; NDC, NCAA (2013); Tawiri [63]; NDC [50]

| Year	Cattle	Sheep and goats	Total TLU*	% TLU, sheep and goats	Source
1960	161,034	100,689	122,793	8.20	McCabe et al. (1992)
1962	142,230	83,120	107,873	7.71	McCabe et al. (1992)
1963	116,870	66,320	88,441	7.50	McCabe et al. (1992)
1964	132,490	82,980	101,041	8.21	McCabe et al. (1992)
1966	94,580	68,590	73,065	9.39	McCabe et al. (1992)
1968	103,568	71,196	79,617	8.94	McCabe et al. (1992)
1970	64,786	41,866	49,537	8.45	NCAA, own data
1974	123,609	157,568	102,283	15.41	McCabe et al. (1992)
1977	110,584	244,831	101,892	24.03	NCAA, own data
1978	107,838	186,985	94,185	19.85	McCabe et al. (1992)
1980	118,358	144,675	97,318	14.87	McCabe et al. (1992)
1984	109,724	100,948	86,902	11.62	NCAA, own data
1987	137,398	137,389	109,918	12.50	McCabe et al. (1992)
1988	122,513	152,240	100,983	15.08	McCabe et al. (1992)
1993	77,243	148,288	68,899	21.52	NCAA, own data
1994	115,468	193,294	100,157	19.30	NCAA, own data
2003	129,231	173,364	107,798	16.08	NCAA, own data
2007	136,550	193,056	114,891	16.80	NCAA, own data
2013	131,509	330,079	125,064	26.39	NDC, NCAA 2013
2016	115,562	181,281	99,022	18.31	Tawiri 2016
2017	38,173	29,910	29,712	10. 07	NDC 2017 (losses)**

*1 cattle = 0.7 Tropical Livestock Units; and 1 sheep or goat = 0.1 TLU (Jahnke et al., 1988)

**2017 data are calculated by deducting the losses reported in NDC 2017 from the census by Tawiri 2016

Table 3 Shows the human—wildlife interaction model. Source: Field data

Direct interaction			Indirect interaction		
Response	Frequency	Percent (%)	Response	Frequency	Percent (%)
Yes	160	40.4	Yes	396	100
No	236	59.6	Total	396	100.0
Total	396	100.0			

Fig. 2 Shows shared habitat resources
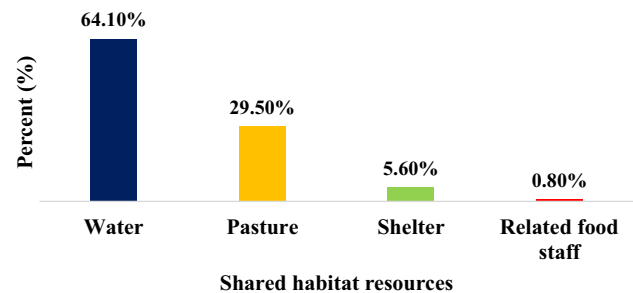
3.6 Human—wildlife interaction model

Direct interaction between humans and wildlife is reported by 40.9% of the respondents, as shown in Table 3. Human movement in search of basic needs has driven into direct interaction with wildlife with consequence effects such as injuries, deaths, and disease transmission. Fetching of water from the water sources that are co-used by humans and wildlife is done by women. This has driven and increased the direct interaction between humans and wildlife. The water sources are found at a distance from the community residences and involve movement leading to encounters with wild animals. The need for firewood for energy that is collected in forests has made women susceptible to being invaded by wildlife. The forest in the NCA is the resting place for wildlife in the daytime, making women more susceptible to being invaded in the process of collecting firewood. As noted by Karmebäck et al. [27] and that of Hodgson [21], collecting firewood, fetching water, treating animals, and storing food and preparation in pastoralist communities are vested in women. On the other hand, indirect interaction with wildlife is reported by all (100%) of the respondents, as also indicated in Table 3. Cohabitation and sleeping arrangement, i.e., humans and calves in the same house, co-usage of water or pasture accounted for indirect contact between human—wildlife. The same livestock (calves) sleep in the same shelter as humans, resulting in the transmission of infectious diseases, particularly airborne diseases such as tuberculosis. Ryan and Ray [56] reported that the transmission of infectious diseases might occur through physical contact, contaminated objects, body fluids, food, vector organisms, or airborne inhalation. With regard to human—wildlife interactions, the buffalos create more risks to humans than other wildlife in the NCA. The pastoralists face the risk posed by buffalos during grazing or when women are in the process of searching for firewood in the forests. The attack on women by the buffalos always takes place in the forests while collecting firewood, where the latter used to rest for wildlife during the day. Hemson et al. [20] reported that the communities residing close to protected areas are vulnerable to fearful herbivores such as buffalos, hippopotamus, elephants, and carnivores, i.e., lions, spotted hyenas, and leopards.

3.7 The influence of habitat on human—wildlife interactions

Habitat is reported by all 396 (100%) of the respondents as the main driver influencing human—wildlife interaction in the NCA, as indicated in Fig. 2. The NCA is a wildlife reserve where humans and wildlife co-exist i.e., human activities are taking place together with wildlife conservation. As noted by TAWIRI [64], the native Maasai have been sharing the area with wildlife for hundreds of years while profiting from pasturelands for their livestock, traditional herbal medicines, shelter, and food supply. Water was reported by 64.1% of the respondents as the main driving force for human—wildlife interactions in the NCA, 29.5% pasture, 5.6% shelter, and 0.2% related to food staff. A limited supply of habitat resources coupled with the negative effects of climate change drives humans together with their livestock and the resident wildlife in co-usage. As noted by Tarver et al. [62], the anticipated temperature rise poses serious threats to the main resources

in the NCA and could affect the tourism business. As a result, it drives and fuels interactions between humans together with their livestock and the resident wildlife in the NCA, hence increasing conflicts.

Discussion with FGDs and KIs revealed that humans, together with their livestock and resident wildlife, share drinking water sources, hence increasing interactions in the NCA. Field visits also observed elephants destroying a house to access stored food. This could trigger more interactions and conflicts leading to injuries and deaths.

3.8 The influence of livestock on human−wildlife interactions

Figure 3 substantiates what the researchers reported earlier: more than half (53.3%) of the respondents in the study area keep cattle, 17.9% keep goats, 12.4% keep sheep, 8.6% keep donkeys, 6.3% keep dogs and very few (1.5%) keep cats. A large number of the responses showing cattle are kept by more than half of the respondents signifies the major economic activities of the pastoralists whose livelihood relies on livestock keeping. Keeping a large number of animals increases human−wildlife interactions in the NCA. Due to livestock-wildlife interactions, the predators mingling with the wildlife eventually attack livestock. The predators attacking livestock provoke humans, leading to retaliation for livestock loss. On the other hand, livestock co-grazed with wildlife and cohabit with humans during the night. This cohabitation between humans and livestock leads to disease transmission, particularly airborne diseases, as in the case of tuberculosis. It was noted that the majority (797 people) of inhabitants of the NCA were affected by airborne diseases that spread in all the villages. The building of Endulen Hospital intends to combat tuberculosis, which is pervasive and widely spread in the NCA. As reported by URT [69], 797 people (390 men (49%) and 407 women (51%)) in the study area suffered from tuberculosis over four years (2016–2019). In addition to other livestock, community members in the NCA also keep donkeys assisting in carrying water and transporting luggage. This happens as water sources are found far away from the residents. Donkeys are also used to carry grains to milling machines for grinding flour. As noted by Swai [59], donkeys are used for carrying water, sacks of grain, and other goods. Consequently, the livestock kept by the community members in the study area increases contact between humans and wildlife, resulting in conflicts leading to injuries, deaths, and the transmission of infectious diseases.

The pastoralists keep dogs for security purposes, particularly to protect human settlements and livestock from encroaching by wildlife. Moreover, the co-grazing of livestock accompanied by dogs with wildlife increases interaction. The same dogs interact with wildlife and cohabitate with humans, resulting in the transmission of infectious diseases such as rabies. Lithgow and Lawick [35] and that of Bardosh [1] noted that dogs in Sub-Sahara Africa are used for shielding families, herding livestock against wildlife and thieves and are also responsible for rabies transmission. Thus, the association of dogs with wildlife, particularly the hyenas in search of food, fuels the transmission of rabies to humans through biting as dogs cohabit with humans.

During field visits, the researchers observed dogs kept by the Maasai community at Meshili village, as indicated in Fig. 4.

3.9 The influence of sleeping arrangements on human−wildlife interaction

The sleeping arrangements show that almost all (99.2%) of the respondents in the study area share houses with livestock (calves). Such that the same door in the house is used by humans and livestock to enter the dwellings. The main reason for humans sharing houses with livestock is to avoid suckling calves being attacked by predators. Wildlife, such as buffalos and zebra, sleep around shelters "Bomas" during the night to protect from predators. Conversely, the wildlife sleeping closure to human shelters increases contact with humans, leading to conflicts resulting in injuries, deaths, and disease transmission, such as tuberculosis, which is associated with buffalos. The study by Lithgow and Lawick [35] and that of

Fig. 3 Livestock kept in the study area
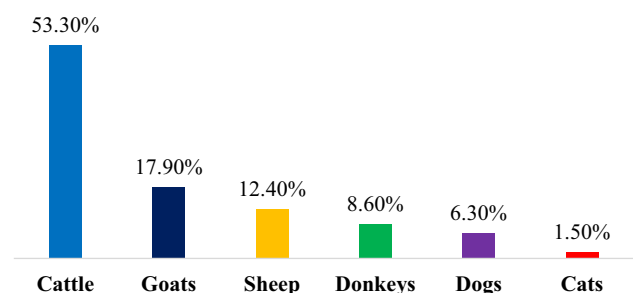
Fig. 4 Dogs kept by the respondents' in the NCA

Nyerembe and Bushesha [52] reported that the use of poles instead of tree branches to construct fences and bomas might reduce wildlife attacking livestock quickly.

During field visits, the researchers observed calves entering unventilated human dwellings at night risking infectious disease transmission, such as anthrax and tuberculosis, as calves co-grazed with wildlife, which are the main sources of infectious diseases transmitted to humans.

3.10 Community-reported sources of energy for human−wildlife interactions

Firewood was reported by almost all (99.2%) of the respondents as among the driving factors for human−wildlife interaction in the NCA. Understandably, in rural areas, firewood is the primary source of energy for cooking, lighting, and warming during the cold weather period. It is easy to obtain and is in proximity to the community. It does not involve a cost in terms of money that the rural community cannot afford. More than 85% of people living in Tanzania's rural areas still depend on traditional sources of energy for cooking, such as charcoal, firewood, plants, and animal dung [18, 42, 59]. The communities' over-dependence on firewood as the main energy source in the NCA has driven human−wildlife interaction. The collection of firewood in the forests, i.e., the dwelling place for wildlife, is done by women; hence, they become more vulnerable to dangerous wildlife. As noted earlier, the wildlife uses the forest for rest in the daytime when the sun is hot. Direct contact between humans and wildlife leads to sudden attacks resulting in injuries and deaths. Fathallah and Pyakurel [16] note that the firewood collection for energy exposes women to injuries or attacks by wildlife.

3.11 Community-reported traditional medicines for human−wildlife interactions

A substantial number (48.0%) of the respondents mentioned "Iloondwa", as among traditional herbal medicines collected from the forest for disease treatment in the NCA, 22.2% mentioned "Okonyil", 13.6% mentioned "Olkokola", 7.6% mentioned "Omukutan", 5.1% mentioned "Olosuki", and while very few (3.5%) mentioned "Okitalaswa" (Table 4). Concerning the treatment of diseases, "Iloondwa" and "Olkokola" are similar, as they are used to treat syphilis and pain arising in the backbone and leg joints. The same traditional herbal medicines are also used for the removal of wastes from human bodies. Stomach aches, backbone, and pain from leg joints are cured with the use of "Okonyil". Malaria and worms are treated with "Omukutan". Moreover, "Omukutan" is used as an ingredient for making a person vomit, particularly pregnant

Table 4 Shows traditional medicines used to treat diseases in NCA. Source: Field data

Traditional herbal medicines	Frequency	Percent (%)
Iloondwa	190	48.0
Okonyil	88	22.2
Olkokola	54	13.6
Omukutan	30	7.6
Olosuki	20	5.1
Okitalaswa	14	3.5
Total	396	100.0

women, when they feel uncomfortable. It was mixed with boiled animal blood and oil during the treatment. Pneumonia, chest pain, and fever accompanied by sneezing are healed with the use of "Olosuki". Lastly, "Okitalaswa" treats severe fever and is also applied as an ingredient for the digestive system. The vernacular terms refer to the names of herbal medicinal plants for the treatment of diseases. Conversely, the collection of traditional herbal medicines in the forest, i.e., the dwelling places for wildlife, drives human—wildlife into interactions in the NCA. The Maasai communities are endowed with the knowledge of traditional herbal medicines for disease treatment. The shortage of modern dispensaries/hospitals coupled with the harsh environment has forced the Maasai communities to be more involved in the use of traditional herbal medicines, hence driving them into constant contact with wildlife in the forest. The study by Mkiramweni et al. [39] noted that the pastoralists' community engaged in the extraction of materials such as medicinal plants, fuelwood, and poles for construction. As a result, conflicts might emerge leading to injuries and deaths for both humans and wildlife. The conservation of wildlife is blamed for the disenfranchisement of people, repudiating people's access to traditional and appropriate rights, disease transmission, and danger to human life through attack by wildlife and damage to property [58].

During physical field visits and discussions with key informants, it was revealed that wildlife injured a number of people, but they were unreported to the dispensaries/hospitals as they were treated by traditional herbal medicines.

3.12 The community killing the predators

All 386 (97.5%) of the respondents reported that Maasai hunters do not kill predators. The agreement between the community and NCAA prohibited the Maasai hunters from killing the predators. The Maasai are promised incentives for any damage inflicted by wildlife, such as the predators killing livestock, which are the sole economic of the pastoralists. As reported previously, livestock is the driving factor influencing human—wildlife interactions in NCA. The killing of livestock by predators in NCA is unavoidable, as there is human-wildlife co-existence. The vulnerability caused by wildlife leads to community involvement in conflict mitigation and the payment of incentives to improve the tolerance of lions across the NCA [46]. The involvement of the community in safeguarding wildlife includes patrol and law enforcement. It intends to avoid the killing of wildlife by humans as retaliation after the wildlife invades humans or domestic animals. As reported earlier, the introduction of Kope Lion organization in the NCA improves human-lion co-existence aiming at tolerance and avoiding the killing of lions. Mhuriro-Mashapa et al. [38] reported that the conflicts and damage resulting from human—wildlife interactions lead the communities to retaliate by killing wildlife and poaching. Thus, human—wildlife interactions have caused conflicts that lead to injuries and deaths.

3.13 Challenges related to human, domestic animal, and wildlife interaction

About 35.9% of the respondents mentioned disease transmission among the challenges related to human, livestock, and wildlife interaction in the NCA; 22.7% destruction of property; 19.9% mortality of humans, wildlife, and livestock; 17.4% serious harm to humans; 3.5% loss of income; and 0.5% others, such as competition for grazing lands and water supply (Fig. 5). With these responses, humans and livestock are at higher risk due to interaction with resident wildlife, as the interaction could lead to the transmission of infectious diseases. The co-existence among humans, livestock, and wildlife is the main driving factor for interaction in the NCA. The NCA is designed as the multiple land use where humans and wildlife co-exist i.e., human activities such as livestock keeping are taking place together with wildlife conservation. As mentioned previously, the interaction could also be driven by the sharing of habitats, which in turn brings disasters to the communities. The notable challenge of human—wildlife interaction is the transmission of infectious diseases originating from wildlife to humans. As noted by URT [69], 797 people (390 men (49%) and 407 women (51%)) suffered from tuberculosis disease in four years (2016–2019) in NCA.

Fig. 5 Challenges of human—wildlife interactions
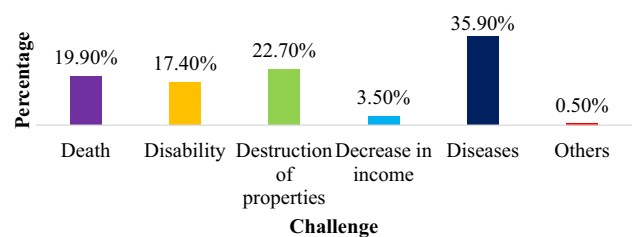
During the questionnaire interview, the researchers observed a person attacked and injured by buffalos in the NCA. The communities residing in the NCA are under constant invasion by wildlife; hence, precautions are needed by the communities as they are in wildlife residences.

### 3.14 People hospitalized due to attacks by wildlife 2015–2020

During questionnaire interviews and discussions with key informants, it was revealed that human—wildlife contact led to the attack of 158 people in the NCA in a period of five years (2015–2020), as indicated in Fig. 6. The distribution showed that 59 people (37%) were attacked by buffalos, 21 people (13%) by elephants, 19 people (12%) by lions, 9 people (6%) by leopards, 20 people (12%) by hyenas, 3 people (2%) by cheetahs, 4 people (3%) by hippopotamus, 9 people (6%) by wild dogs, and 14 people (9%) were bitten by snakes in a period of five years. On the other hand, 21 people (13.3%) among 158 invaded by wildlife died due to elephant attacks. However, the lack of consistency in record keeping has made it difficult to obtain records in some years. The provided data for wildlife attacking humans were obtained from only one hospital. An awareness of the importance of records keeping could be the main reason for the failure to keep records. The dispersed settlements coupled with limited hospitals or health centers in the NCA have contributed to the difficulty in keeping records. With unclear documentation for referral given to people for further treatment to Kilimanjaro Christian Medical Centre (KCMC) in the Kilimanjaro region due to wildlife, attacks have made obtaining data difficult. The alternative choice for attending between government or private hospitals has also made it difficult to obtain data on hospitalized people due to different policies for data release. Due to the presented challenges discussed, it is difficult for measures to be taken to minimize wildlife attacking humans in the NCA. A study by NCAA [69] confirmed that carnivore's conflict with humans through attack or predation on livestock.

4 Conclusion and recommendations

The results of this assessment clearly showed that the main driving factors for human—wildlife interactions are habitats that comprise water, pasture, and related food sources. Other driving factors for human—wildlife interactions and conflicts are the increase in wildlife, collections of firewood, domestic animals kept by the community, the influence of sleeping arrangements, searching for traditional medicines in the forest, and rituals killing the predators. Large household sizes coupled with climate change have also driven and fuelled human—wildlife interactions, as they co-use scarce and limited water sources. Conversely, the study identified several challenges threatening human-wildlife co-existence in the NCA, such as injuries, deaths, disease transmission, and destruction of properties. To mitigate human—wildlife interaction and conflicts leading to injuries, deaths, disease transmission, and destruction of properties in the NCA (co-existence area), the following are recommended:

- To increase boarding schools and enrolment of students in schools in the NCA. Also, accessible and reliable transport should be provided to residents to reduce interactions with wildlife.

Fig. 6 Number of people hospitalized. Source: Demographic Health Surveys (DHS)
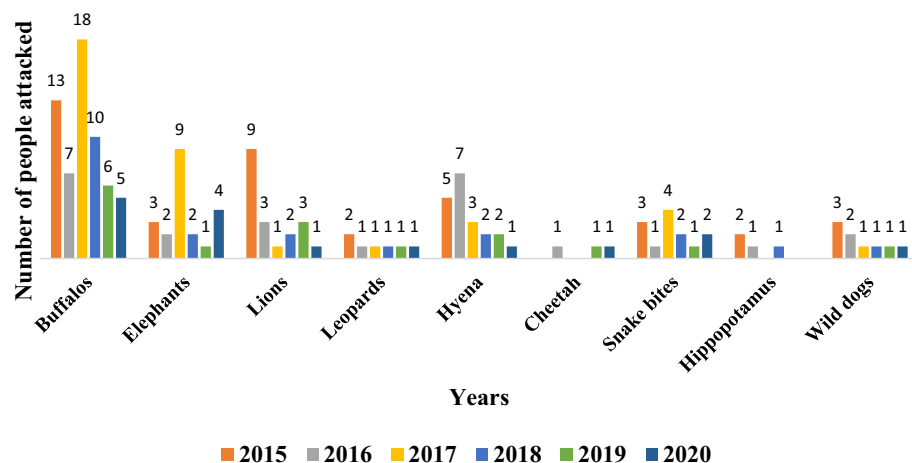
- Increase establishment and distribution of tap water that should be in proximity to residents' houses to avoid co-usage with wildlife to lessen human−wildlife interactions and conflicts
- Increase assistance in terms of food to the community living in poverty to avoid unnecessary movement in the struggle to obtain basic needs hence having better human-wildlife co-exist
- Measures should be taken to control the population increase through reallocation of the population in other areas to avoid human−wildlife competition over scarce resources in the NCA
- To introduce zero grazing, which could lessen human−wildlife interactions in the NCA
- To encourage the community to use biogas to reduce human−wildlife interactions in collecting firewood.
- To discourage community sleeping arrangements, i.e., the community sleeping with calves in the same house, as it could fuel disease transmission
- To provide research findings to the community to benefit from the knowledge obtained from the findings and incorporate them into human-wildlife co-existence

Data availability Data will be provided upon request.

Code availability Not applicable.

Declarations

Ethics approval and consent to participate The study obtained ethical clearance from Ardhi University; the United Republic of Tanzania Commission for Science and Technology (COSTECH), with research permit number 2020-295-NA-2020-123; Tanzania Wildlife Research Institute (TAWIRI) and the Ngorongoro Conservation Area Authority (NCAA) before data collection. The respondents were also informed of the purpose of the research, and confidentiality was assured before conducting interviews. In addition, the final manuscript was read and approved by the National Institute for Medical Research (NIMR), with reference number NIMR/HQ/R.8a/Vol./3474 before it was submitted for publication. All procedures performed in this study that involved human participants were in accordance with the ethical standards of the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Competing interests All authors have declared that they have no conflicts of interest.

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