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Spatio-Temporal Patterns of Increasing Illegal Livestock Grazing over Three Decades at Moyowosi Kigosi Game Reserve, Tanzania

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Abstract: The global increase of livestock has caused illegal intrusion of livestock into protected areas. Until now, hotspot areas of illegal grazing have rarely been mapped, long-term monitoring data are missing, and little is known about the drivers of illegal grazing. We localized hotspots of illegal grazing and identified factors that influenced spatio-temporal patterns of illegal grazing over three decades in the Moyowosi Kigosi Game Reserve (MKGR), Tanzania. We used questionnaires with local pastoralists (N = 159), georeferenced aerial survey data and ranger reports from 1990–2019 to understand the reasons for illegal grazing in the area. We found that hotspots of illegal grazing occurred initially within 0–20 km of the boundary (H (3) = 137, $p < 0.001$; (H (3) = 32, $p < 0.001$) and encroached further into the protected area with time (H (3) = 11.3, $p = 0.010$); (H (2) = 59.0, $p < 0.001$). Further, livestock herd sizes decreased with increasing distance from the boundary ($R = -0.20$, $p = 0.020$; $R = -0.40$, $p = 0.010$). Most interviewees (81%) claimed that they face challenges of reduced foraging land in the wet season, caused by increasing land used for cultivation, which drives them into the MKGR to feed their livestock. We conclude that there is spatio-temporal consistency in the illegal livestock intrusion over three decades, and hotspot areas are located along the boundary of the MKGR. We suggest focusing patrols at these hotspot areas, especially during the wet season, to use limited law enforcement resources effectively.

Keywords: anti-poaching; interviews; protected areas; mapping hotspots; cattle; Eastern Africa

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1. Introduction

Livestock herds roam on more than one-third of the Earth's surface [1–4], often sharing land resources with wildlife [5]. The total number of livestock in the world is approximately 3.6 billion, with an average annual increase of 25 million individuals over the preceding 50 years [6]. Globally, the exponential growth of livestock triggers incidences of illegal livestock intrusion into protected areas (PAs) [7]. For instance, pastoralists let their livestock graze illegally inside protected areas in India, Vietnam, Uganda, Kenya and Ethiopia due to limited forage availability outside PAs [8–12]. These incidents often lead to a negative environmental impact on vegetation resources and the co-occurring of native wildlife in PAs [7,13]. More than 50% of the world's pastoralists are found in Africa [14]. After Ethiopia and Sudan, Tanzania has the third largest livestock population in Africa [4], with 25 million cattle, increasing annually by 5% within the last 15 years [15]. In Tanzania, livestock contributes to 7.4% of the country's GDP [15].

Globally, livestock often shares land and forage resources with wildlife close to PAs [16]. The interaction of wildlife and livestock in PAs increases tension for protecting wildlife and their habitats [17] and triggers human-wildlife conflicts [18]. Further, domestic dogs accompanying herders or the intended poisoning of predators by the herders have negatively affected wildlife [19].

Despite these challenges, only a few studies have examined factors contributing to illegal grazing and localized grazing hotspots and monitored their development over time. Further, these current efforts that examined the spatio-temporal effect of illicit activities in PAs have often combined various illegal activities, assuming they all have one particular cause [17,20]. Reasons for entering into PAs with livestock have repeatedly been named as lenient penalties for illegal grazing compared to other wildlife offences [17], the demand of foraging resources inside PAs, which are not found elsewhere [21], a limited benefit that communities receive from wildlife resources [22,23], owning large numbers of livestock [21] and limited anti-poaching efforts in relation to the size and challenge of the PAs [17,24]. Studying the combination of illegal activities such as illegal fishing, grazing, logging, wildlife poaching and wildlife snaring prevents a deeper understanding of their driving cause, especially grazing activities, and hinders suitable developing approaches towards interventions [17,25].

Often, illegal activities occur inside but close to the borders of PAs [26,27]. Still, little is known about the hotspots of illegal grazing in Tanzania and whether this phenomenon is season-dependent or has increased over time. There is anecdotal evidence that livestock intrusions have increased over the last three decades in the Moyowosi-Kigosi Game Reserve (MKGR), Tanzania (pers. comm.). This intrusion has been reported in the southern part of MKGR but might have recently spread into different areas [28]. Hence, we wanted to create a heat map of hotspots of illegal grazing and entering points for herds in MKGR. Moreover, using questionnaires, we aimed at examining factors that might contribute to illegal grazing. We further wanted to quantify if livestock numbers in MKGR have increased over time and whether livestock grazing incidents have spread further into MKGR, i.e., further away from its boundary into the reserve.

We used questionnaires, aerial census data from 1990–2014, rangers' anti-poaching patrol data from 2017–2019 and reports from relevant authorities to identify locations, extensions and reasons for intrusions. We expected that hotspot areas of illegal grazing would mainly be along the boundary of MKGR and would remain similar in location over a long period (30 years) due to easy access and withdrawal in case of detection [26,27]. We further predicted that the distance of illegal livestock intrusion into MKGR would increase with time, i.e., livestock would be found very far away from the boundary of MKGR into the reserve as herders become increasingly familiar with the reserves [10]. We also hypothesized that livestock herd sizes would become smaller further into the MKGR as illegal manoeuvres inside the reserve would be easier if herd sizes were small [29]. In addition, we expected that the incidences of illegal grazing would be higher during the dry season, when forage and water are generally scarce [30].

Our study will help identify high seasons and hotspot areas for illegal grazing so that anti-poaching efforts can effectively use the limited resources available. Through our interviews, we further highlight factors that influence illegal grazing, which will support developing strategies to maintain both wildlife and livestock as a significant socio-economic income activity at the local and international levels.

2. Material and Methods

2.1. Study Area

We conducted our study in the twin game reserves, Moyowosi and Kigosi Game Reserve (MKGR), which is in the western part of Tanzania, located between 3°15′ and 5°00′ S, and 30°30′ and 32°00′ E (Figure 1). The MKGR was gazetted in 1981 and 1983 and covered 6000 km^2 and 7000 km^2, respectively [31]. Like many protected areas globally, the MKGR was also inhabited by humans before its official gazetting and people were evicted and

denied access to MKGR resources [32]. The MKGR harbours diverse animal species, such as the African slender-snouted crocodile, *Crocodylus cataphractus,* bird species such as the shoebill (*Balaeniceps rex)* and the wattled crane (*Bugeranus caruncuta)*, as well as the African elephant (*Loxodonta africana*), lion (*Panthera leo*), giraffe (*Giraffa camelopardalis)* and African buffalo [33]. Miombo woodland is the primary vegetation type dominated by the African blackwood (*Dalbergia melanoxylon*) and the blood wood (*Pterocarpus angolensis*) [33]. The MKGR is part of the Malagarasi-Muyovozi Ramsar site with extensive wetness throughout the year, pronounced from November to June, and borders the politically unstable countries Burundi, Congo and Rwanda, which has created tension with illegal activities [34]. The number of livestock has been increasing in the MKGR from 326 in 1990 to 23,586 in 2014 [35].

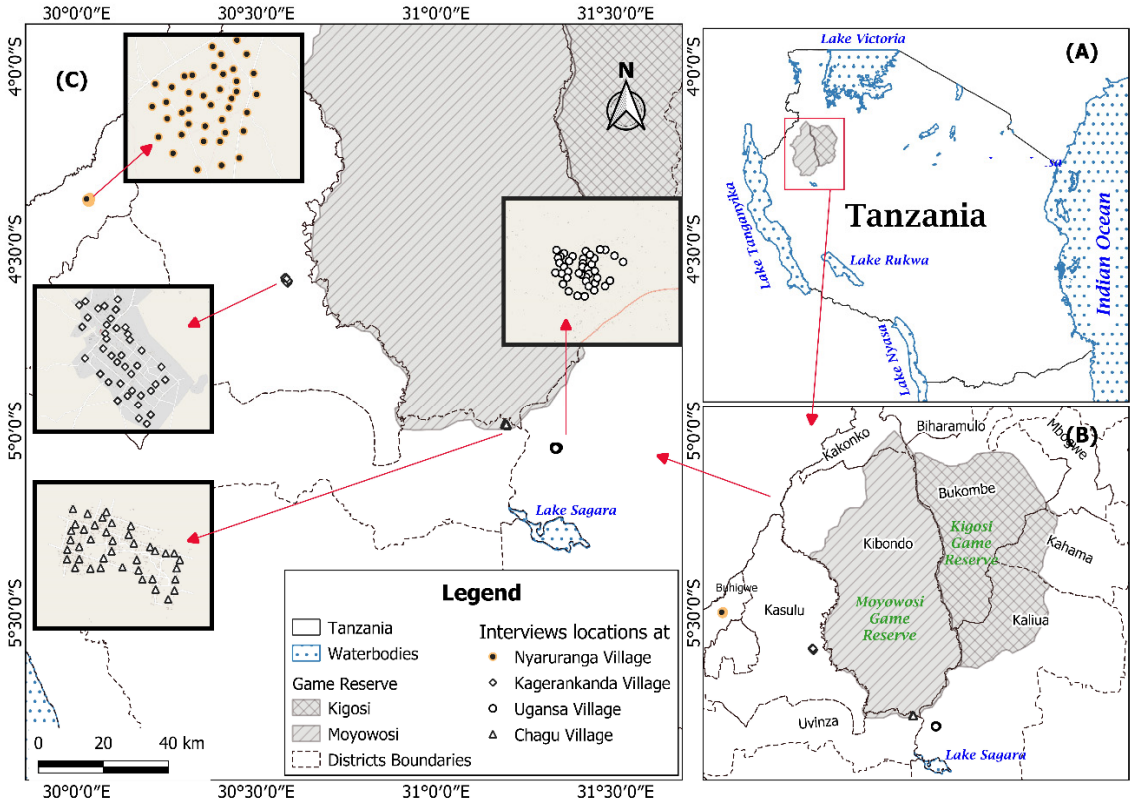

Figure 1. The four districts around the MKGR that are mainly affecting the reserve through illegal grazing. Locations of interviews taken in 2019 at the four different villages shown (Chagu in Uvinza district, Ugansa in Kaliua district, Kagerankanda in Kasulu district and Nyaruranga in Kibondo districts; N = 159). (**A**) The map of Tanzania displaying the Moyowosi Kigosi Game Reserve (MKGR) in the Western (**B**) The mapa of MKGR displaying the four districts where interview took place, i.e., Uvinza, Kaliua, Kasulu and Kibondo districts (**C**) The four villages where interviews were taken (Chagu in Uvinza district, Ugansa in Kaliua district, Kagerankanda in Kasulu district and Nyaruranga in Kibondo districts).

Communities living around the MKGR have limited access to conventional employment and mainly engage in pastoralism, agriculture, beekeeping, fishing and mining activities as a source of their livelihood [36]. Increased anthropogenic activities have been reported, such as illegal grazing, poaching, charcoal making, illegal logging, illegal fishing and uncontrolled burning, which strongly hampers the conservation efforts of MKGR [36,37].

Ranger anti-poaching reports indicate an annual variation in the number of illegal livestock herds encountered in reserve, from 90 individuals in an area barely intruded by illegal herds to 19,397 individuals in an area frequently invaded by illegal herds [38]. Furthermore, the aboveground biomass and grass cover in a place repeatedly intruded by illegal grazing is 55% and 36% lower than the area less invaded by illegal grazing, respectively [39]. The

rangers' patrol effort has recently increased to encounter increasing challenges of illegal grazing. The estimated patrol efforts in the wet season were 3360 worker-days^{-1}, while during the dry season, the patrol effort was 1200 worker days^{-1} [38].

2.2. Data Collection and Analysis

To map and identify hotspots of illegal grazing, we used two data sets: (1) The geographical coordinates of livestock herds encountered from aerial census data of the Tanzania Wildlife Research Institute (TAWIRI) during the dry seasons of the years 1990, 1995, 1998, 2000, 2002, 2003, 2006, 2009 and 2014 [35]. (2) Livestock herds encountered by rangers during their anti-poaching patrol for the 2017–2019 period based on ranger reports in the MKGR. We organized these data into four groups of three year periods; years 1990–1998, years 2000–2003 and 2006–2014 (TAWIRI reports), and separately analyzed trends for the years 2017–2019 (ranger reports) to understand the spatio-temporal trend of illegal grazing in the MKGR over three decades. We used semi-structured interviews to get more insight into the causes of illegal grazing in the MKGR [40]. We interviewed 159 key respondents from four villages in four districts known to enter the MKGR for illegal grazing (MKGR reports, Districts Authority). The villages are Chagu in Uvinza, Ugansa in Kaliua, Kagerankanda in Kasulu and Nyaruranga in the Kibondo districts (Figure 1). The key informants were identified through the assistance of local administration (ward), village government and MKGR staff, based on their daily practices in livestock keeping, beekeeping and agriculture. In each village, 40 households were interviewed. In addition, we trained one primary school teacher from each village who had previously conducted interviews, knowing the village under study, illegal grazing and vernacular language (Swahili, Sukuma and significant language of the village as recommended by village governments). The questionnaires were prepared in English and translated into Swahili, and we conducted pre-test interviews. Interviews were conducted from May–November 2019 during both the dry and wet seasons [41]. We observed the current livestock grazing and forage availability in the districts using informal conversation and grey literature.

2.3. Data Analysis

We analyzed the spatio-temporal trend of illegal grazing in MKGR from 1990–2014. We used georeferenced data to calculate the distance from the boundary of the MKGR and identify hotspots of illicit grazing in the MKGR using ArcGIS and QGIS 10.8 and 3.18, respectively. We visualized the hotspots of illegal grazing by plotting four heat maps with Kernel density for years 1990–1998, 2000–2003, 2006–2014 for TAWIRI'S survey data and the years 2017–2019 based on ranger reports [25]. The distance from the boundary of the MKGR was calculated using the ArcGIS nearest distance tool to determine how far the livestock entered into the reserve over time. Data for frequencies of incidences of illegal grazing and distance from the boundary of the reserve did not obey normality and equal variance [42] and, hence, we applied Kruskal-Wallis followed by pairwise Gomes Howell comparisons tests across four distance categories: close 0–20 km, medium 21–30 km, far 31–40 km and very far away (>40 km) from the reserve's boundary. For those categories, we determined if illegal livestock intrusion predominantly occurred close to the reserve's boundary and whether it encroached further into the reserve with time. We performed correlation analysis to determine if the livestock herd size increased with increasing distance from the reserve's boundary. We performed statistical analysis using Jamovi version 1.2 [43] and R version 4.0.3 [44].

3. Results

3.1. Hotspots of Illegal Grazing at the Boundary of MKGR

Supporting our hypothesis, we found that the hotspots of illegal grazing mainly occurred at the boundary of the Game Reserve, whereby 69% (N = 184) of incidences of illegal grazing were within 0–20 km (H (3) = 137, $p < 0.001$; Figure 2, Table 1). In the years 1990–1998, there were only 25 incidences of illegal grazing, concentrated in the southern

part of the MKGR (Figure 2A, Table 1). However, the incidences of unlawful grazing increased in 2000–2003 by 77%, compared to 1990–1998, and extended further towards the eastern and northern part (Figure 2B, Table 1). The frequency of illegal grazing in 2006–2014 was 82% and 21% higher than those in 1990–1998 and 2000–2003, respectively, stretching from the south towards the north and western part of MKGR (Figure 2C, Table 1). Data from ranger reports depicted similar results, whereby 81% of incidences of illegal livestock grazing occurred within 0–20 km (H (3) = 32, $p < 0.001$; Figure 2D, Table 1), and incidences followed the same pattern as in 2006–2014, except that they extended more in the southeastern and northwestern part.

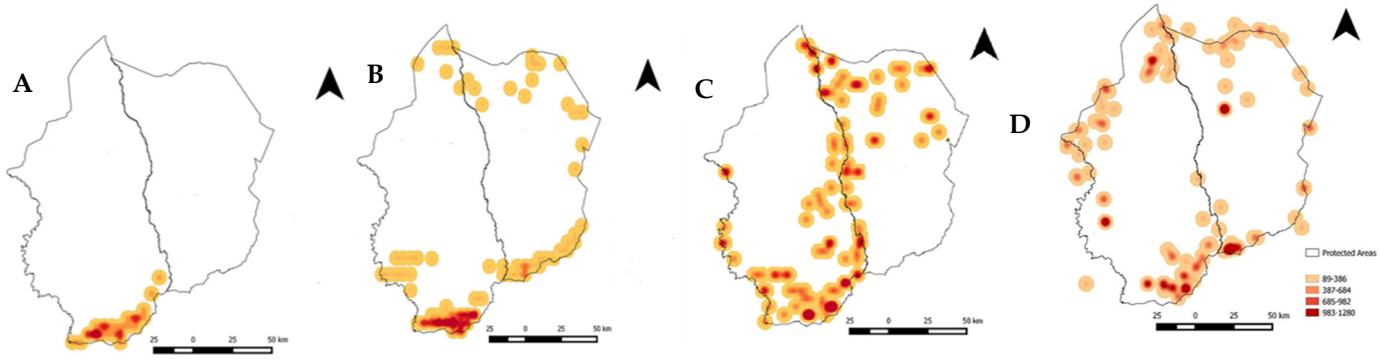

Figure 2. Spatio-temporal patterns of incidents of illegal grazing in Moyowosi-Kigosi Game Reserve between the years 1990 and 2019. (**A**) Spatio-temporal pattern of illegal grazing in the years 1990–1998, (**B**) for the years 2000–2003, (**C**) for the years 2006–2014 and (**D**) for the years 2017–2019. (**A**–**C**) Spatial data from the survey report and (**D**) spatial data from the rangers' report. The colours of circles represent the number of livestock individuals per herd.

Table 1. Frequencies ("per year" = frequency per year category and "cumulative" = cumulative percentage frequency across all years) of incidences of illegal grazing from the reserve boundary across four distance categories away from the reserve's boundary into the Moyowosi-Kigosi Game Reserve. Data are based on survey data for 1990–1998, 2000–2003 and 2006–2014, separately, N = 270. In addition, we used ranger report data for the years 2017, 2018 and 2019, separately, N = 78.

	Close (0–20 km)	**Medium (21–30 km)**	**Far (31–40 km)**	**Very Far Away (>40 km)**	*p*
Survey					
Cumulative (%)	69 (n = 184)	16 (n = 42)	7 (n = 18)	9 (n = 26)	
Per year (%)					
1990–1998	25	0	0	0	<0.001
2000–2003	66	42	0	0	
2006–2014	93	0	18	26	
Ranger reports					
Cumulative (%)	81% (n = 63)	17% (n = 13)	1% (n = 1)	1% (n = 1)	
Per year (%)					
2017	25	13	1	1	<0.001
2018	22	0	0	0	
2019	16	0	0	0	

3.2. Illegal Intrusion Progresses Further into the MKGR with Time

The survey data indicate that the mean distance travelled by livestock away from the MKGR boundary into the reserve increased significantly over time, i.e., across the year categories 1990–1998, 2000–2003, 2006–2014 (H (2) = 11.3, $p = 0.01$; Figure 3A). The longest distance intruded by livestock into the reserve (very far away) was 62.1 km in the year 2006–2014 for surveys data and 46.3 km in 2017 based on rangers anti-poaching reports (Figure 3A). The mean intruded distance for 2006-2014 was 63% higher than in 1990–1998 and 56% higher than in 2000–2003 (Figure 3A). In contrast, ranger report data indicated a

significant decline in the mean distance travelled by livestock into the reserve for the years 2017, 2018 and 2019 (H (2) = 59.0, $p < 0.001$; Figure 3B).

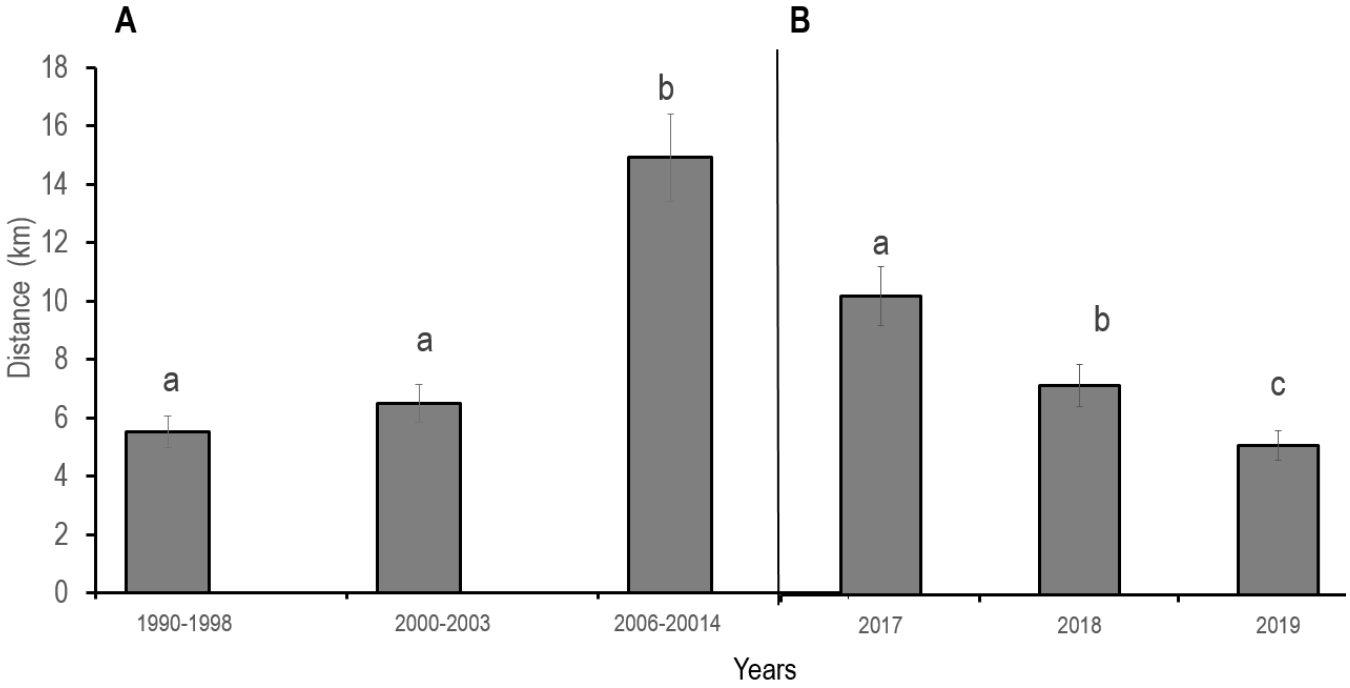

Figure 3. Average (±SE) distances from the reserve boundary into the reserve of locations where illegal livestock intrusion was encountered. Distances are shown as km away from the boundary of Moyowosi—Kigosi Game Reserve (MKGR) into the reserve (**A**) for the years 1990–1998, 2000–2003 and 2006–2014 for survey data and (**B**) for the years 2017, 2018 and 2019 based on ranger report data. Different small letters denote statistically significant differences across year categories by Gomes Howell test at $p = 0.05$.

3.3. Livestock Herd Size Decreased with Increasing Distance into the MKGR

Both survey data (Figure 4A) and ranger report data (Figure 4B) showed that the individual livestock numbers per herd significantly but slightly declined as the distance into the MKGR increased ($R = -0.20$, $p = 0.020$; Figure 4A; $R = -0.40$, $p = 0.010$; Figure 4B).

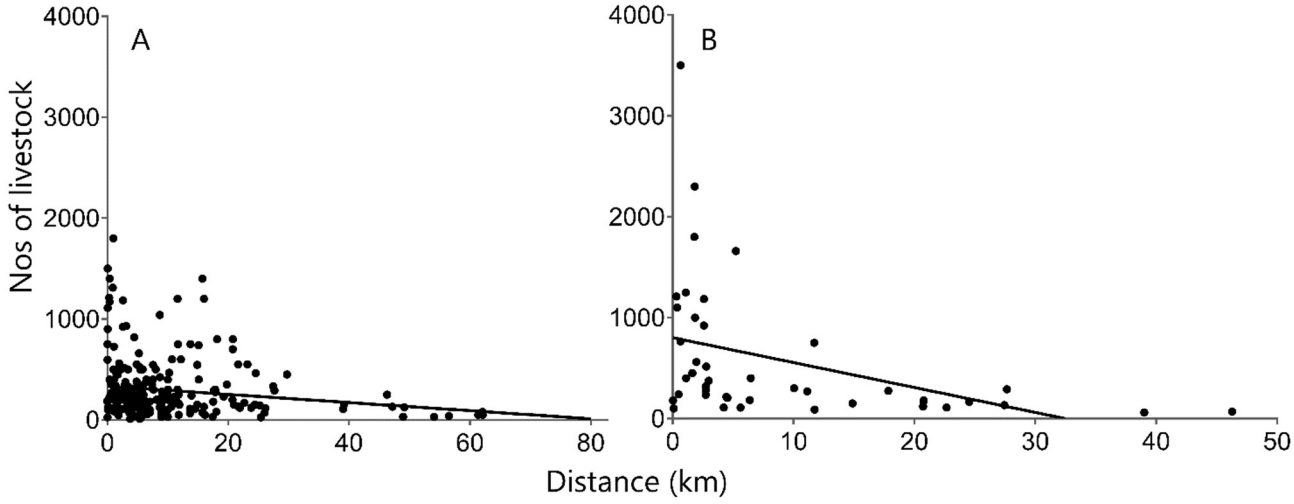

Figure 4. Correlation between the distance from the reserve's boundary into the reserve (distance in km) and the number of individuals' livestock per herd based on (**A**) data taken during the aerial survey for the years 1990–1998, 2000–2003 and 2006–2014 and (**B**) data from ranger reports for the years 2017, 2018 and 2019.

3.4. Communities Face Challenges in Feeding Their Livestock in the Wet Season

Contrary to our hypothesis that the community faces the most significant challenges for feeding their livestock during the dry season, 128 (81%) of all respondents (N = 159) mentioned that they face challenges during the wet season, while 16% said they face challenges in both dry and wet seasons and 15% mentioned dry season only. Further, 118 (74%) respondents mentioned a challenge that there is not enough grazing land during the wet season because the lands available are too close to cultivated farms. As a result, the herders avoid conflicts with farmers, as livestock may forage on farmers' crops. In addition, 18% claimed no crop residues were available during this time, while 8% mentioned a high price of alternative fodder, which they could not afford.

4. Discussion

4.1. Hotspots of Illegal Grazing Are at the Boundary of the Game Reserve

Our results depicted hotspots of illegal grazing to occur mainly at the boundary of the MKGR, particularly in the south but later on in the northern part of the MKGR, which is likely due to an easy escape route for illegal herders before rangers catch them. Similar reasons were observed in Zimbabwe and Kenya, whereby herders illegally grazed their livestock as close to the PAs boundary as possible [26,27]. The hotspots of illegal grazing remained consistent along the southern borders of MKGR from 1990 onwards, likely because of weak anti-poaching patrols by underpaid village game scouts in the ISAWIMA Wildlife Management Areas. The weak anti-poaching patrol possibly encouraged illegal herders to penetrate and graze their livestock in the MKGR. This tendency was also observed by [24] in the Selous Game Reserve, where poachers used the Wildlife Management Areas as their shelter to enter and poach in the Game Reserve.

The observed consistency of hotspots of illegal grazing along the border over the periods of 1990–1998, 2000–2003, 2006–2014 and 2017–2019 can be explained by crime pattern theory [45] and crime concentration law [46]. In this theory and law, criminals commonly familiarize themselves with the target area and repeat the crime when the opportunities arise [45]. This indicates that crime is usually concentrated at specific points, where patrols are scarce [46]. In addition, one crime might trigger other illegal activities, e.g., the presence of illegal herders may cause illegal extraction of resources such as wildlife, fish, wild coffee, mushrooms and trees for charcoal, firewood and construction poles [17]. This was also observed in our study (pers. obs) and reported at Kibale National Park in Uganda by MacKenzie, Chapman and Sengupta [8]. Thus, our data based on the survey and ranger reports highlighted hotspot areas on which rangers' anti-poaching activities act should focus. Therefore, we recommend the MKGR management develop anti-poaching programs such as paramilitary joint anti-poaching, zero illegal grazing campaign, intelligence-led approach and benefit-sharing schemes [47]. These programs will effectively enhance the use of scarce law enforcement resources to address illegal herders at the hotspot areas along the boundary of the MKGR.

4.2. Livestock Intruding further into the MKGR with Time

The distance of illegal livestock intrusion into the MKGR increased by 78% from 1990 to 2014. The herders still penetrated further, i.e., up to 46.3 km inside the MKGR in 2017, regardless of the risks associated with illegal grazing, such as loss of livestock in the wilderness, livestock predation, financial fines and other punishments posed to the pastoralists [47]. The persistent illegal resource use in the MKGR, despite the associated costs experienced, could be an indication that the benefit of grazing livestock illegally in the MKGR was higher than the penalty, or that herders did not fear punishment [48], which was also observed in Ranthambore, Kanha and Nagarahole National Parks in India [10].

Our pastoralist respondents (66%) mentioned that they preferred feeding their livestock inside the MKGR because of particular grass species, which were nutrient-rich and palatable. However, due to long term persistence in livestock grazing along the boundary, they had to graze further into the MKGR, where these plant species were still available.

These species were *Hyparrhenia rufa*, *Themeda triandra*, *Panicum maximum*, *Sporobolus* spp., *Cynodon dactylon*, *Brachiaria* spp. and *Cyperus* spp., which are essential forage grasses in East Africa [49,50].

The features that encouraged illegal grazing to persist inside the MKGR resemble three elements that enhance crime [51]. Firstly, illegal herders are motivated by their need to feed their livestock (motivated offenders); secondly, the presence of nutritious grasses and water inside MKGR that can sustain their livestock during the challenging period (suitable targets) and; thirdly, the absence of rangers that would detect illegal herders (absence of capable guardians against a violation). In MKGR, little has been done in prosecuting illegal herders as The Wildlife Conservation Act of 2009 states it is illegal to enter livestock inside PAs, but it does not state its punishment [52]. This Act suggests confiscating livestock that illegally intrudes into PAs. However, the process for prooving illegal grazing and the successive prosecution takes too long, as our expert interviews with rangers showed. We observed that prosecution time takes 6–12 months in our data sets. The lenient law for suing illegal herders indicates that some wildlife offences have minimal consequences, further triggering poaching and other activities associated with an illegal offtake of PA resources [17].

The fact that rangers' data showed a slight decrease in distance of illegal livestock intrusion for the years 2017–2019 could be an indication that the MKGR management might have developed strategies that enabled rangers to detect illegal herders more readily, and that associated fines, including confiscation of livestock, are working. This might have been successful due to political support in addressing the livestock encroachment in PAs, especially from the 2017–2019 period onwards [53]. On the other hand, the decrease in distance of illegal livestock intrusion might also be an artefact that anti-poaching patrols might not have been able to cover a wide range of areas. Hence, the probability of rangers detecting illegal herders might have been limited due to accessibility or financial limitations. This highlights the importance of using two separate data sets in our study to understand short-term and long-term trends over the last 30 years for appropriate management and conservation actions.

We recommend that livestock confiscation should be the main punishment to stop illegal grazing in MKGR. Furthermore, since the availability of preferred grass species is a pulling factor that encouraged further intrusion inside the MKGR, MKGR management should conduct studies on areas outside the reserve that could be re-seeded with grass species communities preferred by herders.

4.3. Herd Sizes Decreased with Distance from MKGR Boundary

Our data portrayed that livestock herd sizes decreased as the distance of intruding into the MKGR increased. Three reasons could explain this; first, illegal herders might have purposely taken smaller herds as these will be easier to handle while escaping from rangers. Second, predators might have reduced livestock herd size, particularly during the wet season, when predators are scattered due to the presence of water in every part of the reserve [29]. Last, herders might have experienced livestock death or loss during their long journey into the MKGR.

Generally, we found that the pastoralists around the MKGR faced similar challenges as pastoralists elsewhere, i.e., limited land for grazing due to anthropogenic activities, climate change and human and livestock population growth [8,24,54]. Pastoralists in the MKGR strive to provide their livestock with high quality and quantity forage by planning and tracking forage resources, building livestock enclosures close to PAs to minimize travelling distance, mixing herds with others to enhance their protection and employing experienced herders who can protect livestock from dangerous animals [55]. During our study period, we observed that various herders were young boys, which has also been shown to be a successful strategy in other cases, as young boys found inside PAs are generally not prosecuted [56]. Furthermore, the pastoralist respondents acknowledged that livestock in

MKGR has been foraging in the reserve for a long time. Therefore, the pastoralists claimed it was high time to legalize livestock grazing in the game reserves.

Livestock grazing can affect wildlife negatively or positively. Some studies found that livestock grazing can be positive by adding nutrients to the soil through dung depositions, ensuring plant growth and food supply for wild herbivores [57]. Livestock also grazes and remove mature grasses, stimulating the sprouting of new vegetation and enhancing food availability for other wild herbivores [1,58]. The negative impact of livestock grazing on wildlife occurs mainly in areas with high livestock densities [57], which reduce grass cover and biomass, affecting soil penetration and infiltration rate [59,60]. Depending on the body mass of wild herbivores and feeding ecology, wildlife may also compete for water and forage with livestock [5]. We conclude that the observed strategies of reducing herding size when intruding further inside the MKGR, employing young herders and mixing herds to ensure illegal herd survival inside MKGR indicates that illegal herders are determined to continue grazing inside the MKGR. The MKGR management should explore all possible options to end the unlawful grazing in the MKGR.

4.4. Limited Livestock Foraging Resources during the Wet Season

We found that the most challenging time for feeding livestock was during the wet season, which contradicts our hypothesis. Most of our respondents showed that livestock foraging is hampered by agriculture during the wet season. There was no formal land set aside for pastoralists to feed their livestock. Our findings also contradict other studies conducted in Burkina Faso, Benin, Niger, Mexico and Uganda by [8,30,61], which found that livestock mainly intrudes PAs during the dry season when there is a shortage of pasture and water availability. Pastoralists around the MKGR avoid foraging their livestock in farmland during the wet season, fearing quarrelling with farmers, which was also observed by [29,62] in Zimbabwe and Kenya. However, our respondents mentioned that some farmers around the MKGR allowed pastoralists to feed on the crop residues during the dry season because livestock grazing cleared their farms and added free manure. This result contradicts the observation found at Kachia Grazing Reserve, in Northwest Nigeria, where pastoralists and farmers quarrelled [63].

Three factors likely favoured illegal grazing inside the MKGR during the wet season: the presence of dense vegetation as a hideout [64,65], the inaccessibility during rainfall hindering patrol coverage by rangers [24] and the absence of trophy hunting activities during the rainy season, i.e., the low tourist season, which usually complements surveillance in MKGR [54]. Our findings are similar to the results in Zambia and Kenya, where dense vegetation influenced the availability of wildlife snare intensity and illegal grazing [48,66]. The MKGR should construct permanent ranger posts at our identified hotspot areas to minimize access challenges during the wet season, reduce travelling distance and enhance continuous surveillance of the affected areas. This could also help increase anti-poaching coverage on the hotspot areas during the low tourist season, combined with other facilities such as amphibious boats. In addition, the MKGR should furth investigate the possibility of constructing watershed roads to ensure accessibility in areas affected by seasonal rivers and floods and ensure constant surveillance in hotspot areas, even in the rainy season.

5. Conclusions and Recommendations

We found consistency in locations and use of hotspots of illegal grazing over three decades in the MKGR. Factors contributing to illegal grazing included the absence of foraging land outside the MKGR, the presence of high-quality grasses for livestock inside the MKGR, limited anti-poaching patrol as well as the lenient prosecution law. We highlight that the hotspot locations and timings are predictable and that management can address them, e.g., through permanent ranger posts, constructing watershed roads and investing in facilities such as amphibious boats to ensure accessibility of most areas and, thus, constant surveillance. We recommend that the MKGR management use limited law enforcement resources to address illegal herders at the hotspot areas and improve anti-poaching programs,

including establishing awareness campaigns on the ecological, social and economic impact of illegal grazing on the community around the MKGR. These measures will minimize illegal grazing and promote sustainable conservation of this important Ramsar site wetland in Tanzania.

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