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Patterns of mammalian roadkill in the Serengeti ecosystem, northern Tanzania

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Roads that traverse through protected areas if not well managed can have adverse impact on wildlife such as road-kills which is of global conservation concern. Though mammalian road-kills have been reported in different protected areas worldwide, very little information on the problem is available in the Serengeti ecosystem. This study employed both cross sectional observation and opportunistic encounter methods to determine the patterns of mammalian road-kills along the existing gravel road networks in the area. The results indicated that 29 mammals with encounter rates of 0.016 animals/kilometer including herbivores (75.9%), carnivores (13.8%) and omnivores (10.3%) were found killed more frequently on good roads, probably because of over speeding behavior by drivers. Mammals with small body sizes (<10.0 kg, 44.8%) predominantly Cape hares (*Lepus capensis,* 31.0%) and Thomson gazelle (*Eudorcas thomsonii*, 27.6%) were most frequently killed probably because they are less avoided by motorists than larger mammals; and also, smaller mammals move slowly in crossing the roads than larger mammals, which increases the chances of being hit by vehicles. Cape hares and Thomson gazelles are more abundant species in the Serengeti and their behavior of foraging on road verges and frequently crossing roads to access resources in the area is additional risk. The study findings recommend for high penalties to over speeding drivers and placing wildlife warning signs on the roadside, and education to drivers to change behaviour and reduce road-kills.

Key words: Small body-size, impact, mammals, protected areas, roads, tourism.

INTRODUCTION

Road traversing protected areas facilitate transportation of goods and services to promote tourism and other benefits to conservation (Machado et al., 2015), but if not well managed can create some negative impacts such as wildlife roadkills, which is a leading source of vertebrate mortality worldwide (Arévalo et al., 2017; Meza-Joya et al., 2019; Lala et al., 2021; Lyamuya et al., 2021) that need to be considered beside the benefits that tourism can bring (revenues, jobs, economic support for conservation, poverty reductions, etc) in different protected areas. However, few reports have focused on wildlife-vehicle collisions, which often have resulted in mortality of different wildlife species in many protected areas worldwide (Drews, 1995; D'Amico et al., 2015; Braz

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and Franc, 2016). Also, it had been previously found that roadkill is a serious threat to animal populations, and has the potential to drive threatened populations to extinction (Cook and Blumstein, 2013). Wildlife-vehicle collisions are reported to be the primary cause of death for Cape hare (*Lepus capensis*) among mammals and helmeted guinea fowl (*Numida meleagris*) among avifauna (Lyamuya et al., 2021). The dominance of mammals as a major roadkill taxon has also been recorded in several other studies and their difference across studies may be related to local patterns in vertebrate diversity (Lala et al., 2021). In a different study elsewhere it was found that small to medium-sized mammals, which was mostly represented by dik-dik, suffered the greatest roadkill mortality because most of the small to medium-sized mammals are nocturnal species that are easily blinded by strong vehicle headlight and this could have caused high collision incidences (Lala et al., 2021). Therefore, wildlife roadkill is one of the most obvious impacts of roads on wildlife (Barthelmess, 2014).

In order to determine mortality on wildlife population caused by roadkill, counts have been used across seasons and years in protected areas (Behera and Borah, 2010; Braz and Franc, 2016). Several studies on roadkill in Tanzania have reported on the occurrence of dead animals on the roads (Kioko et al., 2015a,b; Lyamuya et al., 2016, 2021; Njovu et al., 2019; Nkwabi et al., 2018), however, none has indicated the influence of body sizes and diet preference of mammalian species.
Therefore, this study aimed at bridging this gap by documenting the patterns of mammalian roadkill of different body sizes among different mammal species in the Serengeti ecosystem. Body size and diet preference have been reported as important variables to explore patterns in interspecies variation in roadkill frequency and how it affects the probability of roadkill (Ford and Fahrig, 2007). The present study therefore hypothesized that mammalian herbivores would have higher roadkill frequency due to their larger home range and higher population density compared to carnivores (Barthelmess and Brooks, 2010; Green-Barber and Old, 2019). Secondly, small sized mammals (<10.0 kg) would be killed more often than larger mammals because the latter are actively avoided by motorists than smaller mammals; and larger animals move more quickly than smaller animals, so they spend less time crossing a road, which reduces the chance of being hit by vehicles (Ford and Fahrig, 2007). Thirdly, mammalian roadkill would be occurring more frequently on good roads probably because of over speeding behavior by drivers as they are attracted to drive fast on such roads.

MATERIALS AND METHODS

Study area

This study was conducted in the Serengeti ecosystem, which has several protected areas under different management categories including Serengeti National Park (SNP), Ngorongoro Conservation Area (NCA), Maswa Game Reserve (MGR), Loliondo Game Controlled Area (LGCA) and Ikorongo-Grumeti Game Reserves (IGGRs) in Tanzania, and Maasai-Mara National Reserve in South-western Kenya (Nkwabi et al., 2018), and lies between 1°15' to 3°30' S and 34°34' to 36°E (Nkwabi et al., 2018). However, the study focused on the main roads passing through NCA and SNP, which are parts of the Serengeti ecosystem, and was conducted between March and August 2015 (Figure 1).

The ecosystem harbors about 70 mammal species and more than 600 avifauna species and supports one of the largest herds of migrating ungulates and highest concentrations of large predators in the world (Lyamuya et al., 2021). High diversity of animal species is a function of diverse habitats ranging from riverine forests, swamps, kopjes, open grasslands and woodlands. For example, in the south-eastern part of the area is open grassland, the northern part is largely wooded, and the western region is a mix of open and wooded grassland with riverine forest. The open grassland zone receives rainfall typically below 600 mm per year (Lyamuya et al., 2021). In addition, the area receives bimodal rainfall, short rain (November-December) and torrential rain (March-May) seasons. However, in some years inter-annual variations are inevitable especially due to climate variability. The woodland area is occasionally interspersed with patches of tall open grasslands and receives an annual maximum rainfall of 1100 mm (Lyamuya et al., 2021). In general, the Serengeti woodlands are mainly composed of *Vachellia, Balanites* and *Commiphora* species with broad leaved species such as *Terminalia*, *Euclea* and *Croton* as sub-dominates (Bukombe et al., 2018; Lyamuya et al., 2021). The woodlands are dominated by the intermediate grasslands and the topography is highly variable, with catena effects having important influences on woody species (Lyamuya et al., 2021).

Survey plan

During the study, a 200 km stretch of gravel road network passing through the Serengeti ecosystem was surveyed for five consecutive days for each study period in 2015 during wet (March-April, 2015) and dry (July-August, 2015) seasons to document the magnitude, patterns and composition of wildlife roadkill. Two sampling periods were conducted daily: the morning period (07:30-11:30 h) as the forward direction and the afternoon (14:00-18:00 h) as the backward direction along the same transect. The survey was performed along five transects each encompassed 40 km in length and included five main gravel roads transect: Naabi-Olduvai, Seronera-Naabi, Seronera-Fortikoma, Seronera-Ndabaka, and Seronera-Lobo (Figure 1). Each of the 40 km surveyed transect was divided into 1 km length segments for sampling and in total there were 40 sampling segments. Each transect/road was randomly selected and driven twice a day (morning and afternoon hours) and therefore making a total of 80 km drive per transect per day. Due to limited resources, each transect was driven four times (two times during the dry season and two times during the wet season), resulting in a total distance of 1600 km after pooling together all surveyed road transects into one data set.

Data collection

In this survey, it was assumed that each kilometer of road segment surveyed was independent from each other; e.g., a 40 km road surveyed twice has equal sampling effort to an 80 km road surveyed once. At the beginning of a transect sampling period, the vehicle odometer was set to zero. Then a researcher started to record on the roadkill data sheet the transect name, GPS location, time, transect length, road width, date, season, and the names of

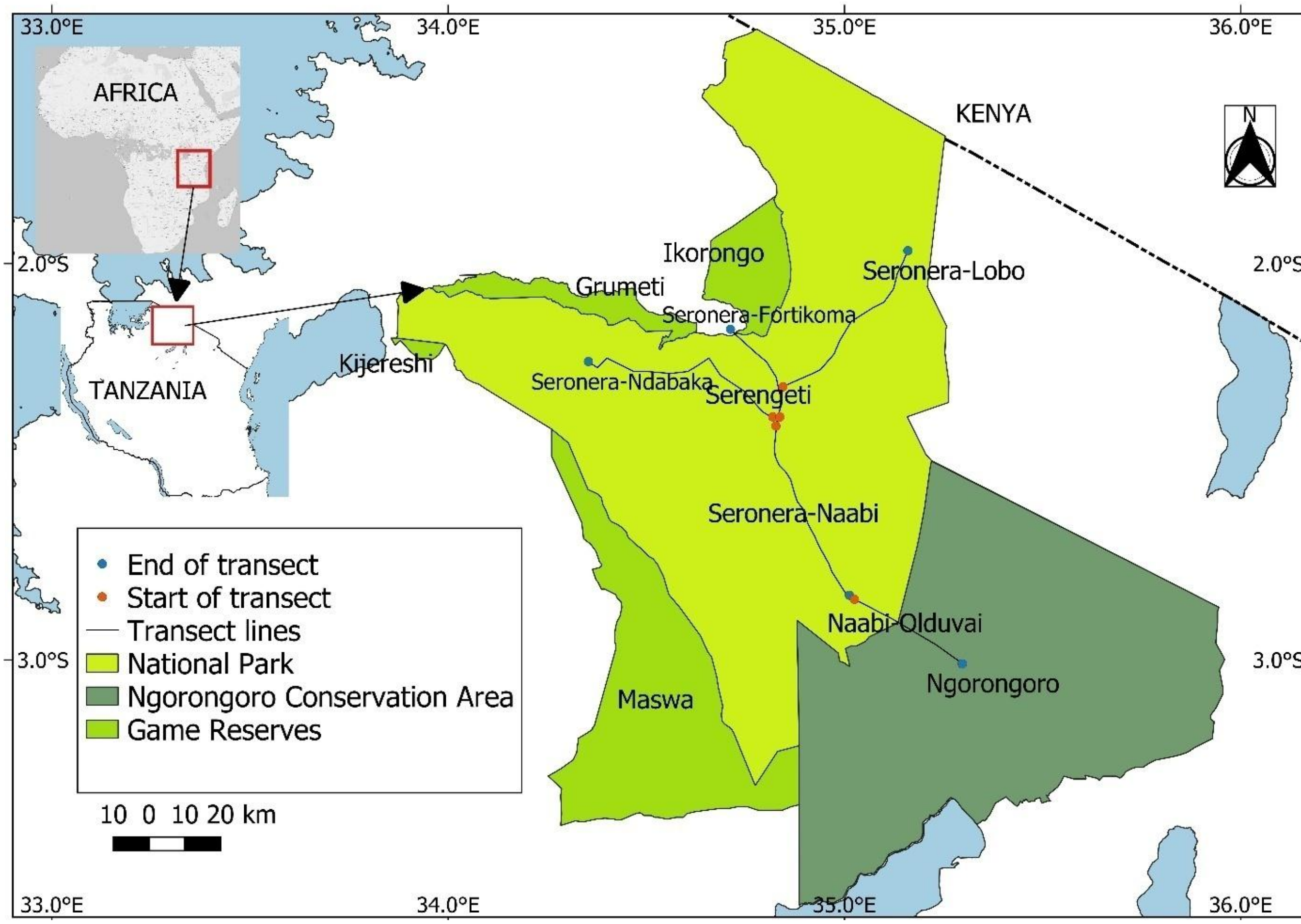

Figure 1. Map of the Serengeti ecosystem showing our study area and transects along the main roads.

the recorders. Thereafter, the vehicle was driven at a speed of approximately 20 km/h or below, as recommended by Collinson et al. (2014) and Teixeira et al. (2017). The four observers in the car were facing forward and made observations on either side of the road, in order to locate any carcass or injured animal. At the point of carcass or injured sighting, each encountered carcass or injured animal species was firstly identified, then other data recorded included GPS location, road width (how wide is the road at the roadkill site and was measured by using a tape measure), time of sighting, condition of the carcass/injured animal(s)(fresh = recent killed, still bleeding and have not started to smell bad/old=long time killed, have started to smell bad), the number of animals (killed/injured), estimated age classes (adults, sub-adults, or juveniles), sex (male/female), time of the day (morning/afternoon hours), road conditions (good = the road is regularly graded, with no potholes and few loose stones or bad = the road has not been graded for a long time and has several potholes and many loose stones) habitat types (general physiognomy vegetation type around the roadkill that is, grassland (>90% of the area is dominated by grass species), woodland (>90% of the area is dominated by tree species), bushland (>90% of the area is dominated by shrub species), wooded grassland (<20% of the area is dominated by trees species), were all recorded in a standard datasheet. Moreover, when the observers spotted any car driving towards the team, they stopped and recorded its speed (km/hr) using velocity speed gun (Model: 101911, Bushnell) and type of vehicle that was encountered (private, tourist, public, or government) and also counted them. After collecting all of the required data, the carcass was removed from the road to avoid double counting. We also used opportunistic encounter methods in addition to the transect method in order to record all the missing data out of data collection days to maximize the number and species of roadkill in the area.

Data analyses

Statistical Package for Social Science (SPSS, version 16.0) software was used for analyzing the data. The data were analyzed using the Pearson's chi-square goodness-of-fit test using Exact Tests with Monte Carlo confidence level (that is, sig. 2 sided). The Exact Tests enabled us to make reliable inferences because our data were small, sparse, heavily tied, or unbalanced and poorly distributed. Also, Exact Tests enabled us to obtain an accurate p value without relying on assumptions that may not be met by our data. Therefore, Pearson's chi-square goodness-of-fit test using Exact Tests with Monte Carlo confidence level (that is, sig. 2 sided) were used to determine whether the distribution of cases (e.g., mammalian roadkill) in a single categorical variable (e.g., " body sizes ", consisting of three groups: " small < 10.0 kg ", “medium 10.0 - 20.0 kg” and " large > 20.0 kg ", “dietary category”, consisting of three groups: “herbivores”, “carnivores” and “omnivores”, “taxonomic group”, consisting of two groups: “families” and "orders", "seasons", consisting of two groups: "dry" and "wet", "session", consisting of two groups: "morning" and "afternoon", and "road conditions", consisting of two groups: "good" and "poor"), follows hypothesized distribution (e.g., a distribution that is "hypothesized", such as the mammalian herbivores would have hi\\192.168.1.30\all operations\BIOLOGICAL SCIENCES DATA\IJBC\DOWNLOADS\2021\3. March\IJBC-07.03.21-1480\Review\from author 2gher roadkill frequency due to their larger home range compared to smaller animals, and higher population density compared to carnivores (Green-Barber and Old, 2019), small sized mammals (< 10.0 kg) would be killed more often than larger animals because the latter are more actively avoided by motorists than smaller animals; and larger animals move more quickly than smaller animals, so they spend less time crossing a road, which reduces the chance of being hit by a vehicle (Ford and Fahrig, 2007). Mammalian roadkill would be occurring more frequently on good roads probably because of over speeding behavior by drivers as they are attracted to drive fast on such roads. However, the proportion of cases expected in each group of the categorical variable can be equal or unequal (e.g., we anticipated an "unequal" proportion of mammalian roadkill based on their dietary category). Additionally, to calculate the rate of mammalian roadkill per kilometer, we divided the number of road-kills by the total distance driven in kilometers during the study period. All tests reported at level of P < 0.05 were considered statistically significant.

RESULTS

Our results revealed that different mammal species were impacted by road accidents, representing 29 individual species occurring at a rate of 1.56 individual mammal per 80 km belonging to 13 mammalian species from 7 mammalian orders (Table 1) were recorded in the area. Moreover, mammal species found killed belonged to different orders with more individual mammal species recorded killed belonged to the order artiodactyla (n = 11, 37.9%) and lagomorpha (n = 9, 31.0%). Thomson gazelles was more affected among artiodactyla (n = 8, 27.6%) and Cape hares was more affected among lagomorphs (n = 9, 31.0%) compared to other orders encountered in the roadkill in the area including carnivora (n = 4, 13.8%), rodentia (n = 2, 6.9%), primates (n = 1, 3.4%), perissodactyla (n = 1, 3.4%) and certiodactyla (n = 1, 3.4%) and their differences were statistically significant (χ^2 = 1.74, df = 72, p < 0.001) with the 99% confidence interval for p = (0.000, 0.000). The Monte Carlo estimate of 0.000 for the exact p value was based on 10,000 random samples from the reference set, using a starting seed of 624387341.

Furthermore, mammals' roadkill differed significantly between families they belong (χ^2 = 2.030, df = 84, p < 0.001) with the 99% confidence interval for p = (0.000, 0.000), with more individuals coming from the bovidea family (n = 11, 37.9%) followed by families leporidae (n = 9, 31.0%), canidae (n = 4, 13.8%), sciuridae (n = 1, 3.4%), cercopithecidae (n = 1, 3.4%), suidae (n = 1, 3.4%), equidae (n = 1, 3.4%) and hystricidae (n = 1, 3.4%) (Table 1). The Monte Carlo estimate of 0.000 for the exact P value was based on 10,000 random samples from the reference set, using a starting seed of 957002199.

Mammals' species found killed differed significantly in body size (χ^2 = 58, df = 24, p < 0.001) with the 99% confidence interval for p = (0.000, 0.000), represented with more small body sized mammals (<10.0 kgs, n = 13, 44.8%) followed by medium (10.0- 20.0 kgs, n = 10, 34.5%) and large bodied sized mammals (>20.0 Kgs, n = 6, 20.7%). The Monte Carlo estimates of 0.000 for the exact p value was based on 10,000 random samples from the reference set, using a starting seed of 92208573. However, the Cape hares (n = 9, 31.0 %) small body sized and Thomson gazelles (n = 8, 27.6 %) medium body sized mammals were more frequently killed than other mammals' species in the area.

Though road-kills occurred more during the dry (62.1%) than wet (37.9%) seasons and again between the morning (69%) and afternoon (31%) hours in the area but their differences were not statistically significant (χ^2 = 13.9, df = 12, p = 0.260) with the 99% confidence interval for p = (0.249, 0.271), and (χ^2 = 13.8, df = 12, p = 0.498) with the 99% confidence interval for p = (0.486, 0.511), respectively. The Monte Carlo estimate of 0.260 and 0.498 for the exact p value was based on 10,000 random samples from the reference set, using a starting seed of 1993510611 respectively. Also, mammalian roadkill occurred most frequently on good condition roads (75.0%) than poor condition roads (25.0%) though their differences were not statistically significant (p = 0.136) with the 99% confidence interval for p = (0.127, 0.145) probably because of the over speeding by drivers as they are attracted to drive fast on such roads. The Monte Carlo estimate of 0.136 for the exact p value was based on 10,000 random samples from the reference set, using a starting seed of 475497203.

Additionally, mammal species found killed differed significantly among their dietary type (χ^2 = 58, df = 24, p < 0.001) with the 99% confidence interval for p = (0.000, 0.000) whereby herbivores were more killed along the roads (n = 22, 75.9%) followed by carnivores (n = 4, 13.8%) and omnivores (n = 3, 10.3%). The Monte Carlo estimate of 0.000 for the exact p value was based on 10,000 random samples from the reference set, using a starting seed of 726961337.

DISCUSSION

This study recorded only 29 mammalian roadkills belonging to 13 species, 7 orders and 8 families in the area. This finding is in line with previous works which revealed that thousands of mammals were killed annually from vehicle collisions, making the issue an important one for if we are to achieve sustainable conservation (Canova and Balestrieri, 2018; Smith-Patten and Patten, 2008). Previous studies have also shown that roads and traffic impact wildlife directly in several negative ways,

Table 1. Mammal species found killed along roads in the Serengeti ecosystem.

Common name	Family	Scientific name	Diet	Body mass	Total killed	% killed
Thomson gazelles	Bovidae	*Eudorcas thomsonii*	H	M	8	27.6
Cape hares	Leporidae	*Lepus capensis*	H	S	9	31.0
Black backed jackals	Canidae	*Canis mesomelas*	C	S	1	3.4
Bat eared fox	Canidae	*Otocyon megalotis*	C	S	1	3.4
Spotted hyaenas	Canidae	*Crocuta crocuta*	C	L	1	3.4
Dikdik	Bovidae	*Madoqua kirkii*	H	S	1	3.4
Wildebeests	Bovidae	*Connochaetes taurinus*	H	L	2	6.9
Zebra	Equidae	*Equus burchelli*	H	L	1	3.4
Cheetah	Canidae	*Acinonyx jubatus*	C	L	1	3.4
Olive baboon	Cercopithecidae	*Papio anubis*	O	M	1	3.4
Warthog	Suidae	*Phacochoerus africanus*	H	L	1	3.4
Squirrels	Sciuridae	*Sciurus carolinensis*	O	S	1	3.4
Crested porcupine	Hystricidae	*Hystrix cristata*	O	M	1	3.4
Total					**29**	**100**

Diet (H = herbivore, C = carnivore, O = omnivore) and body mass (S = < 10.0 kg, M = 10.0 - 20.0 kg, L = >20.0 kg) were determined from Barthelmess and Brooks (2010).

such as decreasing habitat quality, facilitating the introduction and spread of exotic species (Machado et al, 2015; Teixeira et al., 2017; Bukombe et al., 2018), acting as barriers by forming habitat fragmentation, reducing genetic diversity and increasing wildlife mortality due to wildlife-vehicle collisions (Meza-Joya et al., 2019). Additionally, the current study has shown that herbivores were the most affected group (75.9%), followed by carnivores (13.8%) and omnivores (10.3%) in the area. This observation supports our first prediction that mammalian herbivores have a higher roadkill frequency than carnivores or omnivores and corroborates findings by Canova and Balestrieri (2018). The reason for the higher herbivore roadkill was probably the fact that more mammalian herbivores have large home ranges and occur at higher densities (Green-Barber and Old, 2019). Furthermore, mammalian herbivores are attracted to road sides by resources that are rare or limited in other areas, including water and green pasture as source of food (Freitas et al., 2015; Kiros et al., 2016; Green-Barber and Old, 2019) and therefore increase chances of being hit by vehicles.

We also found that, the Cape hares which are small body mammal sizes were more recorded killed than medium and large body size mammal species probably because they are less actively avoided by motorists than larger mammals; and also, smaller mammals move more slowly than larger mammals, so spending more time traversing across a road, which increases their chances of being hit by vehicles (Ford and Fahrig, 2007). Also, Cape hares are commonly abundant species (Caceres, 2011) and their behavior of frequently crossing roads to gain access to other resources (Green-Barber and Old, 2019) in the area. Additionally, since the Cape hares are nocturnal, they might have been hit by vehicles more frequently at night or early morning because of the reduced driver vision (Braz and Franc, 2016), which may shorten the time a driver has to react to an animal on the road, concurrent with high proportion of this species that is active at night (Chyna et al., 2019). Therefore, this finding supports our second hypothesis that small sized mammals (<10.0 kg) would be killed more often than larger animals because the latter are more actively avoided by motorists than smaller animals; and larger animals move more quickly than smaller animals, so they spend less time crossing a road, which reduces the chance of their being hit by vehicles (Ford and Fahrig, 2007) and also because of their frequency of crossing the roads and abundance in the area (Barthelmess and Brooks, 2010). This finding is again in support with the study by Gonzalez-Suarez et al. (2018) who pointed out that species with weights above 2-3 kgs had higher risk of being killed, although for mammals the risk decreased again for species above ~50 kgs due to the reason that divers can see them at a distance and slow down their vehicles.

In this study, also predators or scavengers such as bat eared fox, spotted hyaena, black backed jackals and cheetahs were recorded killed in the area. This was probably because they were scavenging roadkill carcasses on the road which attracted and expose them to a higher risk of mortality by vehicle collision (Freitas et al., 2015; Planillo et al., 2018). Previous study has also shown that some small mammals thrive in verges and reach dense populations and play the role of prey in the ecosystem and can influence carnivore habitat use by attracting them close to roads and increase their mortality risk by vehicle collision (Planillo et al., 2018). This is in support of the previous finding by Smith-Patten and Patten, (2008) who revealed that roadkill is easy prey, albeit coming with a high risk of the scavenger becoming the scavenged. Furthermore, cheetah as an endangered species was hit by vehicle representing a species of conservation concern and therefore may be used as a flagship species (Freitas et al., 2015) for conservation in the area.

More mammalian roadkills were observed along good or smooth roads than along poor roads probably because of the failure of drivers to adhere to safe driving practices (Selvan et al., 2012). This finding support that of Santos et al. (2013), who reported that road characteristics and the quality of the surrounding habitat play a key role in shaping wildlife roadkill patterns. Generally, according to Santos et al. (2013), casualties will increase in good road sections with high traffic volume or low driver visibility, as well as where good or smooth roads cross high-quality habitats, although this effect is species-specific.

Furthermore, we also found that mammalian roadkills occurred more frequently in single than two or more individual carcasses. This finding is in consistent with the study by Collinson et al. (2015) who reported that roads pose a threat to the survival of individual animals and entire populations. Our encounter rates of 0.0156 animals /kilometer are considerably lower than those of the study reported by Njovu et al. (2019) of 0.04 and 0.02 animals/kilometer, which was conducted on tarmac road compared to our study which was conducted on the gravel roads.

Ultimately, the knowledge of mammalian roadkill patterns can inform managers to device strategies to reduce it in the area (Lyamuya et al., 2021; Kreling et al., 2019). This is because the study has shown that roadkill is currently a problem in the Serengeti ecosystem, therefore it should be controlled to prevent perpetual biodiversity loss in this area. This can be accomplished by obliging drivers to reduce speed and placing wildlife warning signs on the roadside to modifying drivers' behaviour (Collinson et al., 2019; Lyamuya et al., 2021) as well as adding steeper penalties for over speeding drivers on roadkill risk areas (Collinson et al., 2019; Lyamuya et al., 2021).

CONCLUSION AND RECOMMENDATIONS

This study, therefore, concludes that though roads are economically beneficial to tourism and other conservation activities in most protected areas worldwide and particularly in the Serengeti ecosystem, however when their usage are not well managed, they can adversely impact a variety of wildlife species such as causing mammalian roadkill. This is because about 29 mammals represented more with herbivores than carnivores and omnivores were recorded killed in the Serengeti ecosystem. Moreover, most of the mammalian raodkill were recorded on good condition roads probably because of the over speeding behavior by drivers as they are attracted to drive fast on such roads. Additionally, mammals with small body sizes predominantly Cape hares were most frequently killed probably because they are less actively avoided by motorists than larger mammals. Furthermore, mammalian roadkill differed between the orders and families they belong with more individuals from the order artiodactyla and families bovidea and leporidae which were represented more with the Thomson gazelles and Cape hares respectively. In order to reduce mammalian roadkill in the area this study recommends that drivers should adhere to the park speed limits of 50 km/h so that they can easily see more smaller mammals on the roads such as the Cape hares from far away and try to avoid them as they do for large mammals. To achieve this, we recommend for the park managers to enforce their park vehicles speed regulations by giving steeper penalties for over speeding drivers. Also, the park managers should install more of pictured wildlife warning signs on the roadside for modifying driver behaviour in reducing mammalian roadkill especially of smaller and more medium mammals in the area.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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