Assessment of roadkills in Hluhluwe-Imfolozi Park, KwaZulu-Natal, South Africa

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Abstract

Anthropogenic land-use activities are considered to be the main contributor to current worldwide changes in natural ecosystems. South Africa is one of the countries that has been severely affected by changing land-use. The changes in land-use in South Africa are driven primarily by the need to provide food, water, and shelter to a growing human population and for economic growth. However, consequences of such actions impact biodiversity negatively with effects that lead to habitat fragmentation, loss of wildlife habitats, wildlife mortalities and species declines. One factor that contributes negatively is the increased number of roads and associated traffic.

This study was conducted in Hluhluwe-Imfolozi Park (HIP), KwaZulu-Natal, South Africa, to assess roadkills on roads of the park. We conducted monthly roadkill surveys on three main roads (R618 corridor road traversing the HIP, paved road from Memorial Gate to Hilltop Resort, and an unpaved road from Memorial Gate to Isivivaneni Lookout) within HIP for a year. Furthermore, we assessed the public's level of awareness about roadkills using questionnaire surveys. Relatively few roadkills were reported in our study when compared with other studies. The taxa that were reported as roadkills included mammals, birds, reptiles and amphibians. The R618 corridor road traversing the HIP had the highest number of roadkills, followed by the paved road then the unpaved road within park. Factors that contributed to reported roadkills were season, type of road, amount of game in the vicinity, and the distance to roadside vegetation from the road. In addition, the public showed limited awareness about roadkills occurring in HIP, but were aware of how they were expected to drive within protected area road networks. Mitigation measures such as mowing, signage, enforcement of harsh laws and introduction of fines were recommended as means that would help in the reduction of roadkills in HIP.

PREFACE

The data described in this thesis were collected in Hluhluwe-Imfolozi Park, KwaZulu-Natal Province, Republic of South Africa from June 2016 to May 2017. Experimental work was carried out while registered at the School of Life Sciences, University of KwaZulu-Natal, Pietermaritzburg, under the supervision of Professor Colleen T. Downs.

This thesis, submitted for the degree of Master of Science in the College of Agriculture, Engineering and Science, University of KwaZulu-Natal, School of Life Sciences, Pietermaritzburg campus, represents original work by the author and has not otherwise been submitted in any form for any degree or diploma to any University. Where use has been made of the work of others, it is duly acknowledged in the text.

Muzi Mkhohlwa
December 2017

I certify that the above statement is correct and as the candidate's supervisor I have approved this thesis for submission.

……………………………..
Professor Colleen T. Downs
Supervisor
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DECLARATION 1 - PLAGIARISM

I, Muzi Nicholas Mkhohlwa, declare that

1. The research reported in this thesis, except where otherwise indicated, is my original research.

2. This thesis has not been submitted for any degree or examination at any other university.

3. This thesis does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons.

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   a. Their words have been re-written but the general information attributed to them has been referenced
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DECLARATION 2 - PUBLICATIONS

DETAILS OF CONTRIBUTION TO PUBLICATIONS that form part and/or include research presented in this thesis.

Publication 1- in prep.

MN Mkhohlwa, MM Zungu & CT Downs

Quantifying roadkills on different roads of Hluhluwe-Imfolozi Park, South Africa and identifying contributing factors

Author contributions:

MNM conceived paper with CTD. MNM collected and analysed data, and wrote the paper. CTD contributed valuable comments to the manuscript. MMZ helped with data analyses and contributed valuable comments.

Publication 2- in prep.

MN Mkhohlwa & CT Downs

Citizen science: Public perspectives of roadkills in Hluhluwe-Imfolozi Park, KwaZulu-Natal, South Africa

Author contributions:

MNM conceived paper with CTD. MNM collected and analysed data, and wrote the paper. CTD contributed valuable comments to the manuscript.

Signed: 

Muzi Mkhohlwa
December 2017

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Thanks to staff of Hluhluwe-Imfolozi Park, especially D. Druce, S. Mbongwa, G. Clinning for making my stay in Hluhluwe-Imfolzi Park easy and workable as I collected my data. To all of my field assistants that helped with collection of data, I thank you so much: D. Phiri, P. Zwane, P. Ntanda and S. Libanje. Without you, it would have been difficult to gather the baseline data. M.M Zungu is thanked for assisting with data analysis and constantly helping with editing and adding valuable comments in whole project. T. Kuiper is thanked for helping with map creation and proof reading my chapters, and adding valuable comments in process. The author would also extend appreciation to Kabir for assisting with data analyses.

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Contents

LIST OF FIGURES AND TABLES

Chapter 1

INTRODUCTION

1.1 Changing land-use and its consequences

Economic development has various benefits for a nation in terms of creating wealth and addressing poverty. However, there are various negative effects of development. South Africa is one of the most rapidly developing countries in Africa. Economic development in South Africa has led to greater economic prosperity, through anthropogenic activities that modify natural ecosystems, with land-use change being the major modifying factor in South African ecosystems (Foley et al., 2005). Changing land-use (converting natural systems to human land-uses such as agricultural activities, roads or new building) affects landscape structures and its ecological functions (Vitousek et al., 1997; Foley et al., 2005; Primack, 2012). Globally, the changing land-use ultimate outcomes are similar and generally alter environment conditions, natural biological processes and wildlife populations (Forman and Alexander, 1998; Iuell et al., 2003; Foley et al., 2005). Changing land-use is the biggest cause of habitat loss, and then habitat loss coupled with fragmentation are together the most significant drivers of species extinction (Fahrig, 2003). Urbanization, building of bridges, agricultural activities and roads are some of examples of changing land-use that contribute to habitat loss. This thesis will focus on the effects of roads on wildlife, and falls within field of road ecology (Forman et al., 2003). Specifically, I will focus on roadkills within protected areas, because relatively little has been documented on roadkills in protected areas.

1.2 Road networks impact on biodiversity

Roads are one of the outcomes of land-use change encompassing human development. Direct and indirect effects of roads impact environment and wildlife populations negatively or positively and this disturbance can be displayed from small to large landscapes (Vercayie and Herremans, 2015). Negative examples include roads being barriers to movement of vertebrates when migrating or dispersing, fragmented nature of wildlife habitats caused by roads prevents connectivity between patches and consequently affects demographics and genetic variability of populations (Wilkins, 1982; Mader, 1984, Reh and Seitz, 1990; Bennett, 1991; Forman and Alexander, 1998; Trombulak and Frissell, 2001; Dyer et al., 2002; Jaeger et al., 2005; McGregor et al., 2007; Bennett, 1991; Magle et al., 2012; Soulsbury and White, 2015). Other examples include roads as generating air, light and other pollution which disturb ecological functioning and also affect individual animals in their existing habitat (Reijnen et al., 1995; de Molenaar et al., 2006). Furthermore, roads increase human impact as they provide platform for hunting, fishing and development (Trombulak and Frissell, 2001). More and more negative effects of roads on environment and wildlife populations are documented and some not document with the above example being few mentioned in current literature.

Roads may also have unforeseen positive effects on biodiversity. Beckman and Shine (2015), for example, found that Anurans used roads for thermoregulation. Birds use the roadside gravel in aiding to their digestive processes (Jackson, 2003). Some wildlife animals, specifically the bird and ungulates, are attracted towards roads because of roadside vegetation as source of food (Dean et al., 2006; Mulero-Pazmany et al., 2016). In addition, vegetation along the road often provide habitat for some wildlife (Bissonette and Rosa, 2009). Road edges sometimes have water points for drinking and some animals use those water points for breeding sites. For example, Smith and Dodd (2003) found that the leopard frogs, *Rana sphenocephala,* preferred nesting or breeding in man-made stormwater retention ponds or dredged canals along roads. Contrary to having water points along road as positive factor, high numbers of roadkills have been recorded in these areas. Examples include collisions of mammals (Philcox et al., 1999), amphibians (Langen et al., 2009), and reptiles (Ashley and Robinson, 1996). This is a clear consequence of animal habitat preferences (Marchand and Litvaitis, 2004).

1.3 Wildlife-vehicle collisions

Through road networks, traffic has increased, therefore more chances of wildlife-vehicle collisions are likely to occur. However, wildlife vehicular collisions have been raised as a concern for almost a century (Stoner, 1925). Moreover, it is important to note that traffic is non-selective and kills a constant fraction of the populations, so rare and endangered species do not escape (Jaarsma et al., 2006; Hayward et al., 2010). In addition, construction of new roads and road resurfacing, and unwinding paved roads, leads to high volume of vehicles with increased speeds (Drews, 1995; Ritters and Wickham, 2003). Increased speed and intensified traffic are suggested to increase the likelihood of wildlife-vehicle collision.

Several studies have documented high numbers of wildlife roadkills through vehicle collisions, often caused by high speeds and increased volumes of vehicles on roads (Forman and Alexander, 1998; Forman et al., 2003; Litvaitis and Tash, 2008; Fahrig and Rytwinski, 2009; Carvalho and Mira, 2011). Despite decreased traffic volume at night, generally nocturnal animals experience higher rates of vehicle-collision compared with diurnal animals and this is likely to be caused by reduced visibility of roads and structures on edge of road at night (Braunstein, 1998; Bullock et al., 2011).

Notably, most of the studies conducted on roadkills due to vehicle collisions have been conducted in Europe, the United States and Australia with little literature from Africa (Bullock et al., 2011). Moreover, relatively little is documented on roadkills in protected areas at a global scale and even less in Africa. The studies conducted have been generally species-specific in certain locations, meaning each study monitored certain species in area of interest. For example, Gagne et al. (2015) monitored vehicle-collisions on barred owl (*Strix varia*) in the city of Charlotte in North Carolina, USA. Cervinka et al. (2015) monitored carnivores roadkills, Bishop and Brogan (2013) monitored avian roadkills, Barthelmess (2014) monitored mammal roadkills, Puky (2005) monitored amphibian roadkills etc. There are relatively few extensive studies that have monitored and quantified numbers of multi-species or class of wildlife roadkills. Examples of such studies included Case (1978), Clevenger et al. (2003), Coelho et al. (2008), Farmer and Brooks (2012), and Boitet and Mead (2014).

Vertebrate wildlife taxa susceptible to vehicle collisions include birds, amphibian, reptiles and mammals. Mammals killed through vehicle collisions in North America include, red squirrels (*Tamiasciurus hudsonicus*), snowshoe hares (*Lepus americanus*), deer mice (*Peromyscus maniculatus*) and many more (Clevenger et al., 2003), porcupines (*Erethizon dorsatum*), raccoons (*Procyon lotor*), striped skunks (*Mephitis mephitis*), muskrats (*Ondatra zibetheicus*), and eastern cottontails (*Sylvilagus floridanus)* (Barthelmess and Brooks, 2010) and wolves (*Canis lupus)* (Zimmermann et al., 2014) etc. Bird mortalities in Northern America often includes owls, barn owl (*Tyto alba*) (Boves and Belthoff, 2012), and barred owls *(Strix varia*) (Gagne et al., 2015). Other birds include, Florida scrub-jays (*Aphelocoma coerulescens*) (Mumme et al., 2000; IUCN, 2008), Audubon's crested caracaras (*Polyborus plancus audubonii*), and Hawaiian geese (*Branta sandvicensis*) (Huijser et al., 2007; IUCN, 2008). Turtle, frogs and snake populations are declining in many countries because of mortalities from vehicles. These mortalities include the following examples of; the native common frog (*Litoria dahlii*) (Beckman and Shine, 2015), striped marsh frogs (*Limnodynastes peronei)*, green and golden bell frogs (*Litoria aurea)* (Hamer et al., 2014), and turtle species like *Terrapene*, *Clemmys*, *Emydoidea*, and Gopherus (Gibbs and Shriver, 2005). Snakes killed by vehicles included desert nightsnakes (*Hypsiglena chlorophaea*), striped whipsnakes (*Masticophis taeniatus*), gophersnakes (*Pituophis catenifer*), terrestrial garter snakes (*Thamnophis elegans*) (Jochimsen et al., 2014). In southern Africa (Addo Elephant Park) some documented roadkills included the yellow mongoose (*Cynictis penicillate*), greater kudu (*Tragelaphus strepsiceros)*, eastern leopard toad (*Amietophrynus pardalis*), southern boubou (*Laniarius ferrugineus*), puff adder (*Bitis arietans*) and other roadkills (Nuttall-Smith, 2015).

1.4 Roadkills in South Africa

A list of studies about roadkills in Africa was compiled (Table 1). Most have been conducted in South Africa but compared with global studies. However, relatively little research has been conducted on the effects of roads, particularly roadkills, on wildlife populations in South Africa (Bullock et al., 2011; Collinson, 2013). These studies include assessment of roadkills conducted in highways or national roads and a few on roads within or crossing protected areas. For example, Bullock et al. (2011) assessed roadkills on the Upington to Twee Rivieren main road in the southern Kalahari, Eloff and van Niekerk (2008) assessed roadkills on a road between Uitenhage and Graaff-Reinet in the Eastern Cape Province, Collinson (2013) conducted her study in the Greater Mapungubwe Transfrontier Conservation Area which is recognized as an important conservation area and last two studies were under Endangered Wildlife Trust (EWT) (EWT, 2015 and Nuttall-Smith, 2015) in Pilanesberg National Park and Addo Elephant National Park respectively. Another study that related to assessment of roadkills was conducted by Dean et al. (2006), who examined use of roadkills and roadside verges by pied crows (*Corvus albus*) and Cape crows (*C. capensis*) on the N1 from Prince Albert Road to Worcester, along the N1 from Beaufort West to Three Sisters, along the N12 from Zeekoegat to Beaufort West, and along the N12 from Three Sisters to Kimberley. Note, the above examples are not only the examples of studies conducted in South Africa about roadkills.

South Africa's road networks occupy approximately 789,000 km out of the country's 1.2 million km^2 (Karani, 2008). Moreover, there has been budget allocation for upgrading and maintenance of South African roads for better economic growth of country (Karani, 2008). For 2016/2017 in South Africa, R23.4 billion has been projected to be spent on road networks (Intergovernmental Fiscal Reviews 2015). Considering that South Africa is ranked third on a global scale for its biodiversity (IUNC, 2012), government delegates, park managers and private companies should consider conservation of biodiversity (including reduction of roadkills) as of priority rather than focusing on large budgets for maintenance and upgrading of roads. In addition, the biodiversity that South Africa embraces, attracts tourists and increases the economy of the country (Mulero-Pazman et al., 2016). Therefore, the importance of research studies on roadkills in South Africa is of great importance, so as to reach a balance between economic growth and the conservation of biodiversity.

Table 1.1 Studies that have been conducted in Africa about roadkills.

Author	**Year**	**Country**	**Research topic**
Dorfling et al.	1976	South Africa	
Lewis	1989	Kenya	Assessment of roadkills
Drews	1995	Tanzania	Assessment of roadkills
Dean and Milton	2003	South Africa	Diet and Management
Eloff and Niekerk	2005	South Africa	Ecology and Management
Dean et al.	2006	South Africa	Diet and Management
Eloff and Niekerk	2008	South Africa	Assessment of roadkills
Laurance et al.	2008	southwestern Gabon	Assessment of roadkills
Mkhanda and Chansa	2011	Zambia	Assessment of roadkills
Bullock et al.	2011	South Africa	Assessment of roadkills
Loehr	2012	South Africa	Assessment of roadkills and Management
Collinson	2013	South Africa	MSc. Ecology
Collinson et al.	2014	South Africa	Management
Koiko et al.	2015	Northern Tanzania	Behaviour
Koiko et al.	2015	Northern Tanzania	Assessment of roadkills
Mulero-Pazmany et al.	2016	South Africa	Behavior
Nuttal-Smith et al.	2015	South Africa	Assessment of roadkills

1.5 Conclusions

Globally, land-use activities have altered many ecosystems functionality and configuration. Therefore, a need for management is of concern for conservation of biodiversity. Core source for land-use change is the need for continued development by humans. In our knowledge of understanding, land-use change has detrimental effects on wildlife population regardless of whether the impact is direct or indirect. This is evident, as extensive empirical data have displayed result of loss of habitat, reduced genetic variability due to barrier effect (Newsome et al., 2015), inbreeding, deaths of wildlife due to vehicle collision, etc. caused by land-use change, particularly road networks in our circumstance.

Collection of roadkill data is necessary when looking at the absences or few long-term projects for monitoring populations that are affected. Lack of data for roadkills narrows equitable models that could be management aspect for declining population. Roadkills are useful sources for understanding population studies (Case, 1978). Roadkill studies provides information that may include status of a species in relation to International Union for Conservation of Nature (IUCN), educate public about well-fare of wildlife, create link between researchers and public, specifically the government policy makers, and help with decision making for better implementation of mitigation measures for conserving biodiversity etc.

South Africa has few studies conducted on road kills (Table 1), specifically in protected areas. Factors like vegetation cover, road characteristics, road verges and others do affect the likelihood of vehicle-wildlife collisions. Effectiveness of mitigation measures for roadkill require detailed and ongoing monitoring of studies that will give adequate information for decision making about which mitigation measure is suitable.

1.6 Problem statement and significance of the study

South African tourism is expected to increase significantly resulting in more traffic and intense pressure in protected areas. Balancing between the need for an efficient transport network to support the tourism industry in protected areas and the conservation of biodiversity will therefore be a challenge. Hluhluwe and Mfolozi Game Reserve are two adjacent protected areas known as the Hluhluwe-Imfolozi Park in KwaZulu-Natal Province, South Africa, that have a relatively high turnover of tourists and further have a busy main road called the Hlabisa Road traversing them. Many roadkills on this Hlabisa Road as well as the roads in the protected area have been observed but there has been no study to quantify these roadkills (various pers. comm.). Management needs a detailed study and recommendations.

Hluhluwe-Imfolozi Park is a home to Africa's 'big five' animals. Furthermore, the Africa's 'big five' animals play a crucial role in South Africa's economy and history. The park also has a high diversity of animals and birds. Lack of monitoring of roadkills in protected areas with no mitigating measures, could elevate to decline of significant animals in protected areas.

1.7 Aims and objectives

The main aim of the study was to determine roadkills rate at HIP. To ensure that, the following aims were addressed:

(1) Measure baseline data for roadkill in HIP.

(2) Identity roadkill hotspots in HIP.

(3) Examine road characteristics and environmental factors for potential contributing factors on the occurrence of roadkills.

(4) Raise public awareness of roadkills as a threat to biodiversity in HIP staff and tourists visiting HIP.

(5) Highlight mitigation measures that could be of fundamentality to HIP with roadkill reduction.

1.8 Study outline

The thesis is comprised of five chapters, of which two data chapters are presented for submission for publication in relevant international peer-reviewed journals, and thus some repetition in the chapters was unavoidable. The hypotheses and predictions are presented in the respective chapters.

The chapters are arranged in the following order:

Chapter 2. Quantifying roadkills on different roads in Hluhluwe-Imfolozi Park, KwaZulu-Natal, South Africa and identifying contributing factors.

Chapter 3. Citizen Science: Public perspectives on roadkills in Hluhluwe-Imfolozi Park, KwaZulu-Natal, South Africa.

Chapter 4. Management implication for roadkill reduction in Hluhluwe-Imfolozi Park, KwaZulu-Natal, South Africa.

Chapter 5. The concluding chapter that summarizes the various components of this study.

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Chapter 2
Quantifying roadkills and identifying contributing factors on different roads of Huhluwe-iMfolozi Park, South Africa.

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Road ecology describes the effects caused by roads in the interaction between organisms and their environment. Consequently, road ecology has become a topic of focus because of its effect on population dynamics, ecosystems and biological process. Despite a few positive effects (roads used for thermoregulation, breeding site etc.), generally roads negatively impact wildlife. The latter includes increased roadkills, barriers to movement of wildlife, modification of wildlife behaviour, and loss of habitat. Of concern are the negative impacts of roads in protected areas. We determined roadkill rates within Hluhluwe-Imfolozi Park (HIP), KwaZulu-Natal, South Africa. We collected monthly data for a year in HIP to determine monthly roadkill rates, hotspots for roadkills, potential factors contributing to roadkills, and which wildlife (mammal, birds and reptiles) were more prone to roadkills. Three different road transects (paved corridor passing through HIP, paved and unpaved roads) were monitored during this period, with each transect driven back and forth by vehicle. More roadkills were found on paved roads, particularly the R618 corridor road. There was no significant difference in the roadkills number between the monitored roads transects nor with season. Several factors contribute to occurrence of roadkill, with closeness of vegetation to road being one such factor. It was hoped that our study would raise public awareness in HIP and other protected areas about the negative impact of roadkills.

Key words: roadkills, season, road type, contributing factors, HIP.

INTRODUCTION

Road ecology describes the effects caused by roads in the interaction between organisms and their environment, and has become a topic of growing discussion in recent years due to its effect on population dynamics, ecosystems and biological process (Broekhuysen 1965; Lewis 1989; Drews 1995; Forman *et al*. 2003: Malo *et al*. 2004). Forman and Alexander (1998) also termed road ecology "the sleeping giant" as its effects are relatively great and have not been properly recognized. More broadly, road ecology can be described as the relationship between the natural environment and road systems (Forman *et al*. 2003). Road ecology may either affect ecosystems and populations positively or negatively. Perhaps, it is important to highlight that road networks effects are skewed more to the negative rather than the positive when wildlife populations are concerned. Previous ecological studies have shown that wildlife populations have been affected by roads in many ways, but most often negatively (Fahrig & Rytwinski 2009; Ascensao *et al*. 2017). The first documentation of the ecological effects of roads and traffic on the natural environments was conducted by Stoner (1925). He travelled 632 miles on a road trip in Iowa at the USA where he detected 225 vertebrate roadkills, and identified 29 species in his observations. However, most documentation on the ecological effects of roads on wildlife population only gained momentum around 1970, and is still ongoing (Bellis & Grave 1971; Oxley *et al*. 1974; Ascensao *et al*. 2017). Road networks effects on wildlife populations have raised global scale recognition. However, most documented studies have been taxa group specific or species specific rather than generalizing across taxa and are often localized. Examples of roadkills published for specific vertebrate taxonomic group include mammals (Clevenger *et al*. 2003; Malo *et al*. 2004; Seiler 2005; Farmer & Brooks 2012; Barthelmess *et al*. 2014; Cervinka *et al*. 2015; Arscensao *et al*. 2017), birds (Erickson *et al*. 2005; Ramp *et al*. 2006; Kociolek *et al*. 2011; Bishop & Brogan 2013), and reptiles and amphibians (Ashely & Robinson 1996; Carr & Fahrig 2001; Puky 2006; Orlowski *et al*. 2008; Langen *et al*. 2009; Surtherland *et al*. 2010; Crawford *et al*. 2014; Beckman & Shine 2015). Europe, North America and Australia have had relatively more studies, publications and symposia of wildlife roadkills (Van der Ree *et al.* 2011).

It is crucial that we are aware of trends in wildlife populations within protected areas (PAs) as changing land-use continues to reduce the land available to wildlife (Forman & Alexander 1998; Benitez-Lopez *et al.* 2010; Barthelmess 2014). PAs are established to conserve species by separating them from threatening processes, but threats to wildlife within PAs are growing. In particular, expanding road networks contribute to the detected decline of wildlife populations in some PAs. A 2015 report (EWT 2015), suggested that poaching, habitat loss, hunting and disease are other potential contributing factors to the decline in wildlife population in some PAs.

Collisions of vehicles with wildlife in PAs have a direct impact in terms of decreasing the number of individuals in wildlife populations (Hels & Buchwald 2001). This effect is facilitated by new paved roads and increased human traffic within PAs (Drews 1995; Mkhanda & Chansa 2011). Few studies have been documented on roadkills in South African

Parks. Accurate data for determining effects and population trends on wildlife within PAs due to roadkills are fundamental if mitigation measures are to be implemented for conservation.

In South Africa, only eleven studies have been conducted on roadkills and road effects on wildlife (Chapter 1). Of the eleven, only two were conducted in PAs, namely Pilanesberg National Park (PNP) and Addo Elephant National Park (AENP). The study conducted in PNP in 2015, quantified roadkill rates, determined hotspots and identified relevant mitigation measures for the reduction of roadkills. The same goals were implemented in AENP as in PNP but with further analysis on formulating a model to predict where roadkills would occur and understanding driver behaviour and how this could be influenced to reduce the likelihood of roadkills. Our study in Hluhluwe-Imfolozi Park (HIP), KwaZulu-Natal, South Africa also has the same goals as the AENP and PNP case studies, but was different in that, our study (1) analyzed factors contributing to wildlife roadkills, (2) addressed the effect of seasonality, and (3) was conducted over a longer data collection period (12 months).

Our study aimed at determining number of roadkill within HIP. We hypothesised that there roadkill rates on different types of monitored roads, and between seasons differed. Collinson (2013), results showed more roadkills on paved roads compared with unpaved. Nuttall-Smith *et al*. (2015) also had similar results to Collinson (2013). We also predicted that more roadkills would be detected on roads with vegetation close to road and high game (area with high probability of visit by wildlife because of resources it has). Beyond the scientific study, it was hoped that our study will raise public awareness about wildlife roadkills and will also help in the implementation of mitigation measures for conservation purposes in this PA.

METHODS

Study site

HIP (S28° 0´to28° 25´, E31°42´ to32° 0´) in KwaZulu-Natal, South Africa, is a fenced reserve covering 96 000 ha on the first escarpment on the west side of the Zululand coastal plain (Whateley & Porter 1983). This PA was established in 1895. Hluhluwe and Imfolozi Reserves were established separately and recently joined. Vegetation varies from grasslands to Acacia (*Vachellia* spp.) woodlands and denser thickets, however the majority of HIP is savanna, classified as Northern Zululand Sourveld and Zululand Lowveld (Mucina & Rutherford 2006). *Vachellia nigrescens* woodlands, *Vachellia tortilis* woodlands and *Spirostachys africana* (Pooley 2003) woodlands predominate (Whateley & Porter 1983). The mean annual rainfall and altitude decreases from the northern Hluhluwe section (990 mm and 450 m asl), to iMfolozi in the south (635 mm and 60 m asl) (Balfour & Howison 2001). Mean ambient temperature between summer and winter varies between 13^{o}C and 33^{o}C (Balfour & Howison 2001). The terrain varies between plains, hills and valleys. HIP contains a high diversity of mammals, birds and plant life.

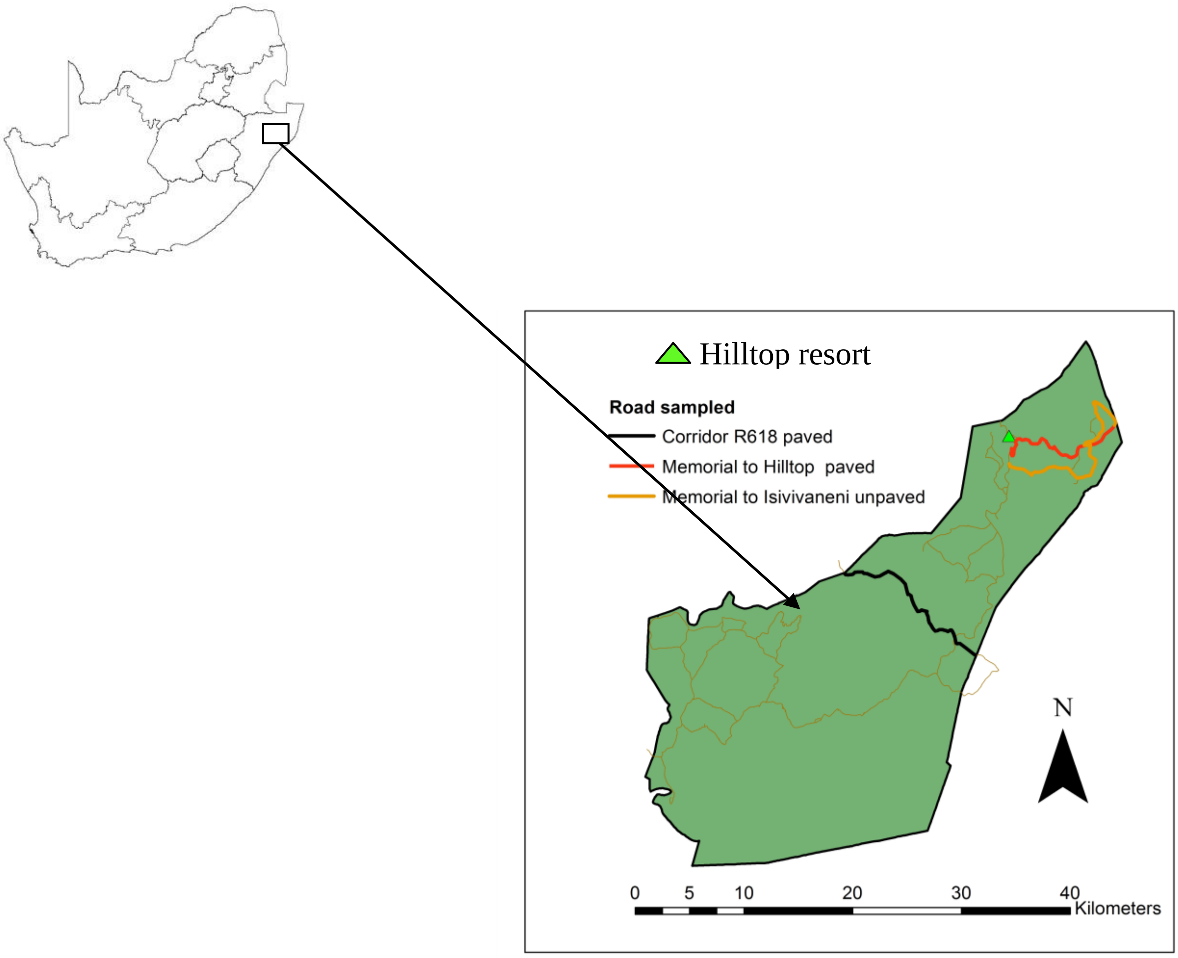

Fig. 2.1. The three types of roads monitored for roadkills in Hluhluwe-Imfolozi Park.

Monthly field transects to assess roadkills

Data were collected for a year from June 2016 to May 2017. Three different road transects were monitored during this period, with each transect driven back and forth by vehicle as detailed below. The three transects were: (1) the corridor (R618) (paved) which is a public road crossing the park, (2) the paved road from Memorial Gate to Hilltop Resort, and (3) the unpaved road from Memorial Gate to Isivivaneni Lookout (Fig. 2.1). Monitoring of roadkills on transects within the park were only conducted on Hluhluwe but the corridor transect included both Hluhluwe and Imfolozi. Based on information given by honorary rangers and park managers, Hluhluwe has higher traffic volumes and more game than Imfolozi and the Hluhluwe River is another contribution factor for increased wildlife when comparing the two reserves (pers. comm.). Moreover, the routes chosen were used frequently by game drivers and tourists (pers. comm.). The length of R618 corridor, paved and unpaved road transects were measured to be 18.2 km, 15.4 km and 22.5 km respectively. Data were collected during the early mornings (06h00-11h00) and late afternoons (15h00-18h00) while the routes were driven. Each road transect was driven at least six times per day (including early morning and late afternoon). Consequently all road transects were monitored for roadkills for six days per month, however during the first month (20-29 June 2016) of collection, a period of 10 days was spent monitoring for roadkills. During the roadkill data collection, a driver which was also an observer and at least one additional observer would look out for dead wildlife on the road transect they were driving. Speed limits were adhered too as transects were driven and monitored for roadkills. The corridor (R618) was driven with a speed range of 40-60 km/h, the paved road inside park was driven with speed range of 30-40 km/h and the unpaved road was driven with speed range of 20-40 km/h.

For each roadkill detected the following data were recorded in addition: species identification, a photograph, geographic positioning system (GPS) coordinates, amount of game in the vicinity (ranked data, 1= vegetation only, 2= vegetation and water source or infrastructure, 3= all in one place), vegetation, road characteristics and infrastructure (flat or steep, curve/ bend, river or bridge), distance to roadside vegetation from road (ranked for visibility from the road, 1 m away from road ranked as 1, 2 m away from road ranked as 2 and 3 m and more ranked as 3), date, time, weather, number of observers, vehicle type, phase of moon (full moon or not), and if it was a holiday period. However, some of the variables were not used for analyses in our study (vegetation, full moon phase, number of observers and others). The amount of game in vicinity was ranked at a radius of 50 m from the roadkill. Furthermore, samples of carcasses were taken for DNA storage in the DNA Bank at the University of KwaZulu-Natal for later genetic analysis (Dr S. Willows-Munro). We also recorded the time, distance covered per transect, average speeds, weather, number of observers/per transect, dates and type of road for each day of data collection (even if no roadkills were found) to determine the probability rates of road kills and detection rates of roadkills in park during period of study. On the last three days (22, 23 and 24 May 2017) of monthly field transects survey, 70 non roadkills points were assessed to compare environmental factors and road characteristics on presence and absence of roadkills. Random numbers were generated in (Microsoft) Excel 2016, which indicated distance in kilometers for each of these data points. The range for random numbers depended on transect monitored which included 1-19 km for R618 corridor, 1-23 km for the unpaved road and 1-16 km for the paved road (Memorial Gate to Hilltop Resort). Data point numbers for non-roadkills on these roads were similar as those recorded for roadkills. The same additional data collection procedure was followed as for the roadkill points described earlier.

Statistical analyses

ArcGIS 10.2 (ESRI, Redlands, CA, USA) was used to create point maps of each roadkill located. Coordinates were also recorded for non roadkills and used in process of identifying hotspots in HIP roads. To identify hotspots, monitored roads were divided into stretch of 4km and presumed that if more than five roadkills were recorded on each road stretch, that road stretch would be considered a hotspot.

SPSS version 20.0 was used to analyze our data. Game vicinity and distance to roadside vegetation from road predictors were analyzed with Chi-square test since the recorded values were categorized as ranks. Road type predictor was analyzed with the Kruskal-Wallace test Assumption for normality were not met even after log. transformation when we analyzed road type predictors with One-way ANOVA. An Independent-sample test (T-test) was used to compare number of roadkills between summer (October 2016 to March 2017) and winter (June 2016 to September 2016 and April 2017- May 2017). Furthermore, the Partial Least Squares Discriminant Analysis (PLS-DA) method was used to predict which factors were important on the prediction of roadkills in HIP. PLS-DA is based upon the classical partial least square regression method for constructing predictive models (Wold *et al*. 2001). PLS assumes a model that is driven by a few latent factors or components, which are linear combinations of explanatory variables (X) and have maximal covariance within the variable of interest (Y). In our case the response variable are the roadkills and explanatory variables are the contributing factors (season, terrain, weather, amount of game in vicinity and distance to roadside vegetation from road). Since PLS-DA does not show which explanatory variables are effective or important, the Variable Importance in the Projection

(VIP) would be next step to take. VIP is a measure that is used to create ranked scores for each factor in the dataset (Wold *et al*. 2001) and was defined as follows:

$$\mathrm{VIP}_k = \sqrt{K \sum_{a=1}^{A} [(q_a^2 t_a^T t_a)(w_{ak}/\|w_k\|^2)] / \sum_{a=1}^{A} (q_a^2 t_a^T t_a)},$$

where VIP_k is the importance of the k'th factors based on with a component, w_{ak} is the corresponding loading weight of the k'th factor in the a'th PLS-DA component, t_a, w_a, and q_a are the a'th column vectors, and K is the total number of factors (Gomez *et al*. 2008). The important features in the PLS-DA model were identified by those factors that had a VIP score of greater than 1, since the average of the squared VIP scores is equal to 1 (Wold *et al*. 2001). VIP was done using the Tanagra data mining statistical software package.

RESULTS

Descriptive results

After driving a total of 10607.4 km and 328.5 h over 70 days (mean of 4.7 h per day) in a year, 70 roadkills were recorded with 31 species identified for all roads monitored in the study (Table 2.1). Roadkill rate was 0.0066 per km. Of the 70 roadkills recorded, 30% (n = 21) were mammals, 25.7% (n = 18) were birds, 25.7% (n = 18) were reptiles, 14.3% (n = 10) were amphibians and 4.3% (n = 3) were unknown (Table 2.1). Of the mammalian taxa, five species were identified with African pygmy mouse *(Mus minutoides)* having more roadkills (n = 17), reptilian taxa had ten species identified with the giant legless lizard *(Acontias plumbeus)* having the most roadkills (n = 5). The amphibian taxa had four species identified with eastern olive toad *(Amietophrynus garmani)* having the most roadkills (n = 5). On the other hand, birds had ten species identified with relatively equal roadkill species range and five species were unknown due damage caused by vehicles on road (Table 2.1). Three species could not be identified to species nor taxon. The largest species recorded as a roadkill was the African buffalo (*Snycerus caffer)* and smallest was the blue waxbill (*Uraeginthus angolensis*). None of the species recorded in this study were threatened according to International Union for Conservation of Nature (IUCN) Red Data List of Threatened Species. Most recorded roadkills were listed as least concern species with a few of the snakes having an unknown conservation status according to the IUCN Red Data List of Threatened Species.

Table 2.1. Roadkills recorded on three road transects (paved, unpaved and R618 corridor) at Hluhluwe-Imfolozi Park over a period of a year in 2016-2017.

Taxa	Common names	Scientific names	Counted number	Conservation status
Amphibia	Eastern olive toad	*Amietophrynus garmani*	5	LC
	Frog	*Anura* sp.	3	Xx
	Lizard	*Lacertilia* sp.	1	Xx
	African helmeted turtle	*Pelomedusa subrufa*	1	LC
Aves	Bird	*Aves* sp.	5	Xx
	House sparrow	*Passer domesticus*	3	LC
	Fiery-necked nightjar	*Caprimulgus pectoralis*	2	LC
	Malachite kingfisher	*Corythornis cristatus*	1	LC
	Cuckoo finch	*Anomalospiza imberbis*	1	LC
	Scarlet chested sunbird	*Chalcomitra senegalensis*	1	LC
	Blue waxbill	*Uraeginthus angolensis*	1	LC
	Rattling cisticola	*Cisticola chiniana*	1	LC
	Dark-capped bulbul	*Pycnonotus tricolor*	1	LC
	Common fiscal	*Lanius collaris*	1	LC
	Glossy starling	*Lamprotornis nitens*	1	LC
Mammalia	Pygmy mouse	*Mus minutoides*	17	LC
	Bushpig	*Potamochoerus larvatus*	1	LC
	African buffalo	*Syncerus caffer*	1	LC
	African savanna hare	*Lepus microtis*	1	LC
	White tailed mongoose	*Ichneumia albicauda*	1	LC
Reptilia	Giant legless lizard	*Acontias plumbeus*	5	LC
	Spotted bush snake	*Philothamnus semivariegatus*	3	X
	Blue-headed gecko	*Agama atra*	2	LC
	Puff adder	*Bitis arientas*	2	X
	Leopard tortoise	*Stigmochelys pardalis*	1	LC
	Tortoise	*Testudinoidea*	1	xx
	Twig snake	*Thelotornis capensis*	1	LC
	Snake	*Serpentes* sp.	1	xx
	Rhombic night adder	*Causus rhombeatus*	1	x
	African tiger snake	*Telescopus semiannulatus*	1	x
Unknown	Unknown (colon)	Unknown	3	xx

x = not assessed on the Red Data List of Threatened Species, xx = species could not be identified during study.

Mapping hotspots in HIP

Hotspots were defined as areas where several road kills occurred during the study. Hotspots were found on the R618 corridor road and the paved road (Memorial Gate to Hilltop Resort). The unpaved had no hotspots as few records of roadkills were detected during the study. In the current study, hotspots were found at approximate 4 - 12 km (second, third and fourth stretch) on the R618 corridor road from Hlabisa town to Mtubatuba direction and about 2 km (first stretch) on paved road from Memorial Gate to Hilltop Resort direction and the last 7 km (third and fourth stretch) before reaching Hilltop Resort (Fig. 2.2).

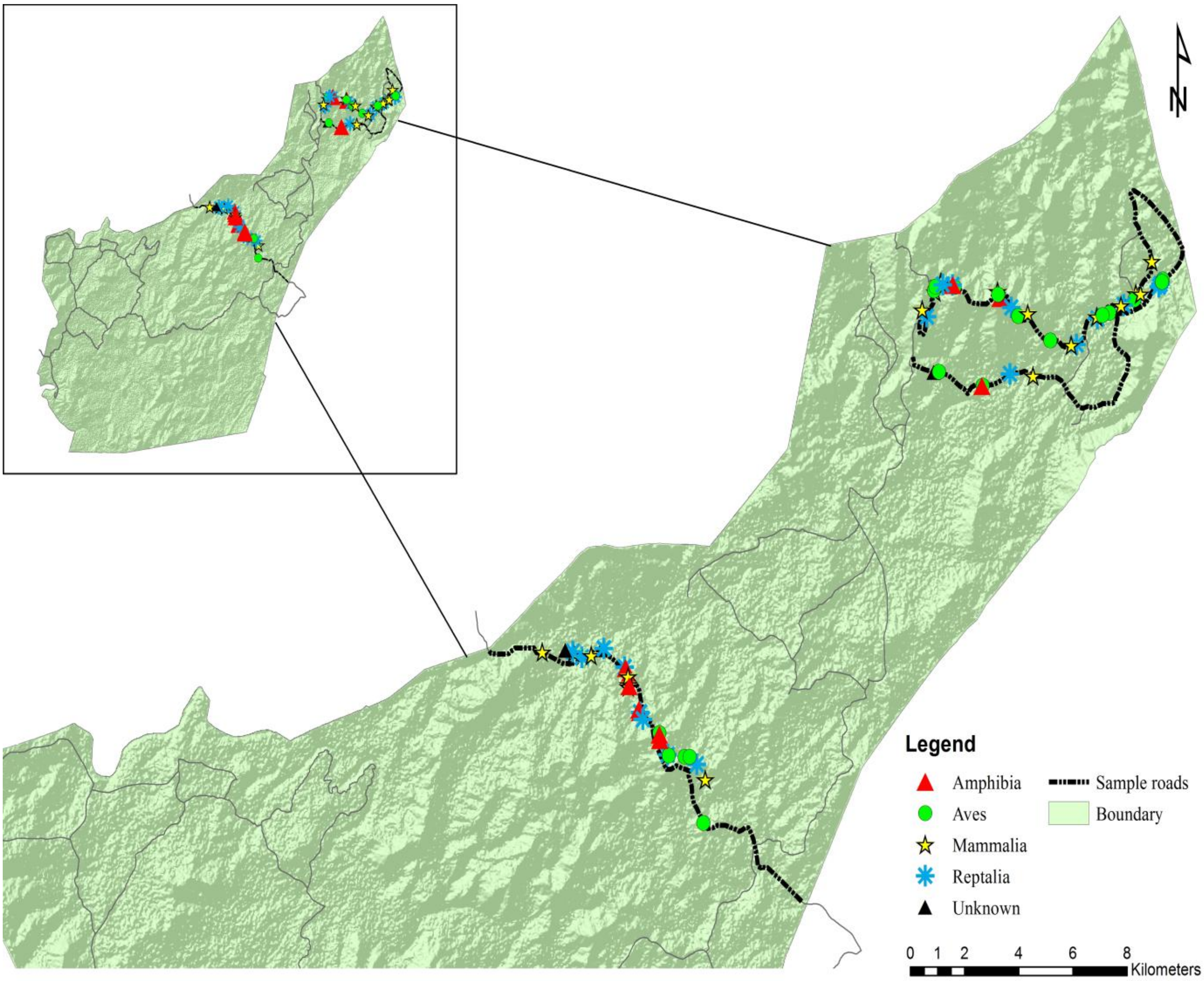

Fig 2.2. Map of Hluhluwe-Imfolozi Park (HIP) with overlaid type of roadkills on the three roads monitored in HIP, to identify hotspots during the current study.

Type of road effect

There was a significant difference in roadkills rates between the monitored road transects (ANOVA, F = 10.235, df = 3, P = 0.005). However, relatively high roadkill rates were detected on the R618 corridor road (paved) with 0.010 roadkill km^{-1} (34 incidences or 48.8%), followed by the paved road from Memorial Gate to Hilltop Resort (0.009 roadkill km^{-1}; 28 incidences or 40.0%), with relatively few on the unpaved road from Memorial Gate to Isivivaneni Lookout (0.002 roadkill km^{-1}; 8 incidences or 11.2%). All the three road transect were not different from each other ($p = 1.00$; post-hoc test). The various taxa had relatively equal proportions of roadkills on the R618 corridor road, however reptilian taxa had more of a range in species. Birds had the highest species range of roadkills on the paved road (Memorial Gate to Hilltop Resort). Altogether, the taxa had relatively equal proportion of roadkills with the amphibians having the least ($n = 2$) roadkills. The mammals had relatively high numbers of roadkills compared with other taxa on the unpaved road (Memorial Gate to Isivivaneni Lookout). However, the detected number of roadkills had more numbers of African pygmy mouse which was four of the five recorded for mammals on the unpaved road.

Season

Season as a potential predictor for roadkills in HIP was not significant. Roadkills detected in winter and summer were not significantly different from each other (T-test, $t = 0.51$, $d = 10$, $p = 0.621$). Winter, however, had a higher number of roadkills ($n = 41$) compared with summer with 29 roadkills recorded (Fig. 2.3). However, both seasons had a relatively equal range of species identified. Mammals ($n = 20$) and birds ($n = 10$) had higher numbers of roadkills in winter, whereas reptiles ($n = 11$) and amphibians ($n = 9$) had higher numbers in summer (Fig 2.3). Of the 20 roadkills of mammalian taxa, 17 were African pygmy mouse, one was an African buffalo, one was an African savanna hare *(Lepus microtis)*, and one was a bush pig *(Potamochoerus larvatus)*. White-tailed mongoose *(Ichneumia albicauda)* was the only roadkill that was detected in summer of the mammalian taxa. For birds, there was a relatively equal proportion of the respective species from roadkills found in winter, while in summer there were four unknown avian roadkill species from the eight avian roadkills identified. Of the amphibian roadkills in summer, five eastern olive toad roadkills were identified. Roadkills species were generally evenly distributed for reptilian taxa for both seasons, although summer had more (Fig. 2.3).

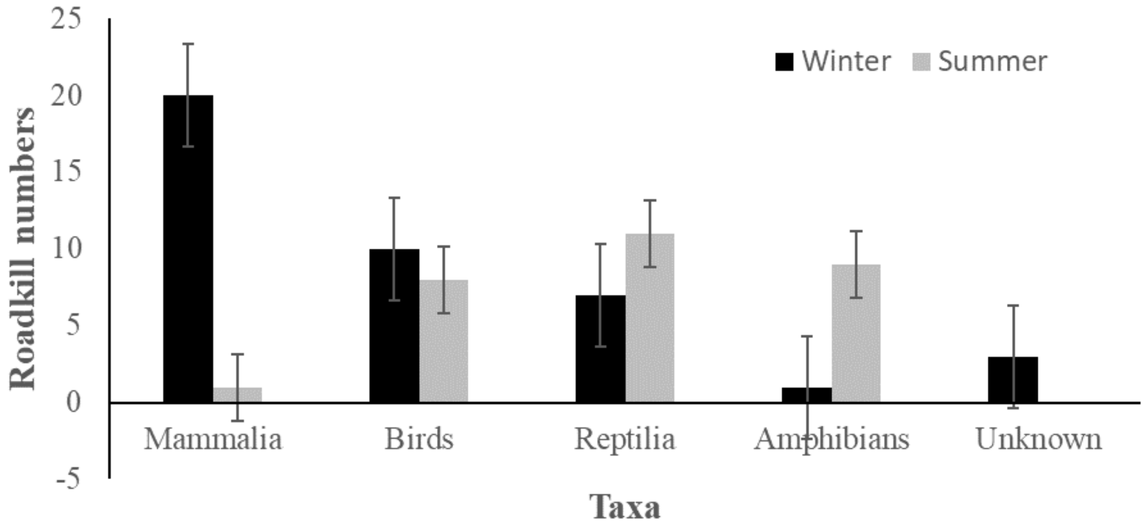

Fig. 2.3. Number of roadkills reported by taxon per season on the three monitored transects (paved, unpaved and R618 corridor) of Hluhluwe-Imfolozi Park in 2016-2017.

Distance to roadside vegetation from road

Roadkills potentially accounted for by distance less than 1 m (Rank 1) for roadside vegetation from the road was 68 and distance less than 2 m from the road (Rank 2) was only two roadkills. No roadkills were recorded when distance to roadside vegetation from the road was 3 m or above (Rank 3). The roadkill frequency deviated significantly from expected frequency (0.5: 0.5), and was skewed towards rank 1 (X^2 = 62.229, P < 0.0005).

Amount of game in the vicinity

A total of 59 roadkills were recorded when amount of game in vicinity was ranked as 1 and 11 roadkills were recorded when amount of game in vicinity was ranked as 2. No roadkills were reported when amount of game in vicinity was ranked as 3. The roadkill frequency deviated significantly from expected frequency (0.5: 0.5), and was skewed towards rank 1 (X^2 = 32.914, P < 0.0005).

Partial least squares (DA) and (VIP)

The PLS-DA model yielded an overall accuracy of 69.7% with 30.3% error rate when using five factors (season, terrain, weather, amount of game in vicinity and distance to roadside vegetation from the road) as classifiers of roadkills in HIP. Season and the terrain were the contributing factors that were more important in the prediction of roadkills since they had VIPs greater than 1, with VIP scores of 1.281 and 1.127 respectively (Fig. 2.4). The amount of game in the vicinity and distance to roadside vegetation from road factors were also important with VIP scores of 0.850 and 0.855 respective and later the weather with a VIP score of 0.797.

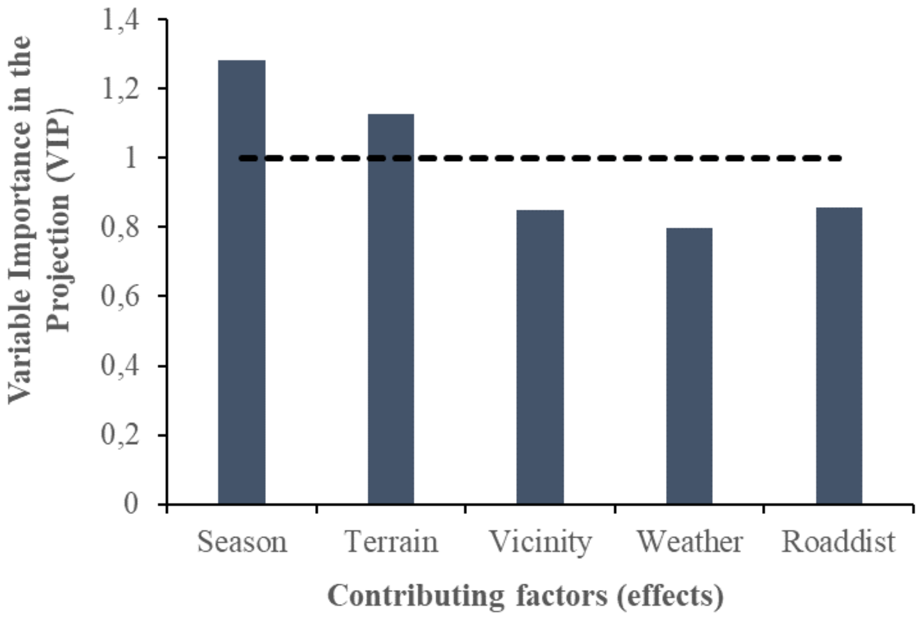

Fig. 2.4. Contributing factors to predicted roadkills (effects) measured as ranked scores in the variable importance in the projection in HIP in 2016-2017. (The important contribution factors are those with scores greater than one above the solid dashed line. * Roaddist = distance to roadside vegetation from road).

DISCUSSION

A total of 10607.4 km was driven with 70 roadkills detected during the study period. The roadkill rate was 0.0066 roadkill km^{-1}, which was relatively small when compared with other studies that followed a similar protocol. For example, Clevenger *et al*. (2003) had a roadkill rate of 0.01 roadkill km^{-1} after driving 65253 km with 677 roadkills detected. In another African study, Kioko *et al*. (2015) found 0.13 roadkill km^{-1} after driving 750 km and detecting 101 roadkills. Possible explanations for the relatively low observed roadkill rate in our study included the possible disappearance of carcasses before detection (pied crows (*Corvus albus*) were observed scavenging on roadkills during study, pers. obs.), HIP has culverts on their paved roads that may assist in reduction of roadkills, and the possible removal of carcasses from roads to the road verges by drivers. These likely reduced roadkill detection abilities for observers. In addition, we also assumed that larger wildlife involved in collisions with vehicles likely die further from the road after the collision, consequently reducing counts of roadkills on roads. Hobday and Minstrell (2008), also suggested that 30% of animals struck by cars die some distance from the road, where they were unaccounted. Another confounding factor that underestimates roadkills counts is observer error (Longcore *et al*. 2012; Teixiera *et al*. 2013), however, in our study the same observers were involved in the monthly surveys.

Mammalian taxa had higher number of roadkills (n = 21), followed by birds (n = 18) and reptiles (n = 18), and amphibians (n = 10) in our year-long study in HIP. Only three species could not be identified to taxon or species level. Although mammals had a higher number of roadkills, most of the roadkills identified were the African pygmy mouse (n = 17, 81% of mammals killed) suggesting it was selective. However, this likely followed a rodent population explosion as documented elsewhere where rodent reproduction and numbers have increased following good rains (Taylor & Green 1976) with many killed on roads (Downs unpublished data). Previously drought has severely impacted rodent populations in HIP but then there has been a population explosion following good rains (Bowland 1986). The African pygmy mouse is a free roaming mammal with increased diversification capability because of its climatic adaptations, small body size and diversified chromosomal pattern (Shea & Bailey 1996). Fortunately, the African pygmy mouse is listed as Least Concern (LC) according to IUNC (2012). Awareness for rare and endangered species is particularly needed since traffic is generally non-selective in roadkills (Hayward *et al.* 2010).

In our study, we could not identify names for hotspots identified, therefore we accounted for the closest distance from known named areas. Hotspots for roadkills reported on the R618 corridor road were generally found on steep roads, road bends and when the road was wider. Road stretches and road designs or characteristics influence the vehicle speed and the driver's visibility of the road (Clevenger *et al*. 2003; Seiler 2005). In our study, hotspots were reported on steeper roads because vehicle speed likely increased at these steeper road segments and the visibility of drivers' was reduced on bendy roads thereby increasing chances of collision of animals in roads with oncoming vehicles. Paved roads (Memorial Gate and Hilltop Resort) hotspots for roadkills increased with water sources (pans) and steep areas. Water sources often attract wildlife close to roads increasing their chance of being hit by vehicle. Drews (1995) study reported that, ‘hot spots’ of roadkills in Mikumi National Park occurred close to waterholes.

Roads monitored in our study were significantly different from each other in terms of roadkill rates, however more roadkills were detected on the R618 corridor (0.010 roadkill/km), followed by the paved road from Memorial Gate to Hilltop Resort (0.009 roadkill/km) then the unpaved road from Memorial Gate to Isivivaneni Lookout (0.002 roadkill/km). Our hypothesis was rejected. The results showed a different trend with Nuttall-Smith *et al*. (2015), were they detected more roadkills on R342, followed by park paved roads then lastly the unpaved roads of Addo Elephant National Park. Collinson (2013) also reported a different trend in her study in Greater Mapungubwe Transfrontier Conservation Area (GMTFCA), Limpopo Province, South Africa. Collinson (2013) detected 991 roadkills on paved while only 36 on unpaved. The observed result may have been due to the little data we recorded making hard to determine difference between roads.

Reptilian taxa had more species range of roadkills on the R618 corridor compared with other taxa. The possible explanation is that, reptiles are often considered small and slow, consequently their probability to be hit by vehicle increased on roads like R618 corridor which is a national road with a wide road width, is surfaced, has increased traffic volume and speeding vehicles. Jaarsma *et al*. (2006) also reported that traffic volume and animal’s traversing speed also influence whether a collision occurs. Speed is considered a factor for increased numbers of roadkills (Illner 1992), however few attempts have been made to statistically relate wildlife roadkills to traffic speed (Lauren *et al*. 2010). Moreover, there has been an ongoing concern by conservationists about surfaced road being conducive to speeding, leading to increased roadkills (Mkhanda & Chansa 2011). On the paved road (Memorial Gate to Hilltop Resort), birds had high numbers of roadkills. During the study, the dark-capped bulbul *(Pycnonotus tricolor)* was observed foraging around anthropogenic supplementary food (two slices of bread on the road), which could have been thrown away by tourists. Birds are attracted to roads because of road verges with lower grazing pressure, increased water runoff, a higher plant species richness, taller individual plants, insects and more seeds (O’Farrell 1997). The elevated trip from Memorial Gate to Hilltop Resort (paved) had all the mentioned above resources for birds (pers. obs.). Two species of reptiles (spotted bush snake (*Philothamnus semivariegatus)* and giant legless lizard) and one from a mammalian taxon (African pygmy mouse) were identified on the unpaved road (Memorial

Gate to Isivivaneni Lookout) as roadkills. The unpaved road had debris and rocks on it which is often preferred by some reptilian species.

There were no significant differences in roadkills between seasons in HIP. However, during winter more roadkills were detected compared with summer. This supported our hypothesis. Coelho *et al*. (2008) suggest an alternative hypothesis that may have explained the lack of seasonal variations in road mortality for most vertebrate groups evaluated and the absence of association with traffic volume to be the effect of random chance. The effect of season on roadkills is a challenge, because it includes different processes that wildlife experience during the different seasons. These processes include biological processes (life stages of different animals at different times of the season, breeding, rutting etc.), migration and hibernation or torpor. All these processes involve animals becoming increasingly active and are expected to move around in search for different resources. During such periods, animals are at risk of being involved in vehicle collisions. The African pygmy mouse contributed to the high number of roadkills (n = 17) in winter. Of interest, the African pygmy mouse is a sexually inactive in the early rainy season (May) (Fichet-Calvet *et al*. 2009), however in our study many roadkills were detected in May 2017 with few exceptions in late April 2017. This observation explains the likely increased rodent numbers at this time following increased breeding after summer rains as mentioned previously.

The closer an animal is to a road, the higher likelihood that it can collide with vehicles on the road. In our study, vegetation close to road increased incidence of roadkills compared with vegetation far from road. However, Boitet and Mead (2014) found the opposite in their study. They found least roadkills on the road with the lowest verge width (3.26 m). They also found high roadkill numbers on the US Highway 441 which had the highest road width (8.68 m). For reduced roadkills in PAs, cutting of vegetation 1 m close to road is recommended and this method was observed to be implemented for the paved roads of HIP. To our knowledge, vegetation cover has been documented in some studies as a potential factor increasing roadkills, however the distance of vegetation cover to road has not been documented extensively.

Often survival of any wildlife is determined by the access to food, water, and their defensive structure to help them defend against predators. In our study, amount of game in the vicinity ranked as 3 (vegetation (source for food), water source and infrastructure), were assumed to be visited more by wildlife due to resources available for wildlife in such vicinities. However, there were no roadkills recorded when the amount of game in the vicinity was ranked as 3, but there were many roadkills recorded when the amount of game in vicinity was ranked as 2. Our reported results confirm the need for removal of water sources close to roads as they attract wildlife to roads, but this is a conflict of interest as tourists often see game at waterholes so want these close to roads. Drews (1995) reported that 'hot spots' of roadkills in Mikumi National Park occurred close to waterholes. Poles, towers, bridges and any other infrastructure close to roads also often attract animals to road. Poles and towers are often used for nesting by birds.

Modelling techniques are measures that we assume assist with predicting future outcomes based on the present data. The PLS-DA method was used to predicted presence of roadkills given specific explanatory variables. In our study, the PLS-DA model yielded an overall accuracy of 69.7% with a 30.3% error rate when using five factors (season, terrain, weather, amount of game in vicinity, and distance to roadside vegetation from the road) as classifiers for occurrence of roadkills (mammals, birds, reptiles and amphibians) in HIP. The unknown species reported in the study were not included in the analysis of PLS-DA since there were only three. The result of 69.7% accuracy for the presence of roadkill in HIP, meant that, if its winter, the road is steep, the vegetation to road is less than 1 m, and the vicinity has water sources or infrastructure and vegetation, the chances for presence of roadkill was 69.7%. The method of variable importance in the projection showed that season and terrain were important factors in the prediction of presence of roadkills in HIP. Season has been an important explanatory variable in various studies of roadkills (Clevenger *et al*. 2003; Coelho *et al*. 2008; Bullock *et al*. 2011). As mentioned earlier season affects the movement and activity of species. For many terrestrial species there are seasons where they are reproductively active, migrate, disperse etc.. This seasonal variation may cause wildlife to be potentially greater observed on roads during particular seasons. However, there are other variables that are important in assessment of roadkills, namely the road characteristics, composition and configuration of vegetation adjacent to road, drivers' behaviours, and any historic data on the location of assessment of roadkills.

Wildlife do not roam on or near roads for no reason, therefore the resources that attract wildlife to areas with roads are one of the reasons wildlife occur there and so increase their potential to collide with vehicles. Moreover, their biological processes also cause them to cross roads, namely the breeding, dispersal, migration etc. Understanding all the reasons that cause wildlife to be attracted to roads could assist in reducing the number of roadkills observed on roads, especially in PAs. Our study contributes information to roadkill research and understanding which aims at measuring and reducing roadkills in PAs in South Africa, raising public awareness, formulating models that enables determination of where roadkills are likely to occur and determining mitigation measures that reduce roadkill rates in PAs.

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Chapter 3
Citizen science: Public perspectives of roadkills in Hluhluwe-Imfolozi Park, KwaZulu-Natal, South Africa

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Citizen science has expanded in many disciplines of science and is influenced by its effectiveness in collecting data. Modern technology including cellphones, internet, software and applications makes it even easier to collect data through citizen science initiatives. Citizen science is explained as a process whereby public assists voluntarily with acquiring and processing information locally, regional and at larger scale for researcher purpose. Despite the bias citizen science has, citizen science data are easier to collect, time effective, covers more spatial range and cost effective. We used citizen science data to determine awareness and number of roadkills occurring in Hluhluwe-Imfolozi Park. Two protocols for collection of data through citizen science were implemented and these included the standardized and roving data approaches. The study showed that respondants interviewed in HIP were significantly aware of roadkills occurring at HIP. Moreover, respondants were significantly aware of rules and ways that may potentially reduce roadkills when driving inside HIP. A question that arises then is why do roadkills still continue to occur although the public are aware of roadkills occurring within protected areas? More importantly, the study highlighted the need for more studies that use citizen science as a tool to gather information on roadkills in order to develop a database that can be used by the HIP staff to identify trends for which mitigation could be implemented.

Key words: roadkills, awareness, citizen science, protected areas.

INTRODUCTION

The ongoing development and effectiveness of using citizen science as a tool for collecting data has expanded in many disciplines of science studies which can be attributed to modern technology (software application, smartphones, internet etc.) (Silvertown 2009; Bonney *et al*. 2009; Vercayie & Herremans 2015). For example, various ornithological projects have gathered information on phenology, distribution, numbers and/ detection of invasive species with use of citizen science (Ashcroft *et al*. 2011; Downs *et al.* 2014). Citizen science is explained as a process whereby public assists voluntarily with acquiring and processing information locally, regional and at larger scale for researcher purpose (Cooper *et al*. 2007; Silvertown 2009). In contrast to data collected by researchers, citizen science data are relatively easier to collect, less time consuming, cover more of the spatial range and are generally cost effective (Vercayie & Herremans 2015). However, citizen-science-based data are often biased. For example, public volunteers often have less experience on the study conducted, data collected by surveyors is generally not valid and non-reliable (recounts), less surveying effort (opportunistically records) and limited knowledge of species range covered (Dickinson *et al*. 2010). Due to citizen science increased recognition based on the information it provides, the effect of bias has been reduced. Different protocols to collect data with citizen science have been implemented, including the standard (compiled questionnaire which will be conducted for certain period) and roving data (opportunistic records, normally for prolonged period) (Vercayie & Herremans 2015).

Road networks in protected areas (PA) are increasing substantially, and this is caused by high demand of tourists visiting PA (Mulero-Pazmany *et al*. 2016). Consequently, wildlife in PAs are negatively affected by roadkills (Hels & Buchwald 2001). This results from perceived increased traffic volume and speed, lack of knowledge of ways to drive within PAs by drivers, naive drivers and visitors often not abiding to signage rules of PAs. Without misunderstanding, such negative effects are attributed from development of road networks to account for tourists needs (Mulero-Pazmany *et al*. 2016). So, it is therefore imperative to conduct research and develop low-cost strategies for identifying the location and causation of roadkills in PAs. Research gathered for hotspots and cause of roadkills will assist in reducing numbers of roadkills, although road networks continue to be a constraint to wildlife populations.

Citizen science is by far the most low-cost strategy, feasible, amicable, has more data coverage and time consuming when looking at our objectives for our study. Both standard and roving data were collected in current study to increase reliability and decrease biasness imposed by collecting data through citizens. Our study was aimed at understanding behaviour of drivers as they drive in PAs and whether they are aware of roadkills occurring in PAs, specifically in Hluhluwe-Imfolozi Park (HIP), KwaZulu-Natal Province (KZN), South Africa. HIP has rules that protect the wildlife within their premises and warning signs that alerts tourist and visits of speed limits and danger ahead. Clear signage of what is expected of tourist and visitors entering HIP are shown on all entry gates. We hypothesized that individuals driving in HIP are aware of roadkills and know of ways to avoid roadkills in PAs. We predicted that most visitors to HIP were aware of the need to drive carefully to avoid roadkills.

METHODS

Study area

HIP (S28° 0´to28° 25´, E31°42´ to32° 0´) was the study area where the questionnaires were used to acquire the data needed for study, with permission given by Ezemvelo KwaZulu-Natal Wildlife's protected areas (E/5123/05) and University of KwaZulu-Natal (HSS/0159/017M). The permit applications were done to comply with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975. The vegetation in HIP varies from grasslands to Acacia (*Vachellia* spp.) woodlands, with mean annual rainfall range of 635 mm to 990 mm and mean ambient temperature ranging between 13^{o}C and 33^{o}C (Chapter 2). The study area is detailed in Chapter two, the only difference was the areas where the data was collected. We used HIP entrance gates (Memorial Gate and Nyalazi Gate), restaurants (Hilltop Resort and the Centenary Centre) and staff accommodation sites to approach tourists and staff to answer questionnaires to obtain data on roadkills in HIP. While in Chapter two, road transects were used to data on roadkills in HIP. For maximum response from respondants (more questionnaire answered and avoidance of rejection), the above location where chosen. The chosen locations for the present study were areas where visitors were relaxed and often in relatively high numbers. As mentioned above, citizen science data were collected as both standard and opportunistic roving data in current study.

Standard data collection

Questionnaire surveys were conducted for period of five days (12 July to 16 July 2017) with 156 questionnaires answered by staff drivers, tourist drivers, tourists and delivery drivers. Questionnaires were either given and collected later from respondants or a formal interview was conducted. Our survey focused mostly on drivers that drove inside HIP and later tourist and staff that were passengers while drivers drove inside HIP. The questions compiled were stimulated from link of Arrive Alive Safety Program (www.arrivealive.co.za/Avoiding-Animals-On-The-Road). Three undergraduates studying Biological Science at the University of KwaZulu-Natal, Pietermaritzburg campus assisted with the surveys. We conducted the survey by standing at HIP entrance gates, moved around parking lots at Hilltop Resort and the Centenary Centre, and we also did a door to door searches for staff (driver or passenger) at HIP staff accommodation. The students were Zulu speaking since we were in an area were Zulu was the main language, but the questions were answered in English. Moreover, a google link (https://goo.gl/forms/vAyUD9nUio566Fk2) for the questionnaire was advertised on the KZN Wildlife Sightings Whatsapp group so tourists could access the questionnaire in their free time and answer the questions. This message was sent once a week for the whole month of September 2017. At the end of September, the received response on google link was combined with formal interview questionnaire for analyses.

Opportunistic roving data collection

Several approaches were implemented to get as much data as possible from roving data, since roving data relies on opportunistic chances of data sourcing. These included firstly the accidental reports of wildlife roadkills which occurred on the corridor road R618 traversing through HIP to Hlabisa town. These reports were requested from the South African Police Service (SAPS) at Hlabisa police station. These accidental reports dated from 2013 to 2017. Secondly we requested data the from Endangered Wildlife Trust (EWT) which provided roadkill data from 2007 to 2016 with all records occurring within HIP and R618 corridor. Thirdly, the staff at the research camp at HIP and some honorary rangers at HIP provided collected roadkill data with records from January 2017 to May 2017.

Statistical analyses

Data collected from both standard and roving data collection methods were captured using Microsoft office Excel 2016 version. Descriptive statistics were used to analyse the demographical information. Chi-square (X^2) tests were used to analyse data collected for driver behaviour and awareness of respondants to roadkills occurring at HIP. All statistics were performed in IBM SPSS Statistics version 20.0.

RESULTS

A total of 156 formal interview questionnaire surveys were conducted and 52 google form surveys were completed during period of study. Of the 156 formal interviews, 69 respondants indicated their nationality and 87 did not indicate their nationality. There was a total of 58 (84.1%) South African respondants and the remaining 11 (15.9%) respondants were international. Of the 58 South African respondants, 29 worked inside HIP (game driver, staff driver or staff member and researcher) and 27 did not work for HIP (delivery trucks, tourist or tourist driver, police member or security). The 11 international respondants did not work for HIP and were either a driver or passenger. Of the 87 respondants that did not indicate nationality, only three respondents worked for HIP (game drivers) and 84 did not work at HIP (tourist driver or passenger or did not indicate at all). The google form questionnaires did not have an option of nationality and whether the respondents were staff at HIP or just a tourist. However, the results for the formal interview and google form surveys were analysed together as one data set.

Most respondants had access to a 4x4 vehicle with only four respondants that used normal light vehicles. Moreover, all the respondants drove in groups of more than two to eleven.

Of the 208 formal interview questionnaire surveys and google form surveys, 66 (31.7%) reported seeing roadkill/s in HIP and the remaining 142 (68.3%) respondants reported to never seeing roadkills at HIP. Respondants were significantly aware of roadkill occurring in HIP ($X^2 = 23.687$, df = 1, $P < 0001$). Four taxa were reported (mammals, birds, reptiles and amphibians) as roadkills with 53 species identified from the reported roadkills in HIP (Table 3.2). The largest animal reported killed was a white rhinoceros (*Ceratotherium simum*) and the smallest was an unknown frog (*Anura* sp.). Only five respondants reported to have collided with an animal in HIP with 203 reporting having never collided with animals in HIP. The roadkills observed in HIP reported by respondants were found more on paved roads, than on unpaved roads or the R618 corridor.

Drivers' behaviour

We found that drivers were aware of the rules and ways of driving that reduce the likelihood of colliding with animal in HIP. The drivers' responses to questions that allowed comparison of understanding and knowledge of rules and ways of driving that decreased the likelihood of roadkills skewed towards answers that displayed knowledge and understanding of what was expected of them as drivers at the PA. All the questions that tested understanding and knowledge of rules and ways of driving that may possibly decrease roadkills in HIP showed a significance difference (Table 3.1).

Drivers were aware not to hoot when they saw animal/s on the road (97.5% = aware, 12.5% = not aware), to always apply brakes when approaching animal/s on road (95.2% = aware, 4.8% = not aware), speed limits at night (98.8% = aware, 1.4% = not aware), decrease speed after passing wild animal/s on road (96.6% = aware, 3.4% = not aware), always scan roadside as they drove on HIP roads (98.1% = aware,1.9% = not aware) and drivers would swerve or stop when wild animal/s were in the middle of road (77.2% = swerve and 22.8% = stop).

Table 3.1. Chi-square results on the awareness of drivers to rules and ways that may possibly decrease roadkills in HIP.

Questions	Chi-square value (X^2)	P value
Do you hoot when approaching animal on road	503.846	0.001
Do you apply brakes when approaching animal on road	358.279	0.001
Do you scan roadside as you drive in park	440.440	0.001
Do you decrease speed after passing animals on road	386.488	0.001
Do you swerve away from animal in middle of road	122.449	0.001

Opportunistic roving data

Amongst the three alternate approaches that roving data were collected, 70 roadkills were reported from 2007 to 2017. Of the 70 roadkills reported, 49 (70%) were from staff at research camp at HIP and honorary rangers, 11 (15.7%) were from the SAPS (Hlabisa Police Station) and 10 (14.3%) were provided by Endangered Wildlife Trust. Four vertebrate taxa (mammals, birds, reptiles and amphibians) were recorded as roadkills. The largest animal recorded was a white rhinoceros and smallest was the striped field mouse (*Rhabdomys pumilio*).

Table 3.2. Roadkills reported from standard and roving data methods of collection in Hluhluwe-Imfolozi Park and R618 corridor. (xx indicates if the roadkill species was reported as standard data or opportunistic roving data or both).

Taxon	Common name	Scientific name	Standardized data	Roving data
Mammals	Giraffe	*Giraffa* sp.	XX	
	Large spotted genet	*Genetta tigrina*	XX	
	Impala	*Aepyceros melampus*	XX	XX
	White rhinoceros	*Ceratotherium simum*	XX	XX
	Greater kudu	*Tragelaphus strepsiceros*		XX
	Cape porcupine	*Hystrix africaeaustralis*	XX	
	African buffalo	*Syncerus caffer*	XX	XX
	Burchell's zebra	*Equus quagga burchelli*	XX	XX
	Rabbit	Rabbit sp.	XX	
	Leopard	*Panthera pardus*		XX
	Striped field mouse	*Rhabdomys pumilio*		XX
	Nyala	*Tragelaphus angasil*	XX	
	Vervet monkeys	*Chlorocebus pygerythrus*	XX	
	Scrub hare	*Lepus saxatilis*	XX	
Birds	Fiery-necked nightjar	*Camprimulus pectoralis*	XX	XX
	Dark-capped bulbul	*Pycnonotus tricolor*	XX	XX
	Crested barbet	*Trachyphonus vaillantii*	XX	
	Spotted thick-knee	*Burhinus capensis*	XX	XX
	Yellow-billed kite	*Milvus aegyptius*		XX
	Red-capped robin-chat	*Cossypha natalensis*		XX
	Red breasted swallow	*Cecropis daurica*		XX
	Lesser striped swallow	*Cecropis abyssinica*		XX
	Bronze winged courser	*Rhinoptilus chalcopterus*		XX
	Spotted eagle owl	*Bubo africanus*		XX
	Black crowned tchagra	*Tchagra senegalus*		XX
	Rattling cisticola	*Cisticola chiniana*		XX
	Pied wagtail	*Motacilla aguimp*		XX
	Common quail	*Coturnix coturnix*		XX
Reptilia	Delalande's sandveld lizard	*Nucras lalandii*	XX	
	Puff adder	*Bitis arietans*	XX	
	Snake	*Serpentes* sp.	XX	XX
	Rhombic egg eater snake	*Dasypeltis scraba*		XX
	Bell hinge-back tortoise	*Kinixys belliana*		XX
	Common purple-glossed snake	*Amblyodipsas polylepis*		XX
	Lizard	*Lacertilia* sp.		XX
	Black mamba	*Dendroaspis polylepis*		XX
	Monitor lizard	*Varanus* sp.	XX	XX
	Leopard tortoise	*Stigmochelys pardalis*		XX
	Blue headed agama	*Agama atra*		XX
	Giant legless lizard	*Pseudopus apodus*	XX	XX
	African helmeted turtle	*Pelomedusa subrufa*	XX	
Amphibians	Toad	Anuran sp.		XX

Frog	Anuran *sp.*	XX	XX

DISCUSSION

Despite 31.7% of the respondents reporting to have seen roadkills in HIP, most respondents (68.3%) reported to have never witnessed it. Our study therefore found that respondants were significantly not aware of roadkills occurring in HIP. The results of our study do not necessarily mean the public and staff in HIP are unaware of roadkills in HIP. A crucial note that needs attention when dealing with roadkill data is to carefully evaluate for potential biasedness before inferring rates of mortality, or using such data to make management decisions (Beckman & Shine 2015). As the surveys were conducted in winter, changes in roadkill number may be expected at other times of the year. Seasonal peaks of roadkills have been documented in studies of roadkill rates (Crawford *et al*. 2014). However, factors like seasonality could aid in mitigation measures for reduction of roadkills. Activity of animals throughout the year varies, therefore ongoing surveys that represent all seasons are recommended.

In addition to seasonality as a potential factor on roadkills, the public has a perception that roadkills are casualties that include big animals that have potential of damaging a vehicle. Kioke *et al*. (2015) suggested that the body mass has an effect on drivers' responses whether they ran over animal rather than stopping or swerving. Taxa with relatively small body mass including birds, reptiles and amphibians were considered less by respondents as roadkills, consequently they are not reported causing our survey to be taxon biased.

The report compiled by Endangered Wildlife Trust (2015) suggested that the attention of drivers in Pilanesberg National Park (PNP) were more on the bush than on the road and that they were more reluctant to stop when they saw the fake animals which used as part of the investigation on body mass as plausible effect for increased roadkills. Most drivers rode over the fake animals. The lack of limited knowledge of roadkills by citizens reduces counts of roadkills and poses a threat to live animals (Dickinson *et al*. 2010).

The result of more roadkills being observed on paved roads compared with unpaved roads was expected in our survey, especially as relatively high speed and increased volume of traffic are associated with paved roads leading to higher probabilities of collisions (pers. obs.). An example of a study that demonstrated similar results to our study was Collinson (2013), were she observed 991 roadkills on paved roads and 36 on unpaved roads. It seems as if the effect of road surface in not a well-recognized factor elsewhere as relatively few studies examine its effect. If countries like South Africa intend developing their economic growth through increased road networks without threatening biodiversity, the first step to implement would to assess roadkills on unpaved roads before construction or resurfacing.

Questions that allowed comparison of understanding and knowledge of road rules and ways of decreasing the likelihood of roadkills skewed towards answers that displayed awareness of what is expected of drivers in PAs. If drivers were aware of rules and ways that could assist in reduction of roadkills, the questions that follows thereafter are, (1) do drivers intentionally collided with wildlife; (2) are drivers negligent or irresponsible; and lastly (3) do drivers not value the safety of wildlife in a PA? Recent studies allude to that drivers intentionally kill animals on roads. Examples include the following: in the USA drivers often consider vehicle collision with deer as unavoidable, therefore they do not avoid deer when driving (Marcoux & Riley 2010); in Brazil, drivers intentionally kill snakes on roads (Secco *et al*. 2014); drivers in Australia claimed to intentionally hit invasive cane toads (*Bufo marinus)* (Beckmann & Shine 2012), and drivers in South Africa never stopped or slowed down when they saw small animals (frogs, snakes) which were fake animals (Collinson 2013). From our survey comment section, many respondants articulated that staff and people delivering goods to the park were the ones speeding in HIP and could be the ones colliding with animals. Behaviour of drivers, their perceptions of roadkills and the way they should adhere to rules of PAs could be addressed with relevant tools implemented. Although, changing behaviour of drivers to avoid wildlife roadkills may take time, it is better than trying to change personal attributes and beliefs of an individual.

Our study highlighted the need for more studies that use citizen science as a tool to gather information on roadkills. Devictor *et al*. (2010) pointed out that citizen science projects are the way to go 'beyond scarcity' of means and data. However, roadkills are in a "blind spot in public perception" and do not receive proper attention in the media (Lunney 2013).

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Chapter 4

Management implication for roadkill reduction in Hluhluwe-Imfolozi Park, KwaZulu-Natal, South Africa

INTRODUCTION

Relatively few roadkills were recorded in the current study (Chapters 2 and 3). However, the need for ongoing roadkill monitoring in Hluhluwe-Imfolozi Park (HIP) is recommended. In this chapter, data collected for quantified roadkills by researchers and citizen science surveys will be used to discuss management requirements specific to HIP roadkills for (Chapters 2 and 3). Roadkill mitigation measures have been questioned for their effectiveness in the reduction of roadkills caused by road networks (Clevenger e*t al*. 2001a). To some degree, this is understandable because the interaction between wildlife and humans is a challenge hence the concept of human-wildlife conflict. The term road ecology is the umbrella between interaction between road networks and wildlife and could be the first term that introduced the need for mitigation measures of roadkills. Van der Ree *et al*. (2011) argued that the overall aim of road ecology research is to quantify the ecological effects of roads, with the ultimate aim of avoiding, minimizing, and compensating for their negative impacts on individuals, populations, communities, and ecosystems

In the simple form, roadkill mitigation measures involve the alteration of drivers' behaviour or the alteration of animals' behaviour. The drivers' behaviour often involves changing mindset of speeding by installing signage, speed limits, camera-traps and lights, whereas animal behaviour involves changing behaviour to avoid roads and use modified habitats and/or installed wildlife-crossing structures (Forman *et al*. 2003). However, a lack of success has been observed with the interventions aimed at changing animals' behaviour (Reeve & Anderson 1993). For example, Magnus *et al*. (2004) study found no difference in animals hit by vehicles when a whistle (ultrasound device) was activated and not activated. However, there are successful studies that showed effectiveness in reduction of roadkills through changing animals' behaviour. Crossing structures and exclusion fences showed 80% of effectiveness, and channeling wildlife away from roads (Clevenger *et al*. 2001a; Bissonette & Rosa 2012; Sawyer *et al*. 2012).

Several factors account for the questioned effectiveness of mitigation measures for roadkills. Firstly, the issue of poor allocation of budget for implementation of mitigation measures for roadkills compared with budget allocated for resurfacing, maintenance and newly built roads. An amount of R23.4 billion was projected to be spent on road networks for 2016/2017 in South Africa (Intergovernmental Fiscal Reviews 2015). However, no funding is given by transport departments and other companies for implementation of mitigation measures for the reduction of roadkills. Furthermore, the installation of wildlife-crossing structures are generally expensive. Delivery and maintenance of provincial roads infrastructure, public transport such as commuter bus services and transport safety and traffic law enforcement are the main focus (Intergovernmental Fiscal Reviews 2015). Secondly, there is a lack of decision making by government and political policy authorities to reduce roadkills. Even with funds available, authorization by government and political policy authorities is required which often is not favourable for wildlife well-being. Government and political policy authorities are generally skeptical about funding for mitigation of roadkills. Lack of consistency in evaluations and reports of roadkill mitigation measures and designs which have been effective could be the reason why management authorities are skeptical about funding for mitigation of roadkills. Evaluations of mitigation success often are based on opinion rather than research (Forman *et al*. 2003). Thirdly, there is a lack of empirical data that support the need for mitigation measures. Data that often guide management decisions are often lacking (Dickerson 1939). Seiler (2005) emphasized the need for understanding and being aware of roadkill patterns and causes for successful management intervention. The data that guides management decisions includes hotspots of roadkills at local, regional and national scales (occasionally), the endangered species that need to be protected, and which mitigation measures are best for protecting the identified species in the specific sections of roads. Furthermore, after choosing which mitigation measure is the best, it is also important to know how to design and implement it.

Poorly designed structures do not only affect the effectiveness of mitigation measures in the reduction of roadkills but could interrupt natural processes that can lead to various ecological problems such as overgrazing, increased erosion, or population declines (Forman *et al*. 2003). In addition, choosing the wrong mitigation measure could end up in unsuccessful management, wasted funds and possibly extinction of the particular endangered species. All the factors mentioned above are inter-related, making it easy to infer decisions that would enable successful management of roadkills. However, more baseline data on roadkills are a high priority and awareness to public and transport authorities is crucial. To assist in the success of the implementation of mitigation measures, the following could be ideal: (1) Conduction of workshops where public, counsellors, politicians and transport planners are educated about the roadkills and the need for mitigation; (2) Intervention of public, counsellors, politicians and transport planners in symposium that takes place in relation to roadkills and management aspects; (3) In protected areas, flyers, pamphlets and electronic notifying messages about roadkills and importance of abiding to rules of the protected areas should be made accessible to staff and tourists; and (4) Initiating Non-government organizations that will assist in raising funds from private companies that involve roads and biodiversity (e.g. Bridgestone, Tiger Wheel etc).

Commonly used mitigation measures

Relatively little literature has examined the mitigation measures of roadkills. Only about 44 studies have been said to examine mitigation measures and how roadkills can be used to further our knowledge of animal behaviour (Clevenger *et al*. 2001b; Malo *et al*. 2004). A variety of mitigation measures are used to reduce the effects of roadkills on wildlife populations, with the examples below being the commonly used across the globe, specifically in North America, Europe and Australia.

Signage

Road signage to reduce roadkills involves displaying warning information on boards adjacent to the road (Fig. 4.1; Magnus *et al*. 2004). This mitigation measure is economically affordable and has displayed some significant effectiveness to some degree with roadkill reduction. A disadvantage with this mitigation measure is that there is no precision that the driver would adhere to warning information presented by signage and sometimes the information displayed by signage is unclear or confusing to drivers (Magnus *et al*. 2004).

Underpass and overpass crossing-structures

The under and overpass crossing structures are built structures designed to allow safe passage for animals across roads, promote habitat connectivity, be accessible, and encourage natural movements (Fig. 4.1a and b) (Glista *et al*. 2009). Underpass crossing structures are normally designed for medium to small animals, with overpass crossing structures designed for large animals. Underpass crossing structures range from culverts to tunnels or wildlife bridges and accommodate a greater variety of species. Overpass crossing structures range from rope bridges, canopy crossings to green bridges, which accommodate far more variety of species compared with underpass crossing structures (Jaeger *et al*. 2005; Glista *et al*. 2009). Both crossing structures are very costly to implement and not all the expected species use this structure. Some animals are afraid of the noise from traffic and some structures do not attract wildlife due to inappropriate designs (Jaeger *et al*. 2005; Glista *et al*. 2009).

Non-structural measures

Non-structural measures to reduce roadkills are another route to consider for the reduction of roadkills. The non-structural measures include odour repellents whereby scented foam is sprayed on vegetation and structures along the road to repel animals away from road verges, habitat modification whereby vegetation close to road is mowed or cut, consequently increasing drivers and animal visibility on the road, ultrasound devices mounted on vehicles to scare animals away from road and road lightning often known as light reflectors (Magnus *et al*. 2004). Obviously, the non-structure mitigation measures have their own disadvantages. For example, odour repellent can kill wildlife that ingest the road verge sprayed with odour repellent, mowed grass adjacent to roads attract some species more because of green flush they get after mowing (Ramp *et al*. 2005), and light has negative consequences on nesting birds (De Molenaar *et al*. 2006).

There are many other mitigation measures not mentioned here that are fundamental and have played a crucial role in the reduction of roadkills. Importantly knowing which mitigation measure to use and how and when should it be implemented for successful management of roadkills. Outlined below are recommendations for mitigation measures that could aid in the reduction of roadkills in protected areas drawn from current study, existing literature and personal observations.

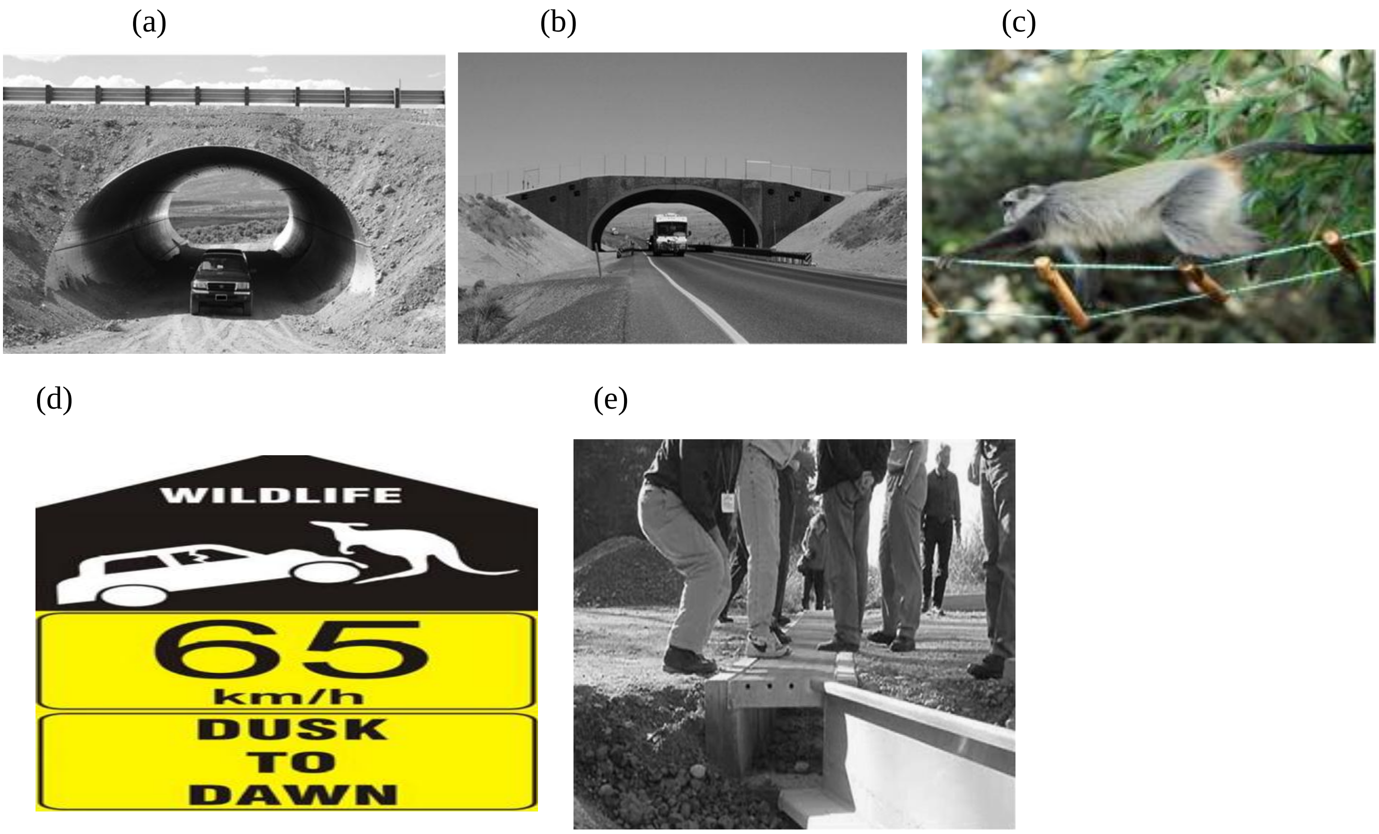

Fig. 4.1. Commonly used mitigation measures in the reduction of roadkills globally showing (a) an underpass crossing structure, (b) an overpass crossing structure, (c) rope bridges (canopy crossing), (d) signage and (e) culverts.

Recommendations

Mitigation measures are recommended for reducing roadkills in protected areas, especially HIP, and are dealt with in detail below. The recommendations have been divided in two: recommendations for researchers and recommendations for the public. Each recommendation entirely depends on the particular road surveyed in HIP.

Researcher recommendations following roadkill study in HIP are as follows:

Mowing or cutting of grass

Most roadkills were detected at the R618 corridor (paved) road and the possible reasons for that could be the intensified traffic volume, increased speed, wider road which caused slow moving animals to be in danger of being hit by vehicles (Chapter 2). During the survey, tall grass swards of *Themeda triandra* and *Cymbopogon excavatus* were observed around early winter (April-May) and could have impeded driver and animals' visibility causing roadkills on the R618 corridor (personal observation.). Pooley (2003) also mentioned that the corridor is allied with dense, tall grass swards, consisting primarily of species of the tribe Andropogoneae such as *T. triandra* and *C. excavatus.* It is therefore recommended that mowing of such grass on an annual basis should be conducted for improved visibility by drivers and animals. The mowing of tall grass inside HIP's paved roads (Memorial Gate to Hilltop) was implemented. The unpaved road (Memorial Gate to Isivivaneni Lookout) had dense closed woodlands adjacent to it and the trees could not be cut since it's become a home for some species (high diversity of birds in area). However, some studies argued that mowing tall grass creates short grass with green flush which acts as an attractant to some species thereby increasing their likelihood of colliding with vehicles (Ramp *et al*. 2005; Klocker 2006). Effectiveness of mowing will depend on baseline data collected in the corridor for roadkills, which will highlight the number of species killed more and identify hotspots on the corridor road.

Signage and law enforcement

Signage on roads has been a method that has been implemented globally to alert drivers of what to expect ahead. Wildlife signages have also been incorporated in areas with wildlife to alert drivers about wildlife nearby (Magnus *et al*. 2004). The R618 corridor had warning signs for wildlife in the area and called for a reduction of speed in area. The problem was that drivers rarely adhered to warning signage (pers. obs.). Although signs displayed speed limits of 60km/h, drivers drove beyond that and neglected signs with awareness of elephants ahead. A report conducted for a month in 2016 by Mikros system showed that 77.5% of vehicles exceeded speed limit on the R618 corridor (Appendix 4.1). We therefore recommend that the wildlife signage in R618 corridor to be integrated with camera traps for drivers to adhere with speed limit in area. Moreover, the wildlife signage should be more clear about the information it portrays (time, distance and what animal to expect) (Fig. 4.1d). In addition, Eloff & Van Niekerk (2005) also supported that drivers pay little attention to signage, therefore suggested that innovative, conspicuous and novel game-crossing warning signs should be developed and placed in dangerous, high-risk areas.

Harsh law-enforcement and fines should be put to practice inside the park for drivers who do not adhere to rules and regulation of the park. Paved roads within the HIP are meant to be driven with speed limit of 40km/h and drivers who drive beyond this limit should get fines and be suspended from HIP for at least three years. The Kruger National Park has a protection unit that enforces the rules of park, making sure tourists, staff and delivery people adhere to the rules. We recommend a protection unit for HIP too and other national parks for safety of wildlife in relation to roadkills.

Fences and crossing structures

Exclusion fences have been questioned for their success in reduction of roadkills (Dodd *et al*. 2004), perhaps the concern is more on the effect of gene flow and genetic variability that is limited by implementation of exclusion fence. However, the combination of fences and crossing structures have showed a positive outcome in animals not crossing the road, hence reducing their likelihood of being hit by vehicles. Dodd *et al*. (2004) showed a 93.5% reduction in the rate of wildlife roadkills through conjunction of a barrier wall and culvert system in Paynes Prairie State Preserve, Florida. Since the R618 inside HIP is only 20 km long, putting an exclusion fence on both sides of the road would have minimal impact on gene flow and genetic variability of animal populations. We recommend that this segment of distance to be fenced, since African buffalo's *Syncerus caffer* and white rhinoceros *Ceratotherium simum* have been evident data of roadkills in R618 (Table 4.1). The collision of huge ungulates like African buffalo and White rhinoceros does not only cause fatalities to animal but to humans as well. Glista *et al*. (2009) also agreed that for many larger species, fencing is necessary because of their inherent avoidance of passages. Moreover, large amounts of money are used by insurance companies in fixing damaged vehicles. In addition, roadkills of ungulates on the R618 corridor were reported at late evening and at night to the South African Police Service (SAPS) (Table 4.1)., giving more reason for fencing the segment of R618 that cross the HIP The incorporation of crossing structure with fences could be implemented with time, given the funds and accurate location for roadkill hotspots. The exclusion fences should not be practiced inside HIP, since this is where wildlife is allowed to roam around. However, HIP has small green culverts around the paved roads which assist with the reduction of roadkills within the HIP.

Table 4.1. Accident Reports (AR) involving wildlife roadkills on the R618 road crossing HIP, with these AR obtained from the Hlabisa South African Police Service (SAPS). (See Chapter 2 for source details).

Date	Time	Common name	Scientific name
22 12 2016	23:30	animal	Animal
07 10 2016	21:00	White rhinocerus	*Ceratotherium simum*
06 10 2016	18:30	African buffalo	*Syncerus caffer*
07 05 2017	19:00	African buffalo	*Syncerus caffer*
02 10 2013	6:45	African buffalo	*Syncerus caffer*
27 06 2016	18:30	African buffalo	*Syncerus caffer*
18 06 2016	20:00	African buffalo	*Syncerus caffer*
13 06 2016	17:00	animal	Animal
30 07 2016	19:05	African buffalo	*Syncerus caffer*
15 08 2013	17:50	Greater kudu	*Tragelaphus strepsiceros*
11 08 2015	18:15	African buffalo	*Syncerus caffer*

Public recommendations following the current roadkill study in HIP are as follows:

Law enforcement

Based on the information given by the respondants during the formal interview surveys (Chapter 3), staff and delivery vehicles are the drivers speeding inside roads in HIP. Apparently, tourists adhere to the rules of the HIP. Respondants recommended law enforcement and fines issued within HIP premises for drivers who do not adhere to rules of the park. The Kruger National Park has adopted the law enforcement and fine issues for drivers who do not abide by the rules.

Some respondants recommended that the Ezemvelo KwaZulu-Natal Wildlife sighting Whatsapp group to be stopped, since it cause drivers to speed to sites where sightings of animals of interest, particularly big five animals, are reported by tourist or visitors of HIP.

Public awareness

Awareness has been an economically affordable strategy to pass information to the public (Van der Ree *et al*. 2011). Respondants recommended that the issuing of flyers and pamphlets at entry gates of the park creates awareness to drivers about speed limits within the park and are important for reduction of roadkills (Chapter 3). However, some respondants argued that it is a waste of time because immediately the drivers receive the flyer or pamphlet, they either throw it away or place it aside on the vehicle's dash board without reading it. Therefore, they recommended message notification to be sent to tourists, staff and delivery people on entry at gates. However, the message notification can be ignored too. But that does not mean we should not continue with issuing of pamphlet, flyers and message notification for creating awareness to public.

CONCLUSIONS

Mitigation measures for reducing roadkills included alteration of driver and animal behaviour. However, alteration of human and animal behaviour is not an easy task, hence the failure of some mitigation measure for roadkills. Accurate location for roadkill hotspot, species endangered or vulnerable species to vehicle collision should be identified, proper design of crossing structure (width, attractiveness (structure built with green vegetation), size, shape etc.), clear signage to drivers, availability of funds and an aware public and government authorities could help in success of mitigation measures for roadkill reduction. Educational and awareness campaigns are highly recommended mitigation measures to reduce roadkills on highways and protected areas as advocated by other studies (Sullivan *et al*. 2004; Eloff & Van Niekerk 2005; Bullock *et al*. 2011). Moreover, more studies of mitigation measures for reduction of roadkills should be conducted. This endeavour will help in getting consistent evaluation of successful roadkill mitigation measures and possibly have standardized technique or guidelines to follow when we want to choose mitigation measure that will be effective.

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Appendix 4.1. Traffic volume and speed limit for a report conducted from R618 corridor road, 100 m west of Tendele Mine Entrance over a month.

TRAFFIC HIGHLIGHTS OF SITE 260011				
1.1	Site Identifier			260011
1.2	Site Name			Imfolozi
1.3	Site Description			100m West of Tendele Mine Entrance on R618
1.4	Road Description	Route :	Road : R618 Section :	Distance : 0.0km
1.5	GPS Position			32 03 46.8E -28 17 26.6S
1.6	Number of Lanes			2
1.7	Station Type			Permanent
1.8	Requested Period			2016/11/01 - 2016/11/30
1.9	Length of record requested (hours)			720
1.10	Actual First & Last Dates			2016/11/01 - 2016/11/30
1.11	Actual available good data (hours)			717
1.12	Percentage good data available for requested period			99.7
		To Nongoma	To Mtubatuba	Total
2.1a	Total number of vehicles (counted)	43925	43693	87618
2.1b	Total number of vehicles (projected for period)	44055	43822	87876
2.2	Average daily traffic (ADT)	1468	1461	2929
2.3	Average daily truck traffic (ADTT)	109	111	220
2.4	Percentage of trucks	7.4	7.6	7.5
2.5	Truck split % (short:medium:long)	74 : 15 : 11	76 : 15 : 9	75 : 15 : 10
2.6	Percentage of night traffic (20:00 - 06:00)	11.5	10.5	11.0
3.1	Speed limit (km/hr)			60
3.2	Average speed (km/hr)	72.7	72.9	72.8
3.3	Average speed - light vehicles (km/hr)	73.2	73.4	73.3
3.4	Average speed - heavy vehicles (km/hr)	67.2	66.0	66.6
3.5	Average night speed (km/hr)	73.3	70.8	72.1
3.6	15th centile speed (km/hr)	57.1	57.1	57.1
3.7	85th centile speed (km/hr)	89.9	89.9	89.9
3.8	Percentage vehicles in excess of speed limit	77.5	76.0	76.8

Chapter 5

CONCLUSIONS

Hluhluwe-Imfolozi Park (HIP) located in Zululand, KwaZulu-Natal Province, South Africa, is a fenced reserve and home to diverse number of species including the "big five" (O'Kane *et al*. 2014). Its diversity of mammals, birds, reptiles, amphibians and plant species has caused a continuous increased turnover of tourists from all around the world in the previous years. Moreover, construction of new roads and maintenance of old roads have been a constrain that HIP managers had to deal with so as to accommodate the tourists as the do sighting of wildlife in HIP. Introduction of roads network have created negative impacts on the individual and population of wildlife. Negative impacts include, loss of habitat, fragmentation, wildlife-vehicle collision which lead to roadkills, reduced gene flow etc. (Newsome *et al*. 2015: Ascensao *et al*. 2017). Balancing between accommodating for tourists and conserving wildlife, specifically in protected areas, is a challenge. The current study ensured the baseline data is collected for roadkills, identified hotspots of roadkills, identified possible explanatory variables for observed roadkills in HIP and recommended mitigation measures that could aid in the reduction of roadkills in protected areas drawn from current study, existing literature and personal observations.

Gathering baseline data

Baseline data of roadkills on roads of HIP were recorded (Chapters 2-3) monthly for a year on three road types in HIP. This ensured awareness about roadkills occurring within HIP with park managers and the public. The number of roadkills reported in our study was relatively low compared with other studies (Chapters 2-3). But the reported results in our study did not mean roadkills do not occur at higher rates in HIP. Results reported in studies could be influenced by carcass disappearance which is often underestimated by many studies. Mammals and birds were more susceptible to roadkills, followed by reptiles and later the amphibians. This observed trend could have been a random chance as explained by some studies (Coelho *et al.* 2008). Therefore, more evaluation and assessment on roadkills are recommended for confident and precise conclusions about wildlife roadkill trends as road networks continue being a threat. In addition, our baseline data showed some localities that were hotspots for roadkills (Chapter 2). In our study, hotspots were found at approximate 4 -

12 km on the R618 corridor road from Hlabisa town to Mtubatuba direction tranversing HIP. Hotspots on the paved road within the park were identified about 2 km from Memorial Gate to Hilltop Resort direction and the last 7 km before reaching Hilltop Resort. There were no hotspots on the unpaved road we surveyed as relatively few records were documented (Chapter 2). The baseline data allowed informed recommendation for mitigation measures on the reduction of roadkills in HIP (Chapter 4).

Identifying explanatory factors for roadkills

During data collection, several variables were recorded as potential explanatory factors for observed roadkills in HIP. These variables were assumed that they are the main reason that wildlife would be at close approximate with roads and end up crossing roads. Moreover, some of these explanatory factors were causes for increased speed by vehicles and reduced visibility for drivers. We reported that, type of road and seasonality contributed to the detected roadkills although there was no significant difference for both factors analyzed separately (Chapter 2). Furthermore, we reported that, the amount of game in vicinity ranked as 2 (area with vegetation and either water source or infrastructure) and distance to vegetation from the road less than 1 m increased the likelihood that wildlife would collide with vehicle. Season and terrain were important explanatory variables in the prediction of roadkill occurrence (Chapter 2). Trends for roadkills are influenced by road characteristics and quality of surrounding habitat (Clevenger *et al*. 2003; Malo *et al*. 2004). Understanding the importance of such components will help in improving the success of the management for reducing roadkills, particularly in protected areas.

Management implications

The baseline data of roadkills we obtained identified localities known to be hotpots in HIP, but the relevant mitigation measures to be implemented rather recommended entirely dependent on locality surrounding and the types of highly susceptible species to roadkills in that location. For example, if an animal like African savanna hare *(Lepus microtis)* were killed more in HIP, we could not recommend overpass as mitigation measure rather we could recommend tunnel (culverts). On the R618 corridor road we recommended mowing of grass adjacent to the road, putting of clear signage of wildlife ahead and relevant information on signage about what drivers should expect and adhere too, installation of camera traps in localities of roadkill hotspots and finally the conjunction of fences and crossing structures

(Chapter 4). Roads inside HIP were also recommended to have road signs along with harsh-law enforcement on drivers not abiding with rules and regulations of the park. Moreover, public awareness is important in educating the staff and visitors in HIP about the importance of being aware on roads while doing wildlife sightseeing.

African protected areas are often centered on wildlife sighting with less recognition on the roadkills that happen during the sightings, therefore, quantifying road impacts is essential to achieve effective conservation and improve planning in the reduction of roadkills. Reduction of roadkill in protected areas depends on our ability to create awareness to public, raise funds for implementation of mitigation measures where needed, have continuous monitoring programme that collects data of roadkills in protected areas, and make the empirical data for roadkills accessible through publishing and through social networks.

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