



MAPPING ROADKILL IN THE KRUGER NATIONAL PARK, SOUTH AFRICA

BY

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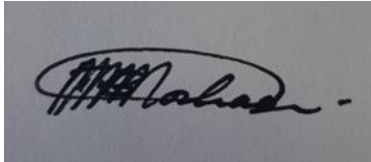
DISSERTATION SUBMITTED FOR THE DEGREE OF MASTER OF ENVIRONMENTAL
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DECLARATION

I **Talifhani Brilliant Mashao** hereby declare that the dissertation for Master of Environmental Sciences degree at the university of Venda, hereby submitted by me, has not been submitted previously for a degree at this or any other university; that it is my own work in design and execution, and that all reference materials contained herein have been duly acknowledged.

Signature



Date 21 February 2024

DEDICATION

I would like to dedicate this dissertation to my **family** and **friends** who always supported me in all my ups and downs, the advice, and the courage to keep pushing harder to achieve this. Special dedication goes to my daughter **Angel Vhuhwavho Mashao** because she was the reason for motivation and as a minor she was, she understood when I had to spend months away from her. I so wish she would academically achieve more than I did in my academic career and this dissertation will form basis for her to be motivated. My lovely partner **Masithi Vuledzani** thanks for the everlasting support and encouragement you have shown me throughout this thesis, I love you more for that.

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Psalms 127v1.

ABSTRACT

Roads not only create barriers for animals by preventing the free movement of individuals between populations but also cause mortality through collisions with vehicles (i.e. roadkill). In South Africa, most of our understanding of roadkill events stems from research on national and regional roads, but the impacts of roads in protected areas have been understudied. Though there have been *ad hoc* roadkill reports in protected areas by members of the public on social media, there have been little systematic roadkill surveys undertaken in South African protected areas and, road signage aside, no effective mitigation measures have been applied except traffic officers who are unable to monitor all roads simultaneously.

This study formed part of a five-year project to undertake an assessment of roadkill in protected areas and assess mitigation measures to reduce it. This two-year project has recorded temporal and spatial roadkill in one section of the Kruger National Park, on both paved and unpaved roads.

During this study a total of 189 roadkill were recorded in a period of 90 days covering 90 kilometres per day, and average roadkill rate was $0.4586 \text{ roadkill.km}^{-1}\text{day}^{-1}$. Roadkill incidents were randomly distributed along the roads. Reptiles and birds had most roadkill, and paved roads had a higher number of roadkill than unpaved roads on a per kilometre basis. Most roadkill happened during the hot-wet season. More awareness of roadkill risks is needed to ensure protection of biodiversity in the protected areas.

Key words: Hotspot, Protected Area, Road Ecology, Roadkill.

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CHAPTER 1 INTRODUCTION

1.1 Background

The biodiversity crisis (Myers 1993) has led to a global awareness of the inadequacy of existing protected area's network for conserving biodiversity. Roads are a threat to biodiversity. Over the next three decades 2020 to 2050, the total length of additional paved roads worldwide will reach 25 million km, enough to circle the planet more than 600 times (Laurance *et al.*, 2014). Nine-tenths of all new infrastructure is built in developing countries (Laurance *et al.*, 2014), primarily in tropical and subtropical regions, which are home to the most diverse ecosystems on earth. Furthermore, it is predicted that there will be 2 billion motor vehicles worldwide by 2030 (Sperling and Gordon 2010), and for the past eight years there were around 1.2 billion motor vehicles on the road (Dennis and Urry 2016).

Traffic control is a challenge, especially in large, protected areas such as Kruger National Park (KNP), as people are often not adhering to speed limits. The results of this include injuries to drivers and passengers, damage to vehicles, and roadkill. In the United States (US), there are 1-2 million car-large animal collisions per year that result in over \$1 billion worth of property damage, 211 fatalities, and 2 900 injuries. (Conover *et al.*, 1995). Canada has ~45 000 incidents annually (Huijser *et al.*, 2007). Drivers react less quickly to smaller animals because they pose less of a risk of damage to their vehicles, compared to damage that can be done if they collide with larger animals (Rowden *et al.*, 2008). However, Collinson *et al.*, (2019) found that drivers responded based on visibility of animals on the road, meaning that when they can detect an animal they will respond regardless of its size.

Although roads have many economic and social benefits, they also have detrimental effects on the environment, such as habitat fragmentation. Roads affect an estimated 20% of the land area in the US, which has a road network of 4 million miles (Forman, 2000). It can be fatal for animals to cross the road.

Forman and Alexander (1998) reported that 1 million vertebrates die on US roads every day, making road mortality the primary cause of death for many wildlife populations.

Growing concerns about ecological impacts of roads resulted in the development of road ecology as a scientific discipline (Forman 2003; Fahrig and Rytwinski 2009). The relationship between living things and the environment around roads and cars is known as 'road ecology' (Franklin *et al.*, 2002). Understanding the ecological effects of roads and traffic on the people, communities, and landscapes they affect is the goal of road ecology, which also examines the interaction between the environment and the road system (Forman 2000).

Road networks result in a variety of negative impacts on biodiversity (Santos *et al.*, 2011). These impacts may be both direct and indirect. According to Hels and Buchwald (2001), one example of an indirect impact is habitat fragmentation. According to Franklin *et al.*, 2002, fragmentation occurs when a single, large, continuous block of habitat is divided into smaller, less continuous blocks by human disturbances like land clearing, vegetation conversion to different land cover types, and transportation-related development and construction (Franklin *et al.*, 2002). Fragmentation may restrict free movement of animals and thus increase population isolation, leading to unstable meta-populations (Holderegger and Di Guilo, 2010).

Due to fragmentation, wildlife species for whom roads pose less of a barrier may have high rates of roadkill (Dodd *et al.*, 2004). Other examples of indirect effects of roads are the barrier effect and dispersal of invasive species hitchhiking on vehicles (Ford and Fahrig 2007; González-Gallina *et al.*, 2013; Seo and Kusakabe 2015). These effects may not be so prevalent as the direct impacts and may only reveal themselves over longer time periods.

A direct impact of roads infrastructure is increased mortality (Clevenger *et al.*, 2003), which in some cases can be a leading threat to biodiversity (Vermeulen and Opdam 1995). Roads attract a lot of animals (Long *et al.*, 2010), such as reptiles that bask on asphalt, and birds which feed on grain from the roadsides (Jackson 2003). Herbivores usually like to graze from the roadside vegetation (Noss, 2002), which often results in fatal accidents.

For small ground-dwelling species, roads can be significant obstacles that restrict the free movement of individuals between populations (Vos and Chardon, 1998). Population isolation may happen if there is less gene flow and less movement between populations, which increases the likelihood that populations will drift apart (Jaeger *et al.*, 2005; Seo *et al.*, 2013).

Roadkill incidents have noticeable impacts, and they can sometimes be fatal to both humans and wildlife. For an example, if a vehicle collides with a larger bodied animal such as African elephant (*Loxodonta africana*) or African (Cape) buffalo (*Syncerus caffer*), this can lead to death of occupants of the vehicle (Malo *et al.*, 2004). Across the world, most of the knowledge on roadkill events is from national and regional roads (Eloff and Van Niekerk 2005). However, the understanding of how roads affect protected areas is extremely limited (Garriga *et al.*, 2012; Collinson *et al.*, 2019). The field of road ecology is gaining increasing scientific attention worldwide (e.g. Seiler, 2004; Sutherland *et al.*, 2010). In South Africa for the past decades very few studies were conducted, but a recent paper by Shilling *et al.*, (2020) has reviewed roadkill in Africa and it appears that much research is currently being done on mitigation measures.

The main goal of protected areas is to preserve species and biodiversity; to this end, stringent regulations, like those governing speed limits and area access, are put in place. However, like other road networks, roadkill does occur in protected areas (Garriga *et al.*, 2012). According to Garriga *et al.*, (2012), this is largely due to the higher density of wildlife in protected areas and the volume of traffic on the small road

network open to the public. However, there is little data to support this due to the paucity of research in protected areas (Collinson *et al.*, 2015). Social media platforms' ad hoc reports are contributing to the reality of animals being killed in protected areas. Rytwinski *et al.*, (2016) states that when developing roads, mitigation measures to save biodiversity are either not included at all or are allocated very little resources.

The study formed a part of a five-year programme conducted by the Endangered Wildlife Trust (EWT) in all most six different South African protected areas (Kruger National Park, Addo Elephant Park, Soutpansberg Protected Area, Pilanesberg, Dinokeng and Table Mountain NP), which aimed to gain an understanding of the causes of roadkill in protected areas and mitigate the impacts. The outcomes will feed into a traffic management plan for protected areas.

A protected area is a “clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values” (IUCN 2008). Protected areas are a mainstay of species protection and at the same time contribute to people's livelihoods, especially at the local level. Protected areas are at the heart of efforts to preserve nature and its services. Due to increased traffic density, they frequently receive large numbers of visitors, which could lead to an increase in wildlife casualties. It is imperative to implement corrective measures to minimize the mortality rate of vertebrates on roads that cross protected areas (UNEP-WCMC 2018).

Globally, protected areas cover ~21 million square kilometers of land and sea. They comprise terrestrial (12.2% of the total land area) and marine (5.9% of territorial and 0.5% of extraterritorial seas, UNEP-WCMC 2018) areas. Protected areas are meant to ensure the protection of nature, and roadkill are expected to be minimal. The protected areas or parks can be fragmented by roads. The impact should be minimal because of attempts to minimize land degradation. However, the roads do contribute to wildlife being endangered by either creating barriers (Dodd *et al.*, 2004; Holderegger

and Di Guilo, 2010; Taylor and Goldingay, 2010) or causing roadkill (Van Langevelde and Jaarsma (2004).

1.2 Problem statement

Roadkill in the protected areas is understudied in South Africa and this study has been done in the southern part of the Kruger National Park to find out the impacts it has on the biodiversity and contribute to addressing that knowledge gap. We know that there is roadkill happening in the national park from the incident reports. However, we do not know the frequency of these roadkill, how they are spatially distributed, and if road type influences roadkill frequency.

1.3 Research Aim

To examine roadkill rates that will inform mapping of hotspots within the study area and attain appropriate mitigation measures that are fit to implement in a protected area.

1.4 Research objectives

- To determine wildlife roadkill hot/cold spot areas in the Skukuza section of the KNP.
- To compare roadkill rates on the paved and unpaved roads in the Skukuza section of the KNP.
- To make a seasonal comparison of multi taxa roadkill.

1.5 Study area

The study area chosen is the Kruger National Park (KNP) in the northeast of South Africa straddling the Limpopo and Mpumalanga provinces. As an International Man and Biosphere Reserve, the park is a part of the Kruger to Canyons Biosphere (K2C), an area that was established by the United Nations Educational, Scientific, and Cultural Organization (UNESCO) in 2004. The KNP is home to 147 mammal, 507 bird,

114 reptile, 34 amphibian, 49 fish and 336 tree species (UNESCO, 2004). The KNP is among the largest game reserves on the African continent and the largest in South Africa. It covers 19 485 km² and has a high density of wild animals. The study will focus on one management section of the park, namely Skukuza section surrounding the Skukuza rest camp (Figure 1) which is located 50 km east of Hazyview at S 24°59'48", E 31°59'69" in Mpumalanga. It is the busiest part of the KNP.

The KNP forms part of the savanna biome. The savanna is one of the world's major terrestrial biomes, comprising a dynamic mixture of trees and grasses (Sankaran *et al.*, 2005). The rainfall that occurs in savannas is seasonal and the animals respond to the seasonality. The KNP is very large, and it supports many ecosystems.

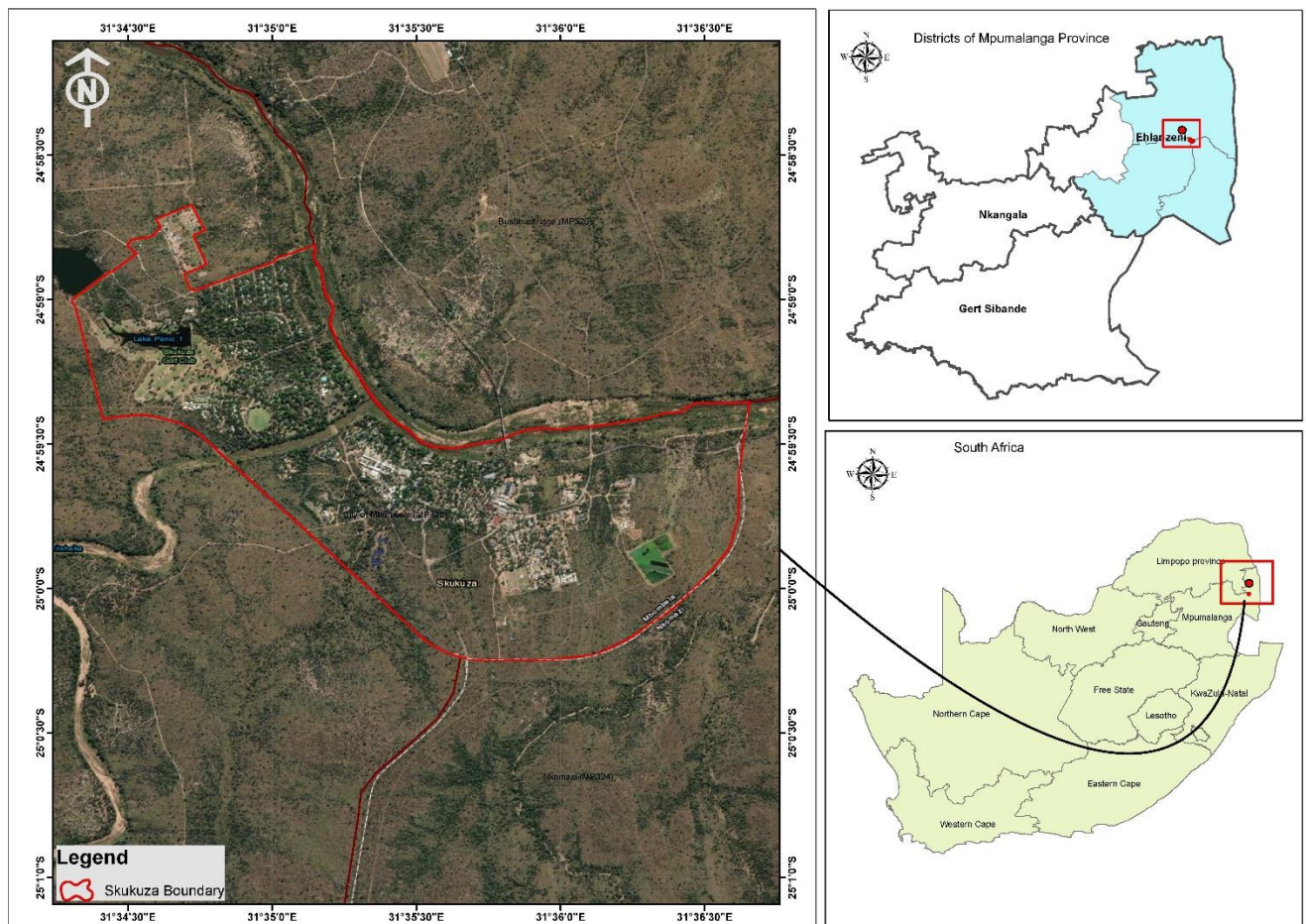


Figure 1 Skukuza section, Kruger National Park (ArcGIS)

Vegetation

The flora of the Kruger National Park consists of 1986 different plant species which include 457 trees or shrubs, 235 grasses, 27 *ferns*, 16 *woody lianas*, 20 *aloes* and 1 213 *forbs* including hydrophytes (Scholes *et al.*, 2001). The Braun-Blanquet technique was used to classify and describe the plant communities found in the Kruger National Park (Van Rooyen 1978; Gertenbach 1978; Coetzee, 1983). It is impossible to identify specific plant communities or associations on a large-scale map due to the intricate patterns displayed by the size and geographical distribution of these plant communities. The Skukuza uplands have an open tree savanna with comparatively few low shrubs. *Terminalia sericea* (Mongalo *et al.*, 2016) and *Dichrostachys cinerea* (Gertenbach 1978) predominate in the woody component of the vegetation. The field layer is made up primarily of more acidic grass species, such as *Hyperthelia* (Scholes *et al.*, 1997) dissolute, and is tall (1-2 m) and dense (70% canopy cover). Dominant woody species are *Vachellia nilotica* (Scholes *et al.*, 1997), a medium to large tree that can reach a height of 10 m, with an average of 4-7 m. This vegetation is representative of the 'compound-leafed' savanna occurring in relatively dry, infertile situations throughout southern Africa (Scholes *et al.*, 1997).

Climate

Climatic conditions of the KNP range from hot and humid in summer to mild and predominately dry in winter with moderate summer precipitation (500-700 mm p.a.) and maximum rainfall in January. Warm to hot temperatures are usually experienced in summer and no frost occurs. The climate is semi-arid subtropical, with hot, rainy summers and warm dry winters characteristic of areas supporting savanna vegetation. Over the brief period of temperature measurement at Skukuza (since April 2000), the air temperature at 17 m is on average 0.5 °C cooler than the 2 m screen temperature at the weather station at Skukuza, due to the slightly higher altitude. The long-term rainfall would be expected to be a few percent higher at other sites within the park than at Skukuza since rainfall increases towards the west (Scholes and Archer, 1997).

During summer, there is presence of tropical cyclonic conditions in the interior of South Africa that give rise to hot and wet conditions over the Lowveld.

Rainfall is essential to many natural processes, including the dynamics of vegetation (Ekblom *et al.*), soil moisture dynamics (Berry and Kulmatiski, 2017), and many others, and patterns of animal migration and dispersal (Seydack *et al.*, 2012). The summer months of November through April account for 84 percent of Kruger's annual rainfall on average (Zambatis, 2003). In the Kruger National Park, rainfall increases from north to south and from east to west as altitudes increase closer to the Drakensberg escarpment see Venter *et al.*, (2003) for a full account of the local climate.

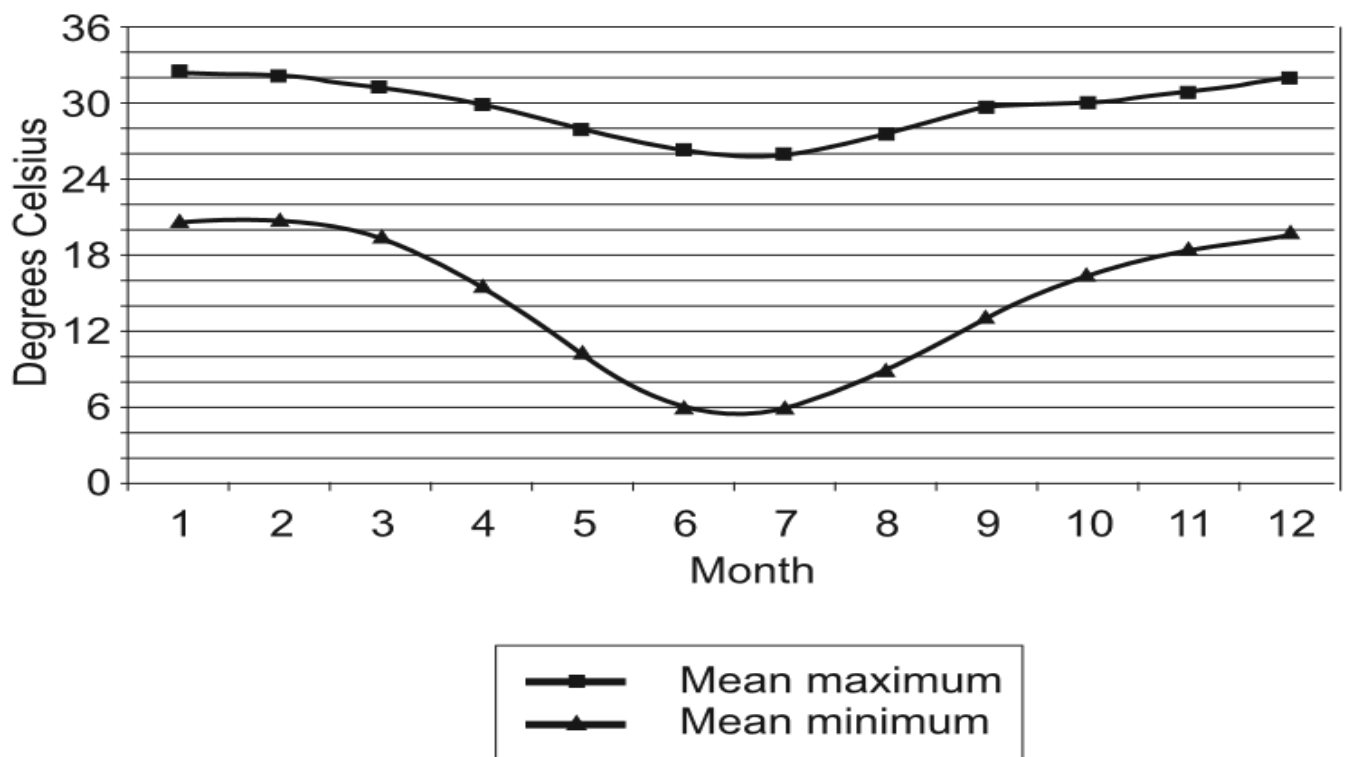


Figure 2 Average minimum and maximum monthly temperature (°C) in Skukuza from 1960 - 2001 (Kruger *et al.*, 2002)

Skukuza is characterised by hot summers and warm winters (Figure 2). High summer temperature is associated with rains during summer.

1.6 Justification of the study

The roadkill knowledge gap was found on the large, protected areas. This has informed the study to focus on a large, protected area such as Kruger National Park. The data and analysis of this study is critical in assisting parks with traffic management plans in the protected areas that receive high volumes of traffic. The study might also assist with updating of the current traffic management plan for KNP. Even though the park is a protected area there are still many roadkill incidents happening around the park. The output of the study may be a guide to the traffic regulations in the protected areas for motorists. This will inform both park management and motorist about the areas of high and low roadkill risk along the transects which are covered.

1.7 Definition of key words

Hotspot - a place of significant activity (Ceballos and Ehrlich 2006).

Road Ecology - the interaction between organism and the environment linked to roads and vehicles (Forman 1998).

Roadkill - animals killed on the road by vehicles. (Collinson, 2013)

Protected area - a clearly demarcated area of land that has been acknowledged, committed to, and managed (either legally or through other practical means) to accomplish the long-term conservation of nature along with the ecosystem services and cultural values that go along with it (IUCN 2008).

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

In certain instances, the impact of roadways on biodiversity has been disregarded or undervalued (González-Gallina *et al.*, 2013). In South Africa, there is work being done to address animal-vehicle collision challenges on national and regional roads in terms of research, but little is done on the implementation preventative methods. Methods such as overpasses and underpasses (Teixeira 2001) for animals are being tested for national roads and highways. These techniques, however, are inapplicable to roads in the protected areas since minimal disruptions of animal mobility is required. According to Bennett (2017), most road ecology studies (76%) are restricted to North America and Europe, and only 23% have considered different taxonomic groups.

The awareness raised by road ecology studies has led to legal obligations to mitigate roadkill in many countries, but in South Africa such obligations are still few. In parks, roads are part of ecotourism development, but they can also act as barriers to animal movement, leading to habitat fragmentation (Forman and Alexander, 1998).

2.2 The development of road networks

Before roads there were trails which were often simple footpaths following animal paths (Helbing *et al.*, 2001), and they were eventually made wider to make cart trails (Lay, 1992) by clearing trees and big rocks from the path. These paths were for people to move from one place to another, usually in search of food and other resources. Roads served towns which were expanding and linked them for military and trade activities (Lay, 1992).

The oldest known paved road in the world was built sometime between 2 600 and 2 200 Before Christ (BC). in Egypt (Wildord, 1994) and the Roman Empire built roads that were generally straight and so durable that parts of them are still usable today (Kumar and Kumar, 2011). Roads in Europe were very difficult to travel until the 19th century. They improved markedly during the industrial revolution. Much emphasis was

on the construction of railroads until the automobile was invented (Chartres and Turnbull 1983), which created a demand for quality roads in the early twentieth century (Lay 1992).

Approximately 750 000 km make up South Africa's entire road network (DOT, 2005). The entire road network includes a rural road network portion of 364 000 km and an urban road network portion of 170 000 km. Of the rural road network component, 63 000 km of road is paved, the remainder, 301 000 km, is gravel (DOT, 2005).

2.3 The South African road classification system

Terms for different types of roads differ worldwide. Classification makes it possible to make judgments regarding a road's management and design that are consistent over its entire length. Assigning accountability for road maintenance and designing routes for navigation can both benefit from classification.

The classification of a route is determined by its intended use, which can include pavement structural design (TRH 4, 1996), traffic composition, traffic count, and transportation planning (Bosman, 1988). Road traffic routes can be classified into four categories by the TRH 4 document according to their significance and design: Category A comprises major interurban freeways and major rural roads; Category B includes interurban collectors and rural roads; Category C includes lightly trafficked rural roads and strategic roads; and Category D includes rural access roads.

Road traffic routes are classified into seven classes for pavement design purposes in the Roads Branch pavement design catalogue of the former Transvaal Provincial Administration (TPA, 1994). These classes are Class I (rural roads), Class II (rural access roads), Class III (rural major roads), Class IV (rural major access roads), Class V (freeways and major access roads), Class VI (freeways and important major access roads), and Class VII (freeways). According to the Department of Transportation

(1991), although there are three categories of roads in South Africa which are primary, secondary, and tertiary roads, often one is a result from another.

2.4. Road ecology at the global level

Roadkill and road ecology are gaining more attention from scientists worldwide (Sutherland *et al.*, 2010; Seiler, 2004), but very little research has been done in South Africa, even though roadkill has the potential to significantly impact biodiversity. North America accounted for 38% of the roadkill assessment studies, followed by Europe (33%), South America (11%) and Australia/New Zealand (7%). Sub-Saharan Africa accounts for 7% of the studies. About 83% of the road ecology studies were conducted after the year 2000 (Collinson *et al.*, 2014).

In the US, engineering solutions for soil erosion and sedimentation, together with vehicle emissions, are the main concerns of environmental transportation policy (National Research Council 1997). In response to local concerns about roadkill or wildlife, a few states have constructed wildlife underpasses and overpasses (Forman and Alexander 1998). In Australia, Hobday *et al.*, (2008) looked at the distribution and abundance of roadkill on Tasmania state highways as the roadkill impact in this area is greater than other states in Australia. A total of 154 journeys were made as part of seasonal inspections along five important routes. After three years of surveying over 15 000 km of road, 5 691 individuals belonging to 54 species were recorded, with an average roadkill density of $0.372 \text{ km}^{-1}\text{-day}^{-1}$. The seasonality, correlation with vehicle speed, and taxonomic clustering in nearby hotspots all point to the possibility that mitigating interventions, like limiting vehicle speed in particular zones, could be successful in lowering the number of animals slain. However, not all species will benefit equally from mitigation measures, and human behaviour changes will be necessary for them to be successful (Hobday *et al.*, 2008).

2.5 Road ecology at local, regional, and continental level.

Globally, dozens of web-based systems for reporting roadkill exist (Shilling *et al.*, 2015) and there is a new form of data acquisition involving public participation (Wilson *et al.*, 2013) or citizen science. There was a study conducted in South Africa focusing on testing the value of citizen science (Périquet *et al.*, 2018). This study used a dataset of 2 666 roadkill reports on national and regional roads in South Africa (total length ~170 000 km) over three years. The study demonstrates that *ad hoc* citizen science has the potential to map roadkill occurrence and identify hotspots in a reliable and robust manner compared to that of trained road patrols and informed reporters. However, the authors proposed that *ad hoc* citizen science data should only be used to identify general patterns or trends, because the citizen data are not scientifically validated.

A study on creating a consistent procedure for counting roadkill has been conducted in the Greater Mapungubwe Transfrontier Conservation Area (Limpopo Province, South Africa) (Collinson 2014). The study examined roadkill on a regional road, and over the course of 40 days, a daily 100 km transect was employed to test the suggested technique. It found 413 roadkill vertebrates, representing 106 different species.

There are several road ecology studies on the African continent, most of which were performed in the eastern and southern part of the continent. Most of the studies were focusing on individual species found locally. Most of these studies unpacked or went beyond measuring impacts of collisions. However, such studies were not covering protected areas (Collinson 2014)

As part of their work, (Joseph *et al.*, 2017) looked at the effects of infrastructure on invasion of a generalist predator by investigating the link between abundance of birds and roadkill, while considering how road infrastructure, socio-economic and driving habits influence roadkill. These studies were carried out in the SADEC countries South Africa, Zimbabwe, and Botswana. Roadkill was eight times more common in Botswana and 20 times more common in South Africa than it was in Zimbabwe. In Zimbabwe,

automobiles had an average of 5.5% and 2.8% times as many occupants as in South Africa and Botswana, respectively. That instance, while there were 4.33% roadkill in Zimbabwe, there were 4.5% people transported for every roadkill in South Africa.

A baseline survey was carried out in Tanzania on a 75 km length of the Arusha highway that runs beside the Manyara ranch and lake Manyara National Park to characterize the pattern of roadkill in one of the ecosystems in Tangarie-Manyara. There were 101 roadkill occurrences in total ($0.13 \text{ roadkill km}^{-1}\cdot\text{day}^{-1}$). But only for ten straight days in November the rainy season was the study carried out. According to research by Kioko *et al.*, (2015), it was discovered that the largest share of roadkill $0.065 \text{ roadkill km}^{-1}\cdot\text{day}^{-1}$ was caused by birds, followed by mammals ($0.043 \text{ roadkill km}^{-1}\cdot\text{day}^{-1}$), reptiles ($0.023 \text{ roadkill km}^{-1}\cdot\text{day}^{-1}$), and amphibians ($0.004 \text{ roadkill km}^{-1}\cdot\text{day}^{-1}$).

2.6 Predictive models of roadkill

There is an increasing prevalence of predictive roadkill models in the recently published literature. Most models, however, are less helpful for management situations that consider numerous target species since few models generalize over multiple taxa. Using a dataset of 653 vertebrate roadkill samples taken from southern Ontario's Point Pelee National Park and Rondeau Provincial Park, Farmer and Brooks (2012), from a set of eight potential predictor variables, they built generalized linear mixed models to identify the simultaneous risk factors for roadkill of birds, frogs, mammals, five-lined skinks (*Eumeces fasciatus*) Farmer and Brooks (2012), snakes, toads, and turtle hatchlings. The posted speed limit was the best indicator of roadkill, followed by the greatest daily temperature, the variety of habitats, and the proximity to wetlands.

According to the model, in the summer, the mean roadkill chance for a specific area would rise from less than 0.1 to 0.75. In contrast, when one's distance from a wetland edge grew from 0 km to 1 km, the probability of roadkill decreased from 0.55 to 0.29 (Farmer and Brooks 2012). The model reflected seasonal patterns of animal

behaviour, movement and tortoise hatching events and they recommended that managers of habitats lower road speed limits, mostly on the roads near diverse habitats and near wetlands and use of temporary signage during seasons with high roadkill incidence.

In a spatiotemporal roadkill distribution model developed by Lin *et al.*, (2019), seasonal effects were observed for four focus reptile species in Taiwan. To simulate the probability of roadkill, the study created a unique spatiotemporal roadkill distribution model. Furthermore, they employed the most common roadkill incidences for multiple species to methodically identify the highest priority road stretches. The top 30% priority segments accounted for more than 70% of roadkill incidents.

Using models derived independently for each taxonomic group, published research identified predictors of roadkill for mammals (Clevenger *et al.*, 2003, Malo *et al.*, 2004, Seiler 2005, Ramp *et al.*, 2006), birds (Clevenger *et al.*, 2003, Ramp *et al.*, 2006), or reptiles and amphibians (Orlowski *et al.*, 2008, Langen *et al.*, 2009). Mammals (Findlay and Houlahan, 1997) and birds (Kociolek *et al.*, 2011) are examples of more mobile species that may die near highways. To effectively reduce these effects, appropriate strategies should be put into place that consider the maintenance of wildlife connectivity between neighbouring wetland and upland habitats without barriers. These strategies could include providing an alternate route configuration, using wildlife crossing structures, or implementing traffic calming measures in key areas (Teixeira, 2001).

A roadkill prediction model was created by the Lake Simcoe Region Conservation Authority (LSRCA). Its purpose was to find out whether there are any areas within the watershed where amphibian and reptile deaths due to traffic are more likely to occur, as well as whether there is a traffic volume threshold above which transportation planners must take wildlife passages into account (Leermakers, 2020).

Over the years, several methods have been developed to simulate how wildlife moves through different environments and the resulting danger of collisions with automobiles. The study by Gunson *et al.*, (2012), which examined land cover near roadways, was possibly the most straightforward. Roadkill occurrence and land use cover are significantly correlated, according to field verification of the locations of deceased reptiles and amphibians along a road network in southeast Ontario (Schueler and Gunson, 2011; Gunson *et al.*, 2012). In regions of Ontario as compared to other initial studies' locations, the Gunson *et al.*, (2012) model has demonstrated the ability to precisely identify places where roadkill is most likely.

In southern Ontario, priority sites for preserving or improving wildlife corridors have also been determined using least-cost path modelling, a comparatively easy method for simulating movement over a landscape (Jalava *et al.*, 2001). When using least-cost path modelling, the modeler must specify the beginning and ending places of wildlife migration as well as the 'resistance' of various land use categories in their area of interest. Given a few basic factors of wildlife movement, the model then calculates the most likely path of movement from the start point to the endpoint, going through the areas of least resistance (Adriaensen *et al.*, 2003). While movement corridors over a landscape can be predicted using least-cost path modelling, this method has come under fire for being unduly predictive because it only finds one corridor between.

In their 2015 study, Girardet *et al.*, (2015) examined how the landscape network affected the location of roadkill hotspots for roe deer (*Capreolus capreolus*) (Girardet *et al.*, 2015). To locate new prospective hotspots along the Franche-Comté national roads in Eastern France, they first demonstrated that the distribution of roadkill from roe deer is not random, and they located hotspots. Next, by combining data relating to road characteristics, connectivity measures, and landscape composition, a predictive model was used to explain the locations of roe deer hotspots. They evaluated the relative contributions of the connectedness measures to the optimal model and tested three centrality metrics at three dispersal distances. They used a fresh batch of roadkill data from roe deer to validate the model.

To combat roadkill brought on by issues with linear infrastructure, a more recent advancement in landscape modelling called as landscape resistance modelling (McRae *et al.*, 2008) has been established. The likelihood that any piece of the landscape will be used by dispersing species is represented by the model's output, even if the input data for landscape resistance models is comparable to that of least-cost path models. As a result, the description of wildlife movement becomes more realistic and is suitable for additional scenario modelling to determine the locations that should be prioritized for habitat restoration or technical solutions to promote connectivity (Beier *et al.*, 2011).

Most methods for identifying high-risk sites for wildlife-vehicle incidents concentrate on the surrounding landscape's structure and land use, although traffic levels on the highways that cross natural areas also matter a lot. The likelihood of wildlife and automobiles colliding is influenced by both the quantity of animals crossing the road (which is probably connected with the local land cover) and the number of vehicles on the road. To concentrate on roads that sustain traffic amounts that are anticipated to result in greater rates of wildlife fatality, the predicted hotspots could be further refined.

2.7 Driver knowledge and attitudes about animal vehicle collisions

In two stretches of a major highway in Northern Tanzania, Adriaensen *et al.*, (2003) observed the patterns and frequency of Animal Vehicle Collisions (AVCs) and correlated these patterns with the knowledge and perceptions of drivers who frequently use the roads. Within the Tarangire-Manyara Ecosystem (TME), the investigation was carried out. Tanzania's TME is an important location for biodiversity. Drivers believed animals to be the most common AVC, even though real field research revealed that more birds were killed by AVCs. Drivers showed little concern for whether AVCs posed a significant risk to other road users, and 67% firmly believed that most AVCs were unintentional (Adriaensen *et al.*, 2003), either because of excessive vehicle speed or inadequate nighttime visibility.

According to Adriaensen *et al.*, (2003), a species' average body mass and the chance of it being struck by a car are negatively correlated. However, this might be because the average abundance of smaller creatures is higher. In Tanzania, just 35% of drivers reported having participated in a program that addressed the effects of roads on wildlife (Adriaensen *et al.*, 2003). This study emphasizes the necessity of joint efforts between the road departments and wildlife conservation organizations to inform drivers about the significance of driving sensibly and taking reasonable precautions for the protection of both humans and wildlife. Effective mitigating measures should be used in conjunction with this to lower the incidence of AVCs. Drivers believed that mammals were the primary cause of AVCs (74% of drivers), even though roadkill from mammals only accounted for 23% of all AVCs. This opinion may arise from the fact that large animals (>10 kg) are easier to spot and that hitting them increases the likelihood of damaging vehicles and injuring occupants (Bjornstig *et al.*, 1984). Alternatively, the low percentage of roadkill mammal could be attributed to the removal of mammal carcasses by locals for their own consumption.

In Tanzania's rural areas, bush meat makes up a sizable percentage of the local diet (Ndibalema and Songorwa 2007). Similar to Tanzania, collecting and consuming AVC carcass is widespread in North America (Davis 2003). The low percentage of amphibian AVCs that drivers in Tanzania and North America, respectively, reported 12% and 7%, respectively may be caused by the semi-arid climate and highly erratic rainfall patterns (Gu, 2011). (Branch 2005). Furthermore, compared to most animal AVCs, amphibian carcasses may be cleared from the road sooner by scavengers or disintegrate after being struck by cars repeatedly (Hels and Buchwald 2001).

According to the drivers' perspectives on the causes of AVCs and the correlation between animal body mass and the risk of an AVC, drivers are more likely to hit species that can inflict less damage to cars. According to drivers, frogs, birds, and dogs are the things they hit most frequently (Bjornstig *et al.*, 1984). Because they are excessively prevalent on roads, dogs have been called a 'nuisance'. Some drivers,

however, claimed that they avoided hitting dogs because they are thought to bring bad luck and because they can seriously harm a car (Adriaensen *et al.*, 2003). Additionally, drivers reported that during the wet season, frogs were hit more frequently. Since frogs are little, their car would not be harmed by them. Rarely did cars come to a stop, slow down, or swerve to stay clear of them. When they come across a small animal that is unlikely to cause harm to their automobile, drivers are less inclined to swerve or stop abruptly, and they have observed that cars have collided with birds as they flew across the road (Davis 2003).

Large leopard tortoises, plains zebra, and African elephants are less likely to be harmed on the continent. Since these species can usually be seen from a farther distance than the smaller ones, the drivers might have taken proactive measures to avoid collisions. In addition, crashes involving elephants, wildebeest, and zebras are likely to cause harm to the car and its occupants (Langley and Mathison, 2008). Similar opinions about white-tailed deer (*Odocoileus virginianus*) were voiced in Southern Michigan (Marcoux and Riley, 2010). In the survey, some drivers stated they preferred tortoises, especially leopard tortoises, while others said they thought hitting the slick shells of terrapins and tortoises could cause the automobile to skid. To ensure the safety of the tortoises, some Tanzanian drivers would remove them from the road so they could be taken home or possibly sold. There are reports that the illegal tortoise trade is well-established in the region (Kabigumila, 1998).

2.8 Influence of ecological variables

Landscape features play a critical role in the distribution of individual species (Van Buskirk 2004; Ficetola *et al.*, 2008). Hence, most of the studies reviewed also considered some of these variables. Roadside habitat (Clevenger *et al.*, 2003) and landscape features may attract animal activities adjacent to roads and increase

roadkill. The distance between roadkill and water source can also be used to evaluate the occurrence, as some species use open water as a breeding site.

2.9 Conclusion

Protected areas now cover more than 12% of global land area (Chape *et al.*, 2005) and are a critical environmental policy tool. Roadkill is a global challenge and since road infrastructure improvement is inevitable, it is better to include more improved methods which will incorporate the biodiversity aspects when planning such infrastructure. Road ecologists should be part of teams designing and building the road and railway infrastructure, road ecology is important in understanding how to conserve biodiversity.

The review examined questions of feasibility of mapping roadkill in a large, protected area, and most of the reviewed publications had shown success in studying roadkill. However, few publications had investigated this in the protected areas. Most of studies have also been conducted on roads next to areas with high biodiversity which were bisecting or passing close to protected areas. Impacts of roads in protected areas are not high according to the papers reviewed, but they must be monitored constantly.

CHAPTER 3 METHODOLOGY

3.1 The transects

The roads selected as transects for the study were the busiest roads in the Skukuza section of the KNP, which is in the southern part of the park. The transect covered three paved and two unpaved roads. The paved roads are the H11 (1.43 km) from Skukuza rest camp to the S1 (26.62 km) from Phabeni gate to Skukuza camp and H1-1 (31.83 km) from Numbi gate. In reference to figure 1 of the study area, unpaved or gravel roads are the S3 connecting to S7 (16.29 km) joining S1 and H1-1 and the S65 (13.83 km). The total distance covered by the whole transect was 90 km. These roads were purposefully selected based on the data of cars entering the gates leading to the Skukuza camp from the KNP database (data from 2017). The volumes of traffic allowed comparison between roads. The roads also connect three major KNP gates which are the Paul Kruger, Numbi and Phabeni gates respectively.

A drive along a transect was undertaken for 1.5 hours after sunrise which was just after the rush hour. The aim was to capture the hits which occurred during the morning rush hour, similar to a study done by (Barthelmess and Brooks 2010). The data from the KNP gates were used to analyse the traffic volumes for the past two years (2018 and 2019). Due to budget constraints, a drive in the afternoon after the rush hour was not possible.

3.2 Data collection and procedure

Data were collected according to the methods used by Collinson *et al.*, (2014) in Addo Elephant National Park (AENP). Three ecological seasons (Main and Allen, 2002; Carvalho *et al.*, 2017), namely cold-dry (June - July), hot-wet (November - December) and hot-dry (February - March) were distinguished and data were collected at the start of each season. The reason for choosing to use ecological seasons was the expectation that animal migratory activity as well as visibility depended on season. The period over which the roads were sampled in each season was 30 consecutive

days. The hot-dry season was covered in February 2018, the hot-wet season in November 2018, and the cold-dry season in July 2019.

Roadkill surveys were conducted using a vehicle. The transect was driven at a speed of less than 40 km per hour on unpaved roads and less than 50 km per hour on paved roads because these are the speed limits permitted in the park and to have better visibility. The transect was driven once a day in the morning until the entire transect was completed. When a carcass was detected, the vehicle was stopped close to the carcass. A photograph of the carcass was taken which assisted in later identification if the carcass could not be identified immediately. Its position on the road and the GPS coordinates were recorded using a handheld Garmin-Etrex 10 GPS that could mark waypoints and save tracks, which then allowed to plan and save routes later through Garmin Basecamp. It also had the ability to set waypoints, and review tracks post-trip on a computer through their proprietary GIS software, Garmin Basecamp. The other recorded data was the roadside habitat or vegetation type, the roadside information entailed if either the vegetation next to the roadkill was dense or not and the road characteristics indicating if the road was straight or bending.

After recording of the data, the roadkill was not removed from the road. A heat map for roadkill was generated based on the roadkill data collected during the three ecological seasons using ArcGIS 10.2, ArcGIS is a comprehensive geospatial platform for professionals and organizations. It is the leading geographic information system (GIS) technology. Built by Esri, ArcGIS integrates and connects data through the context of geography. It provided world-leading capabilities for creating, managing, analyzing, mapping, and sharing all types of data, with Hot Spot Analysis was used to identify significant hot spots and cold spots by grouping point features according to a specified distance (Kirilenko 2022).

3.3 Estimating roadkill rates

According to Garrah *et al.*, (2015) and Kummoo *et al.*, (2020), Roadkill rates were determined by dividing the total roadkill discovered for each monitored road section by km x days. The roadkill number ($\text{km}^{-1}\text{day}^{-1}$) was stated as the unit of measurement for roadkill rates. Due to a lack of funding, this study was unable to calculate the traffic levels for each of the three regional buffer roads that were examined.

3.4 Data analysis and presentation

Maps were created in ArcGIS 10.2. Locations of roadkill were plotted on the map (risk area map) using GPS coordinates. The locations were further used in mapping areas where incidences of roadkill totalled over the three seasons are low (0 - 4 roadkill per 10 km), medium (5 - 9 roadkill per 10 km) or high (≥ 10 roadkill per 10 km).

Cluster Analysis

Point clustering is referred to as a process of grouping point features according to a specified distance (Kirilenko 2022). The distance specified is referred to as the clustering radius which fluctuates cluster sizes and can exclude and include points as the spatial resolution changes (Haynes *et al.*, 2022).

In this study, this process was performed in ArcGIS Pro 2.9 (Jasim and Walli 2023) to simplify and visualise the amount of roadkill within certain distances using the coordinate data to accurately depict where an animal was found and how many were found at each point location. This aids in revealing patterns that may otherwise be difficult to visualise due to data quantity and the tendency of simple maps to only reflect occurrence coordinates (Burian *et al.*, 2022).

Near Distance

The distance between the input and a near feature is known as the near distance. When the method (Balčiauskas *et al.*, 2020) option is set to Geodesic and the input is

in a geographic coordinate system, the value is in the linear unit of the input features coordinate system, or meters. If there isn't a nearby feature, the number will be -1.

One or more feature classes of various shape kinds (point, multipoint, line, or polygon) may be included in the near features. It is possible to utilize the same feature class or layer for both near features and input. To prevent all features from being nearest to themselves in this case, the input feature being assessed is removed from the near feature possibilities. A layer that you have selected can be one of the input features. The selected features were used and adjusted while the tool was being operated. For the remaining features, the values of the newly generated fields were set to -1. When several near features had the same shortest distance from an input feature, one near feature was chosen at random to be the nearest. The input features must be in a projection suitable for measuring distance, such as an equidistant projection, when utilizing the Planar option for the Method parameter. The degree of correlation between the road type variable and the roadkill determinant variables was examined using a chi-square test.

Kriging was used for the prediction map, as it generates estimated surfaces from a scattered set of points in two-dimensional space. This is one of the methods that use a limited set of sampled data points to estimate the value of a variable over a continuous spatial field (Bencin *et al.*, 2019). It differs from simpler methods, such as Inverse Distance Weighted Interpolation, Linear Regression, or Gaussian decays in that it uses the spatial correlation between sampled points to interpolate the values in the spatial field: the interpolation is based on the spatial arrangement of the empirical observations, rather than on a presumed model of spatial distribution. Kriging also generates estimates of the uncertainty surrounding each interpolated value.

In a general sense, the kriging weights are calculated such that points nearby to the location of interest are given more weight than those farther away. Clustering of points is also considered, so that clusters of points are weighted less heavily (in effect, they contain less information than single points). This helps to reduce bias in the

predictions. This procedure is suitable for risk area map production which is showing hot and cold spot areas. The five transects from which data were collected were classified as paved and unpaved roads (Bencin *et al.*, 2019).

G-test of independence

The goodness of fit of observed frequencies to expected frequencies if row and column classifications were independent is tested using the likelihood ratio test, often known as the G-test of independence. G-test of independence is used when you have two nominal variables, and you want to see whether the proportions of one variable are different for different values of the other variable (MacDonald and Gardener 2000). Use it when the sample size is large. The technique relies on a multinomial distribution, in which the totals of the rows and columns are random rather than fixed. The research employed When you have two nominal variables and wish to determine whether the proportions of one variable change given various values of the other, use the G-test of independence. When the sample size is large, use it.

P-Value

The P value, which is the likelihood of receiving a result equal to or more extreme than what was seen under the premise of no impact or difference (null hypothesis), was also utilized in the study. P, or probability, expresses the likelihood that any observed variation across groups is the result of chance (MacDonald and Gardner 2000).

CHAPTER 4 RESULTS

4.1 Wildlife roadkill hot/cold spot areas in one section of the Kruger National Park.

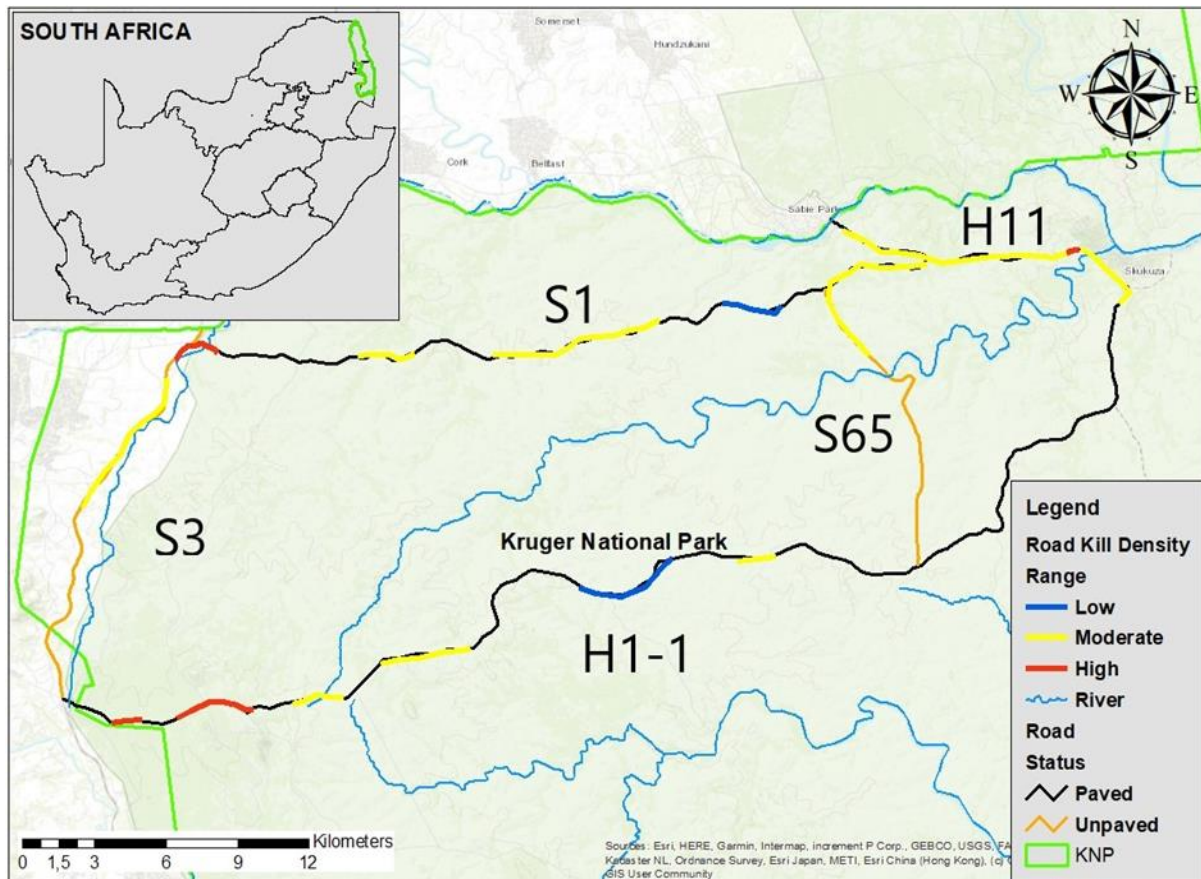


Figure 3 Heat map of roadkill frequency total of all seasons

Ninety one percent of the roadkill incidents were recorded on the paved roads (Figure 3). Areas with low roadkill incidents (blue) have recorded nine incidents or less at that 10 km stretch, and moderate (yellow) indicates 10 to 20 incidents and lastly the high (red) shows areas with 21 or more incidents. The remaining areas had no recorded roadkill incidents. Roadkill locations were numerous kilometres apart from each other, resulting in more areas being classified as cold spots.

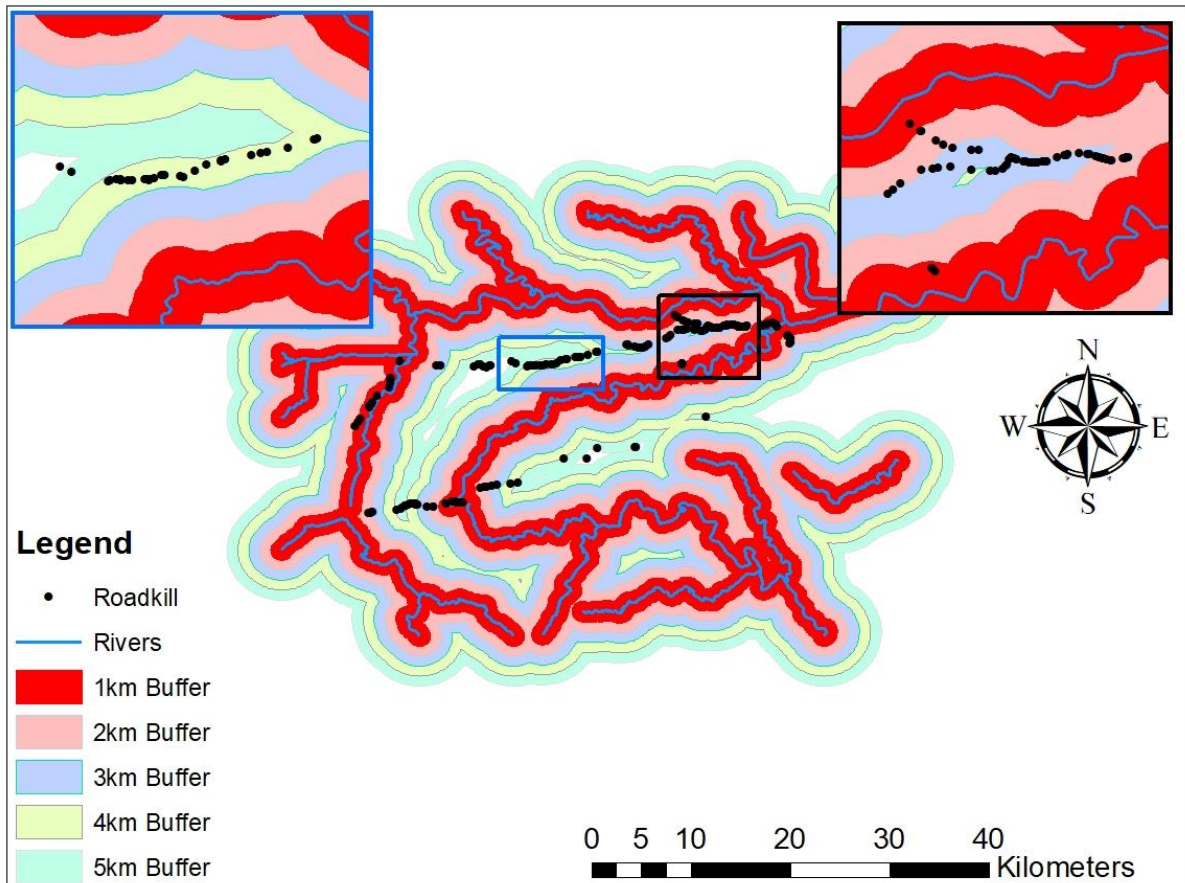


Figure 4 Distance to the nearest river

Based on observations of Figure 4 above, the distance to rivers had a low influence on incidence rates. However, there is hotspot where the S1 crosses the river. Also, on the H1-1 the high incidence area is between the rivers. However, at this area the distance between the rivers must also be noted as it is relatively larger. There are no hotspot areas on unpaved roads as roadkill incidence was low on them. For all seasons taken together on most of the transects roadkill rates are moderate. Season, however, has a highly significant effect on the roadkill rate. During winter (cold-dry) the number of roadkill was very low with 21 cases. A total of 168 roadkill incidents were recorded in the wet seasons.

Most roadkill cases ($n = 168$; 88.9% of the total) were recorded in sections where there was no water source close roadkill location, while only 11.1% of total roadkill cases were recorded in sections of the road where water source was close to the roadkill.

Table 1 Distribution of roadkill next to water body

Water source	Frequency	Percent
No	168	88.9
Yes	21	11.1
Total	189	100

With regards to Table 1, incidents that have been recorded close to water sources, 5.3% of those were tortoises and the serrated hinged terrapin (*Pelusios sinuatus*) (Price *et al.*, 2021). Roadkill was more frequent next to water bodies in the wet season.

4.2 Comparison of roadkill rates on the paved and unpaved roads

The transect investigated consisted of three paved and two unpaved roads. The rationale was that these roads may have different roadkill rates based on their state, busyness, and the speeds at which the vehicles are permitted to travel on them.

Table 2 Roadkill rates for the surveyed roads

Road	Paved (P) / Unpaved (U)	No: Roadkill	Roadkill per km per day
S 1 (26.62 km)	P	68	0.0284
S 65 (13.83 km)	U	5	0.0040
S 3 (16.29 km)	U	12	0.0082
H 11(1.43 km)	P	52	0.40
H 1-1(31.83 km)	P	52	0.018
Total (90 km)		189	0.4586

Table 2 shows road mortality rates for the five roads for the combined seasons. There were three seasons monitored for 30 days each, combining to a total of 90 days and 189 roadkill incidents recorded for the entire duration of the study. From Table 2 roadkill rates differed and road H11 has the highest rate of $0.40 \text{ roadkill} \cdot \text{km}^{-1} \cdot \text{day}^{-1}$. The overall average roadkill rate when considering a total of 90 km, 90 days and 189 roadkill incidents was $0.4586 \text{ roadkill} \cdot \text{km}^{-1} \cdot \text{day}^{-1}$.

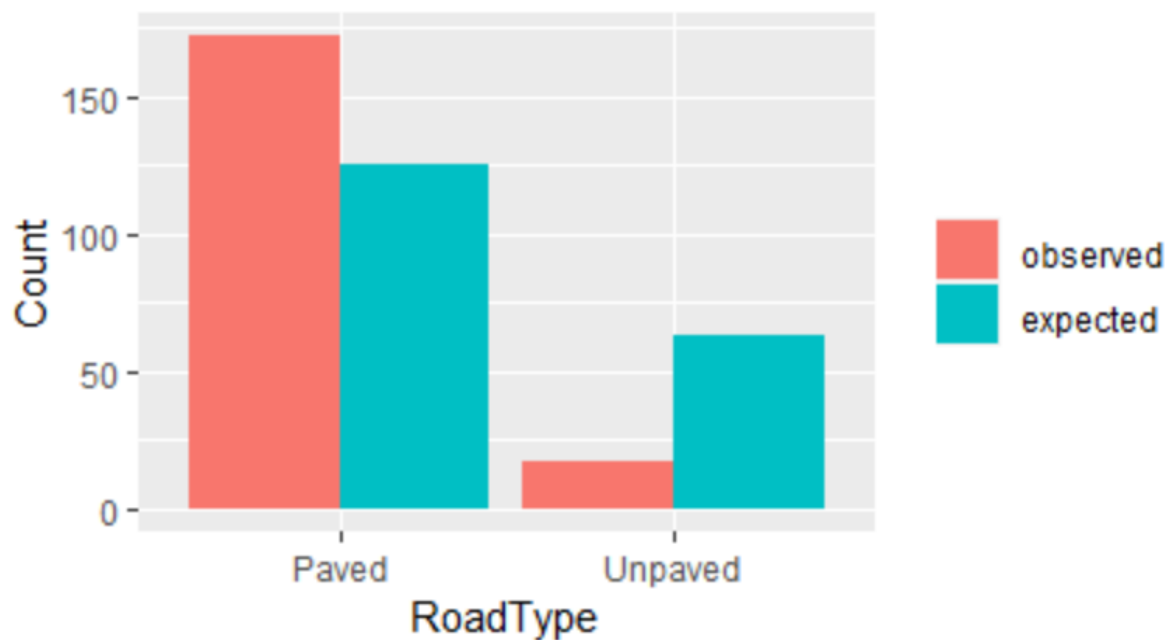


Figure 5 Frequency analysis of road type effect

Figure 5 illustrates the expected and observed count of roadkill incidents on both paved and unpaved roads. Paved roads had a high observed count as compared to expected count. However, unpaved roads displayed low count. A log likelihood ratio (G-test) test of independence was conducted to assess the relationship between road type (presumably categorized as expected roadkill by Road Type) and roadkill numbers (presumably represented by expected roadkill by Road Type). The test yielded a test statistic (G) of 2.7726 with 1 degree of freedom. The p-value associated with this test statistic is significant 0.09589.

The p-value in statistical hypothesis testing indicates the likelihood of getting the observed results or even more severe results should the null hypothesis be true. A common significance level (α) used to decide about the null hypothesis is 0.05. If the p-value is less than or equal to α , it is common to reject the null hypothesis in favor of the alternative hypothesis. In this case, the p-value (0.09589) is greater than 0.05 meaning that we can accept null hypothesis.

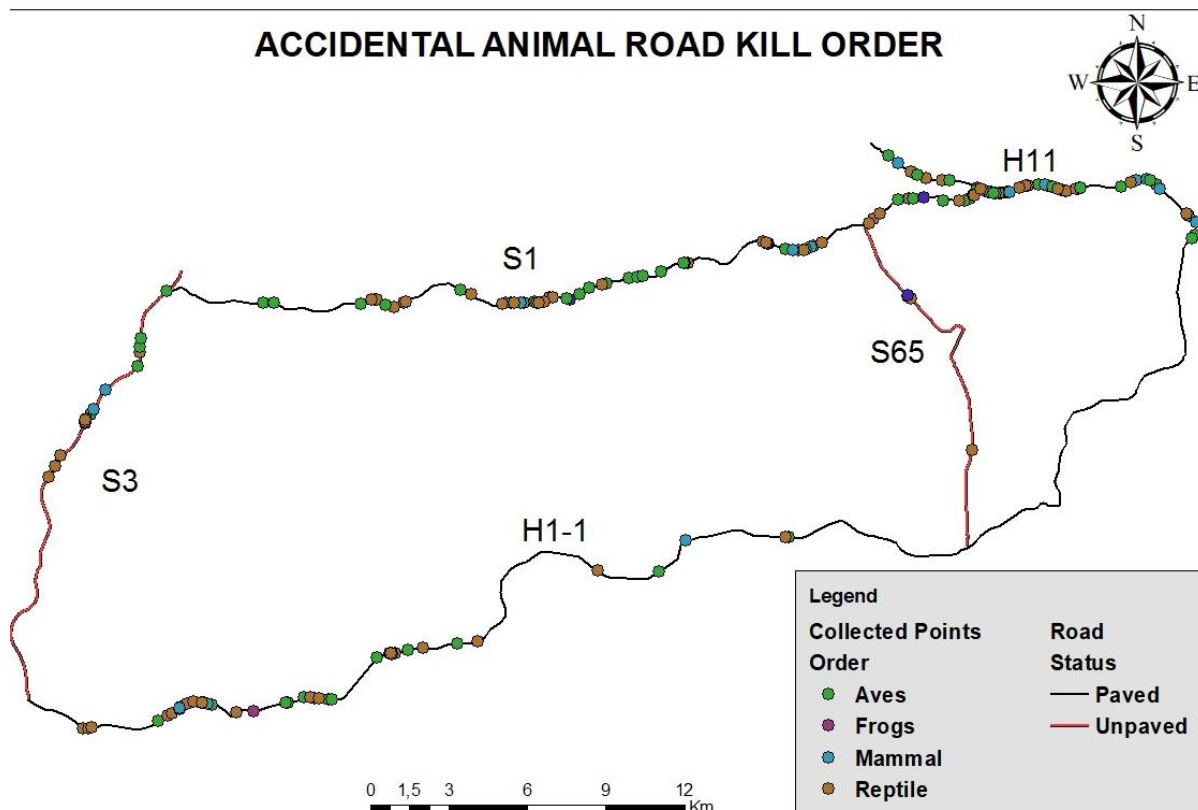


Figure 6 Roadkill incidents by class

Each point in Figure 6 represents a single roadkill incident and the points have different colours that represent different animal classes. Aves are represented by the green colour, Frogs represented in red, Mammals in blue and Reptiles in orange colour. The aim of figure 6 is to show locations where a particular class has been recorded on different roads, an example will be paved roads which has many bird and reptile roadkill incidents and relatively fewer mammals. Based on observations, reptiles, such as leopard tortoises (*Stigmochelys pardalis*) (McMaster and Downs 2008) appendix 10, are having many incidents and of the birds the fiery-necked nightjar (*Caprimulgus*

pectoralis) was most hit. Another field observation about birds was that they tend to be on the roads feeding on insects, seeds and carcasses that are present on the road.

4.3 Seasonal comparison of multi taxa roadkill rate

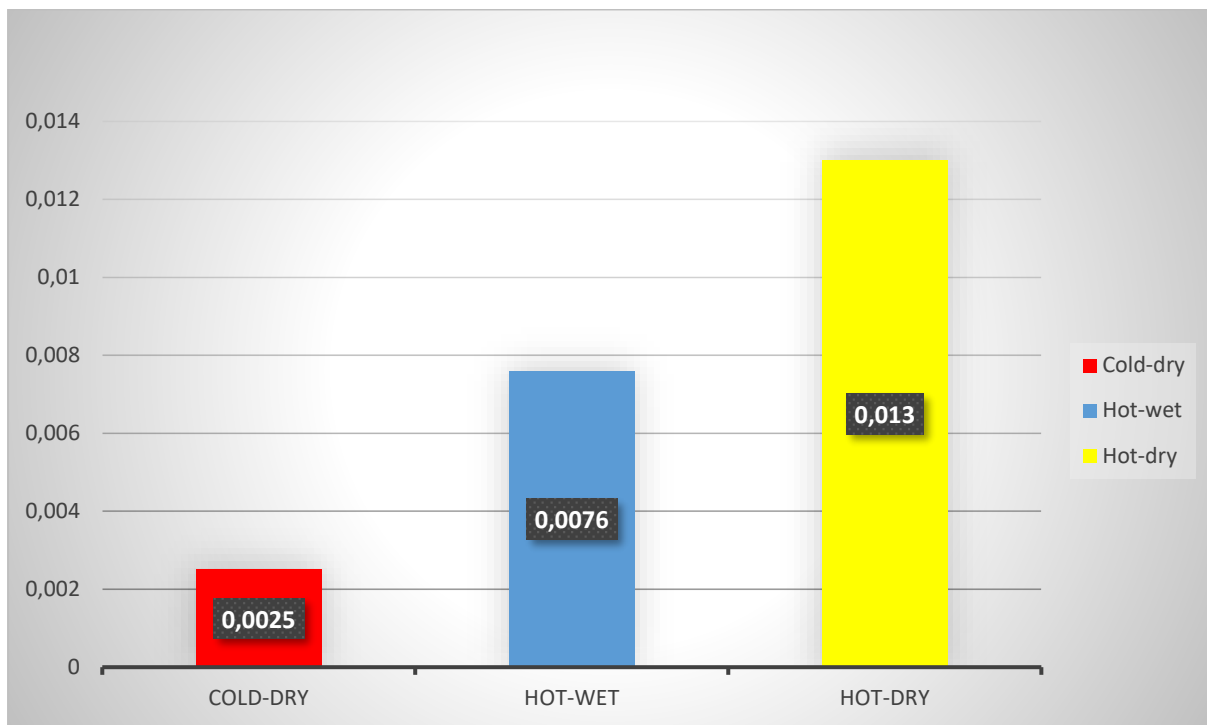


Figure 7 Average Seasonal roadkill

Figure 7 illustrates average roadkill rates calculated for each season for the entire study period. The hot-dry season had the highest roadkill rate, with 0.013 roadkill·km⁻¹day⁻¹. Hot-wet season had the second highest rate with 0.0076 roadkill·km⁻¹day⁻¹. In addition, the cold-dry season had the lowest rates of 0.0025 roadkill·km⁻¹day⁻¹. The hot-dry and cold-dry seasons had limited rainfall as opposed to the hot-wet season. The amount of roadkill for the cold-dry season was 21 in total and for the hot-wet season 62, while hot-dry season had the most roadkill at 106.

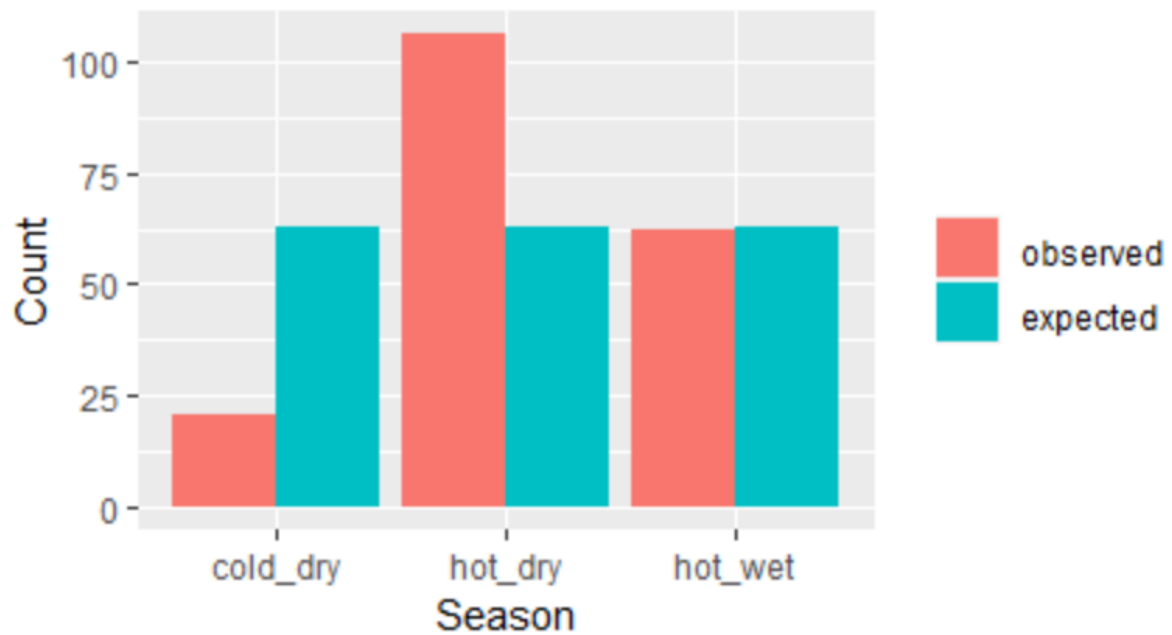


Figure 8 Observed and Expected seasonal effects on roadkill

Figure 8 has illustrated high observed count in hot-dry season with more than 100 counts and for the hot-wet season the count is almost equal, but the cold-dry season had higher expected count than the observed count. To evaluate the impact of season on roadkill counts (probably represented by KillBySeason), a log likelihood ratio (G-test) goodness of fit test was performed. A test statistic (G) of 62.179 with two degrees of freedom was obtained from the test. The minuscule p-value of $3.148e-14$ suggests that there is a very slim chance of achieving either the observed or even more severe outcomes when considering the null hypothesis, which states that there is a seasonal influence.

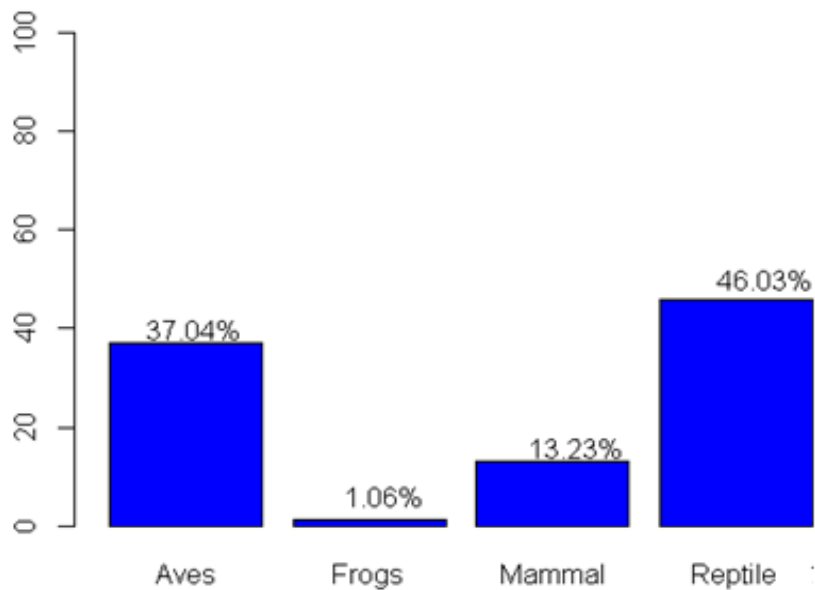


Figure 9 Roadkill distribution

Figure.9 above shows the reptiles and birds had higher numbers of roadkill and they were recorded mostly on the paved roads (Appendix 1).

The purpose of this section is to carry out a seasonal comparison of multi-taxa roadkill through associating taxa roadkill with different seasonal categorical variables.



Figure 10 Leopard tortoise on paved road (left) and tree squirrel roadkill on unpaved road (right)

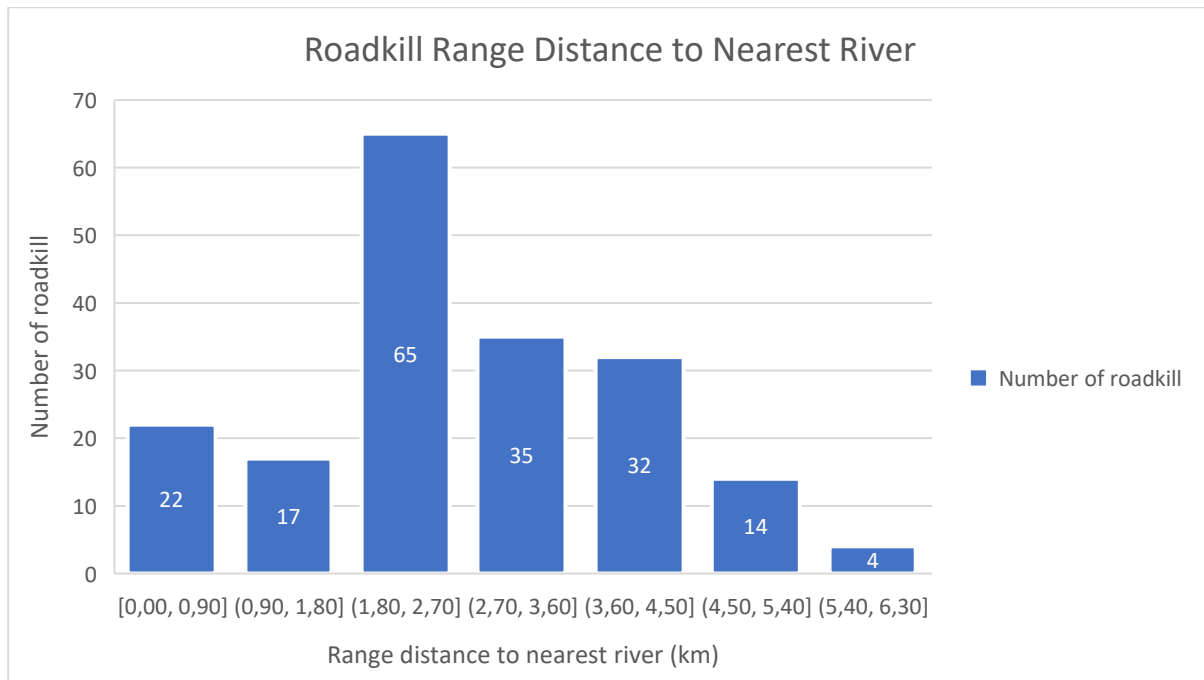


Figure 11 Roadkill Distance to nearest river

The Figure 11 shows the number of roadkill incidents with proximity to the nearest rivers both perennial and seasonal in kilometres, and from 1.80 km to 4.5 km high number of roadkill incidents from the nearest rivers for the three bars and furthest roadkill incidents were low from 5.50 km to the nearest river.

CHAPTER 5 DISCUSSION

5.1 Roadkill in the Kruger National Park (Skukuza section)

Based on observations, roadkill incidents in the study area were randomly distributed (Figure 5), and this is like study findings by Clevenger *et al.*, (2002) who also found roadkill randomly distributed along the road track they monitored. Although there were areas on different roads with high number of roadkill incidents as shown by Figure 3 in the results chapter, there is no indication of significant clustering.

Table 3 Roadkill rates for present study compared to other reviewed studies.

Roadkill rate (roadkill·km ⁻¹ ·day ⁻¹)	Reference	Remarks / Description
0.4586	Present study	National Park
0.06	Da Rosa and Bager (2012)	Highway passing through a protected area
3.32	Garrah <i>et al.</i> , (2015)	Conservation Corridor
0.38	Zhang <i>et al.</i> , (2018)	National Nature Reserve
0.004	Kioko <i>et al.</i> , (2015)	Public road (Highway)

From Table 2, H11 had greater number of roadkill rates compared to other roads although it's length is relatively shorter than other surveyed roads, the other influencing factor is that this road is connecting Paul Kruger and Phambeni gates with the Skukuza rest camp which is considered the main rest camp of the reserve and relatively the busiest hub for commercial activities. The H11 road which covers a length of 1.43 km, this road had 0.40 roadkill·km⁻¹·day⁻¹. However, with regards to observed traffic volume

it was higher as compared to other roads since it connects to two gates. The average rate of $0.4586 \text{ roadkill} \cdot \text{km}^{-1} \cdot \text{day}^{-1}$ is high, since the study did not consider the structural complexity of roadside vegetation, thus we cannot claim with certainty that this has influenced roadkill rates. Roadkill rates rose primarily with road speed limit, with mortalities peaking at more than 50 km/h speeds (Rendall *et al.*, 2021).

The effect of weather

Glista *et al.*, (2008) did a study in Indiana, USA. They detected that roadkill in all months surveyed were weather-related and seasonal patterns in the data and most of the roadkill happened when temperatures and precipitation were at their highest. From the Figures 7 and 8, roadkill was more common in dry season with hot conditions as compared to other conditions, these results correlates with the study by Glista's *et al.*, (2008), where the findings show more collisions were recorded in the wet season with warm and hot conditions. This difference may be explained by greater activity of the animals (Lester 2015) and/or the visibility to motorists because in these seasons' vegetation cover on the road verges is denser in all roads investigated.

Da Rosa and Bager (2012) found that roadkill occurred more in summer than in winter with low precipitation as compared to this study. Most research on seasonal variation in bird found that roadkill was higher in the summer and lower in the winter (Glista *et al.*, 2008), and the results found in this study at the KNP also share same sentiments, as compared to other studies hot-dry season had more observed roadkill counts than expected. Figure 8 shows that during warm weather there were higher numbers of roadkill than when the weather was cold or cloudy, so it can be concluded that the weather factor plays major role in roadkill occurrences (Da Rosa and Bager 2012)

5.2 Comparison of roadkill rates on paved and unpaved roads

Paved roads had higher rates of roadkill compared to unpaved. This was also found by Da Rosa and Bager (2012) in Brazil. However, these roads had different lengths. The S1 had an amount of 68 roadkill incidents which was higher than other surveyed roads. Although the S1 had this high number of roadkill incidents, Figure 3 shows it only has one hot spot area, and it is where the road is curving. Figure 7 and 8 also shows that 90% roadkill is likely to occur on paved roads of the study area preference by motorist.



Figure 12 Permitted speed limits within the park.

On the paved or tarred roads, the acceptable maximum speed limit is 50 km/h for the visitors and 65 km/h for the staff members and reaction personnel such as military, police, and medical vehicles and rangers. On the unpaved or gravel roads visitors are permitted to drive at 40 km/h as shown by figure 12, staff members cannot be ruled out in the possibility of also being perpetrators to roadkill contribution.

Although unpaved roads are thought to be traveled at modest speeds (Jaeger *et al.*, 2015), for example because of pebbles and potholes, this is based on field observations of road conditions. This could, however, be the reason why the study discovered that fewer animals are killed by cars on unpaved roads than on paved ones. Overall, the results indicate that roadkill in the region surrounding the Kruger National Park is significantly lower, with a daily rate of 0.0042 on all studied roads (Zhang *et al.*, 2018).

Clevenger *et al.*, (2003) suggested that the seasonal pattern is connected to life history processes, such as the breeding season, in one of the studies that found higher roadkill during the hot and wet season. Other studies reviewed also found higher roadkill recorded during rainy seasons (Coelho *et al.*, 2008). Beaudry *et al.*, (2010), Costa *et al.*, (2015), Grilo *et al.*, (2009). The results of the current investigation also showed that the wet season killed many tortoises as shown by figure 12.

The conclusion drawn from Figure 3 analysis is that the effect of road type on roadkill numbers (the p-value 0.09589) is not statistically significant at the 0.05 significance level. In other words, there is not enough evidence to conclude that road type has a significant impact on roadkill numbers based on the given data and test results.

5.3 Roadkill seasonal comparison

The hot wet season (Figures 5 and 6) had more roadkill incidents as compared to other ecological seasons sampled with $0.013 \text{ roadkill} \cdot \text{km}^{-1} \cdot \text{day}^{-1}$. In all seasons reptiles and birds (Figure 4 and 7) were the most hit. However, there was no solid evidence for the cause of this. Consequently, the order can be tested for association with other seasonal variables, such as weather condition.

This study presented that during all seasons the park management must make visitors aware of roadkill and the impact it has on wildlife and law enforcement can be vigilant at that period. The findings of a study by Da Rosa and Bager (2012) showed that habitat types and seasonality have an impact on richness and roadkill rates. However, from our results only seasonality had influence with wet seasons having more roadkill incidents than other seasons. Additionally, their research revealed that roadkill was localized in wetlands and rice fields, intensifying in terms of rates and richness throughout the summer and fall, this may be caused by animal movement in search for food in these areas, which was not the case for the present study.

Therefore, the conclusion drawn from the Figure 8 analysis is that the effect of season on roadkill numbers is highly significant. In other words, there is strong evidence to suggest that roadkill numbers are influenced by the season based on the given data and test results. In this case, the p-value (0.09589) is greater than 0.05 meaning that we can accept null hypothesis, indicating a significant association between roadkill numbers and different seasons or influence in season.

CHAPTER 6 CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

The aim of this study was to investigate roadkill rates that will inform mapping of hot/cold spots within the selected area of the Kruger National Park. Impacts caused by roads on animals were examined and that led to development of a hot/cold spot heat map, although incidents were randomly distributed. The length of hot spot areas differed greatly with only two areas having a longer stretch of hot spot that were the roads S1 and H1-1. Roadkill rates which were recorded have proven that roadkill in the study area is high, and it is of concern because this area is protected.

The heat map has effectively highlighted areas of high and low concern when planning against roadkill in the KNP Skukuza area, and results have also clarified the rainy season as one with more roadkill. Generally, roadkill continues to be a very big challenge to biodiversity in unprotected and protected areas around the country, however, based on results of this study it is not that much of a challenge in the study area. As such mitigation measures should be put in place in the planning phases of linear infrastructure. However, it could be limited to emphasising speed adherence within the park. There is evidence of roadkill incidents, and it may be a potential biodiversity conservation concern based on a fact that the study area is one of the busiest parts of the park and is considered the main commercial hub of the reserve with most of services are available there, we therefore cannot generalise results for the whole park.

The KNP infrastructure development is always improving, and roads are part of this development, therefore this should be part of the planning process also especially when the roads inside the protected areas such as KNP are also contributing to mortality of wildlife in the park. The researcher's observations supported other studies' findings that wildlife mortality increases as traffic volume increases (Jaeger *et al.*,

2015, Coelho *et al.* 2008, Beaudry *et al.*, 2010), and that speed limits also have an impact (Da Rosa and Bager 2013).

This was evident as the H11 road connecting the Paul Kruger gate to the Skukuza Rest Camp which have high traffic flow throughout each day.

6.2 RECOMMENDATIONS

The primary purpose of the protected areas is to conserve and protect biodiversity of the country's species, and it is not good to witness roadkill being one of the impacts to the wildlife in these areas. However, the challenge for every citizen is to be responsible when driving on our roads and frequent awareness programs should be held by South African National Parks and their strategic partners to combat roadkill in the protected areas such as the Kruger National Park which receives many visitors every day. Even with extensive global data collection on roadkill, estimating the problem's scope in protected areas continues to be difficult. However, a variety of ecological studies like this one can be enabled with enhancements and standardization of the metadata related to roadkill observations.

When having public awareness sessions, it is advisable to include the topic of roadkill. This topic can also be a standalone and the park can recommend to South African National Parks to adopt this in all protected areas they manage and encourage drivers to drive slowly in the park. Traffic calming measures in protected areas such as the KNP must involve the use of road signs warning about common animals found around certain areas, for example if the area is associated with reptiles such as water monitor lizards (*Varanus salvator*) (Uyeda *et al.*, 2012) because it is close to a water source. The traffic cops should heavily fine speeders when they catch them inside the park.

The recommendation is that, of all the roads, the H11 must be given first preference when implementing mitigation measures considering its small length and high number of roadkill incidents. Based on results, it can be recommended that during tortoise

breeding seasons, especially in summer between November and February (Bian *et al.*, 2013) areas with water sources have signs to show motorists possible presence of turtles and getting message of breeding season upon arrival in the park through posters and other effective communication channels.

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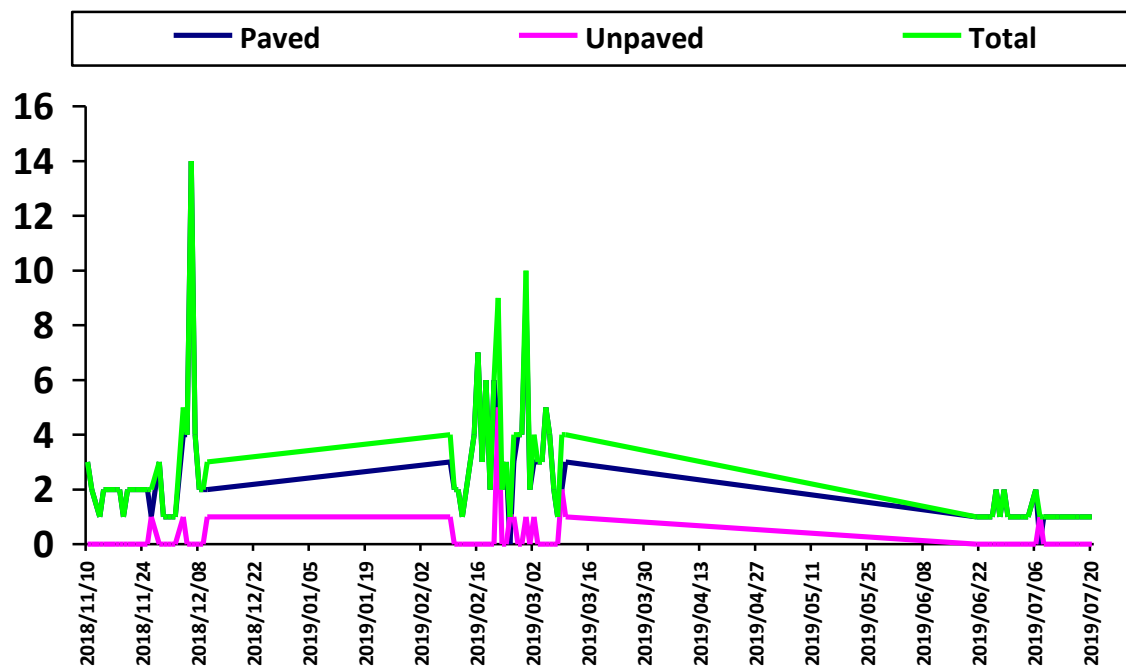
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APPENDICES

Appendix 1: Comparison of roadkill figures between paved and unpaved roads.



Appendix 2: Daily distribution of roadkill recorded in the Skukuza area KNP for 3 ecological seasons.

daily distribution of roadkill

Statistics		
year		
N	Valid	189
	Missing	0
Mean		2018.67
Median		2019.00
Std. Deviation		.471
Range		1
Minimum		2018
Maximum		2019

Year

	Frequency	Percent	Valid Percent	Cumulative Percent
Valid 2018	62	32.8	32.8	32.8
2019	127	67.2	67.2	100.0
Total	189	100.0		100.0

Appendix 3: Statistics for different roadkill determinant variables

Statistics	road type	order	road characteristic	water source	habitat right	habitat left	minimum temperature	maximum temperature	rain within the last 24 hour	road name	weather
N Valid	189	189	189	189	189	189	189	189	189	189	189
Missing	0	0	0	0	0	0	0	0	0	0	0
Std. Error of Mean	.021	.103	.065	.029	.034	.033	.4512	.3490	.034	.080	.056
Median	1.00	4.00	2.00	1.00	2.00	2.00	18.000	33.300	1.00	2.00	3.00
Mode	1	5	1	1	2	2	21.2	35.1 ^a	1	3	4
Std. Deviation	.287	1.419	.899	.402	.473	.458	6.2029	4.7984	.465	1.100	.773
Variance	.082	2.012	.807	.161	.223	.210	38.476	23.024	.216	1.211	.597
Skewness	2.889	-.306	.157	1.504	-.713	-.899	-1.930	.093	.817	.602	-.694
Std. Error of Skewness	0.177	0.177	0.177	0.177	0.177	0.177	0.177	0.177	0.177	0.177	0.177
Kurtosis	6.417	-1.685	-1.751	0.264	-1.508	-1.204	3.127	0.033	-1.347	0.048	-0.329
Std. Error of Kurtosis	0.352	0.352	0.352	0.352	0.352	0.352	0.352	0.352	0.352	0.352	0.352

Range	1	4	2	1	1	1	27.3	24.4	1	4	3
Minimum	1	2	1	1	1	1	-5.2	20.9	1	1	1
Maximum	2	6	3	2	2	2	22.1	45.3	2	5	4

a. Multiple modes exist. The smallest value is shown

Appendix 4: Frequency distribution of roadkill.

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	10-NOV-2018	3	1.6	1.6	1.6
	11-NOV-2018	2	1.1	1.1	2.6
	13-NOV-2018	1	.5	.5	3.2
	14-NOV-2018	2	1.1	1.1	4.2
	17-NOV-2018	2	1.1	1.1	5.3
	18-NOV-2018	2	1.1	1.1	6.3
	19-NOV-2018	1	.5	.5	6.9
	20-NOV-2018	2	1.1	1.1	7.9
	22-NOV-2018	2	1.1	1.1	9.0
	25-NOV-2018	2	1.1	1.1	10.1
	26-NOV-2018	2	1.1	1.1	11.1
	28-NOV-2018	3	1.6	1.6	12.7
	29-NOV-2018	1	.5	.5	13.2
	30-NOV-2018	1	.5	.5	13.8
	01-DEC-2018	1	.5	.5	14.3
	02-DEC-2018	1	.5	.5	14.8
	04-DEC-2018	5	2.6	2.6	17.5
	05-DEC-2018	4	2.1	2.1	19.6
	06-DEC-2018	14	7.4	7.4	27.0
	07-DEC-2018	4	2.1	2.1	29.1
	08-DEC-2018	2	1.1	1.1	30.2
	09-DEC-2018	2	1.1	1.1	31.2
	10-DEC-2018	3	1.6	1.6	32.8
	09-FEB-2019	4	2.1	2.1	34.9
	10-FEB-2019	2	1.1	1.1	36.0
	11-FEB-2019	2	1.1	1.1	37.0
	12-FEB-2019	1	.5	.5	37.6
	15-FEB-2019	4	2.1	2.1	39.7
	16-FEB-2019	7	3.7	3.7	43.4

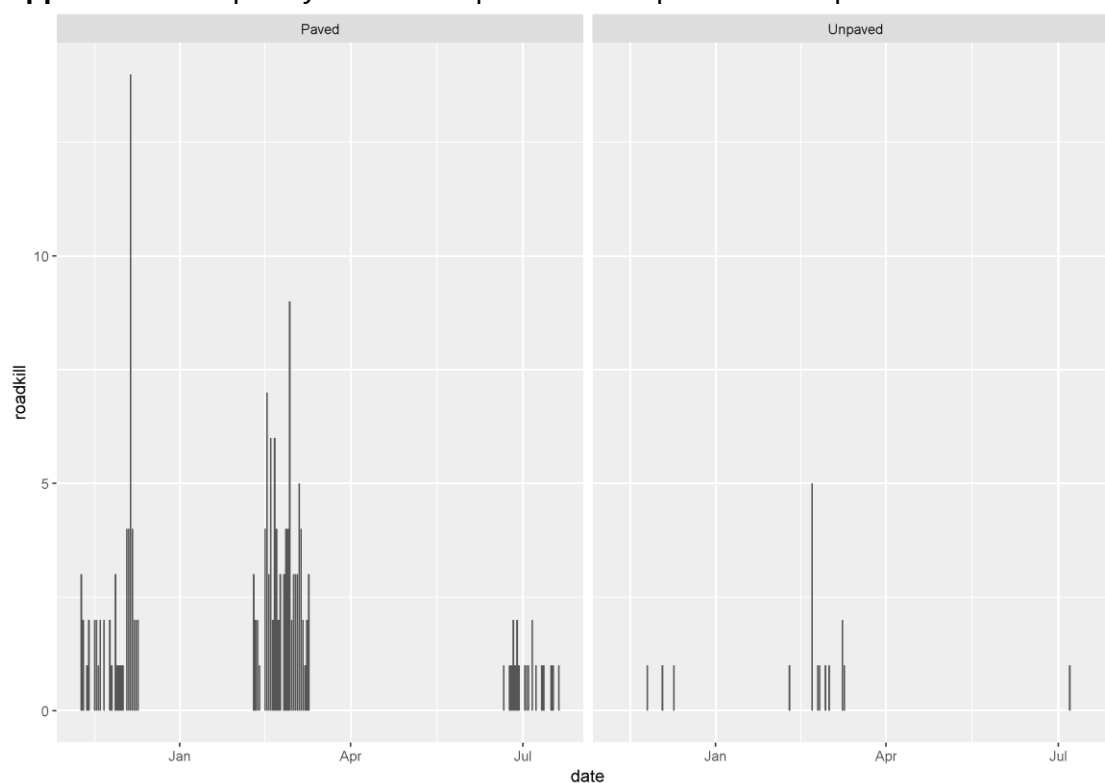
17-FEB-2019	3	1.6	1.6	45.0
18-FEB-2019	6	3.2	3.2	48.1
19-FEB-2019	2	1.1	1.1	49.2
20-FEB-2019	6	3.2	3.2	52.4
21-FEB-2019	9	4.8	4.8	57.1
22-FEB-2019	2	1.1	1.1	58.2
23-FEB-2019	3	1.6	1.6	59.8
24-FEB-2019	1	.5	.5	60.3
25-FEB-2019	4	2.1	2.1	62.4
26-FEB-2019	4	2.1	2.1	64.6
27-FEB-2019	4	2.1	2.1	66.7
28-FEB-2019	10	5.3	5.3	72.0
01-MAR-2019	2	1.1	1.1	73.0
02-MAR-2019	4	2.1	2.1	75.1
03-MAR-2019	3	1.6	1.6	76.7
04-MAR-2019	3	1.6	1.6	78.3
05-MAR-2019	5	2.6	2.6	81.0
06-MAR-2019	4	2.1	2.1	83.1
07-MAR-2019	2	1.1	1.1	84.1
08-MAR-2019	1	.5	.5	84.7
09-MAR-2019	4	2.1	2.1	86.8
10-MAR-2019	4	2.1	2.1	88.9
21-JUN-2019	1	.5	.5	89.4
24-JUN-2019	1	.5	.5	89.9
25-JUN-2019	1	.5	.5	90.5
26-JUN-2019	2	1.1	1.1	91.5
27-JUN-2019	1	.5	.5	92.1
28-JUN-2019	2	1.1	1.1	93.1
29-JUN-2019	1	.5	.5	93.7
02-JUL-2019	1	.5	.5	94.2
03-JUL-2019	1	.5	.5	94.7
04-JUL-2019	1	.5	.5	95.2
06-JUL-2019	2	1.1	1.1	96.3
07-JUL-2019	1	.5	.5	96.8
08-JUL-2019	1	.5	.5	97.4
11-JUL-2019	1	.5	.5	97.9
12-JUL-2019	1	.5	.5	98.4
16-JUL-2019	1	.5	.5	98.9

17-JUL-2019	1	.5	.5	99.5
20-JUL-2019	1	.5	.5	100.0
Total	189	100.0	100.0	

Appendix 5: Frequency distribution per month

Month	Frequency	Percent
June	9	4.8
July	12	6.3
November	26	13.8
March	32	16.9
December	36	19.0
February	74	39.2
Total	189	100.0

Appendix 6: Frequency distribution per month on paved and unpaved roads.



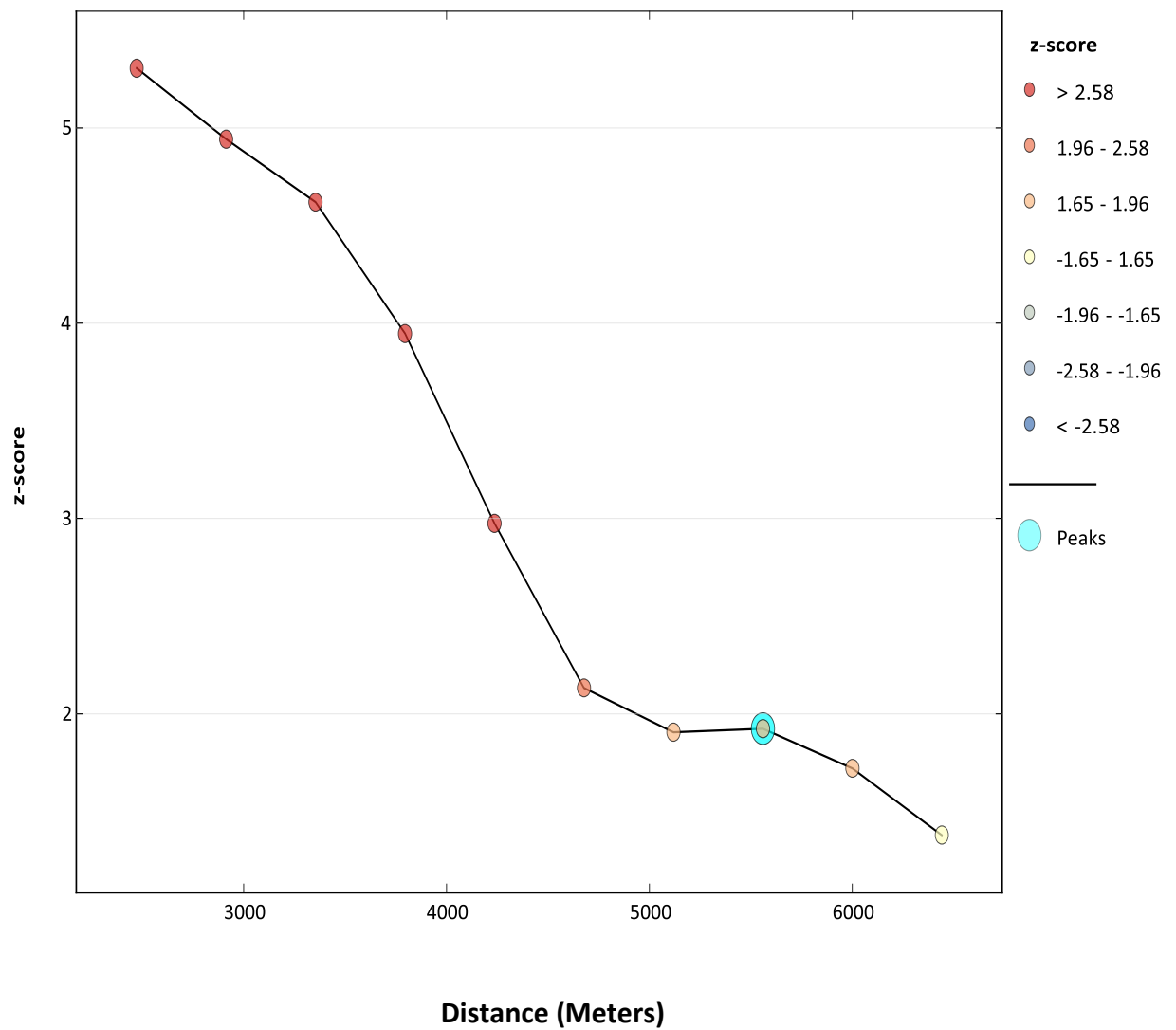
Appendix 7: Yearly distribution of roadkill.

Year	Frequency	Percent
2018	62	32.8
2019	127	67.2

Total	189	100.0
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Appendix 8: ArcGIS Analysis report of spatial autocorrelation.

Spatial Autocorrelation by Distance



Global Moran's I Summary by Distance

Distance	Moran's Index	Expected Index	Variance	z-score	p-value
2472,00	0,272245	-0,009091	0,002812	5,305093	0,000000
2912,97	0,227801	-0,009091	0,002298	4,941677	0,000001
3353,94	0,193455	-0,009091	0,001923	4,619317	0,000004
3794,92	0,152786	-0,009091	0,001682	3,946954	0,000079
4235,89	0,104431	-0,009091	0,001456	2,975021	0,002930
4676,86	0,067910	-0,009091	0,001303	2,132790	0,032942
5117,83	0,055845	-0,009091	0,001161	1,905975	0,056653
5558,81	0,053259	-0,009091	0,001050	1,924152	0,054336
5999,78	0,044534	-0,009091	0,000971	1,721257	0,085204
6440,75	0,032167	-0,009091	0,000895	1,379294	0,167804

First Peak (Distance; Value): 5558,81; 1,924152

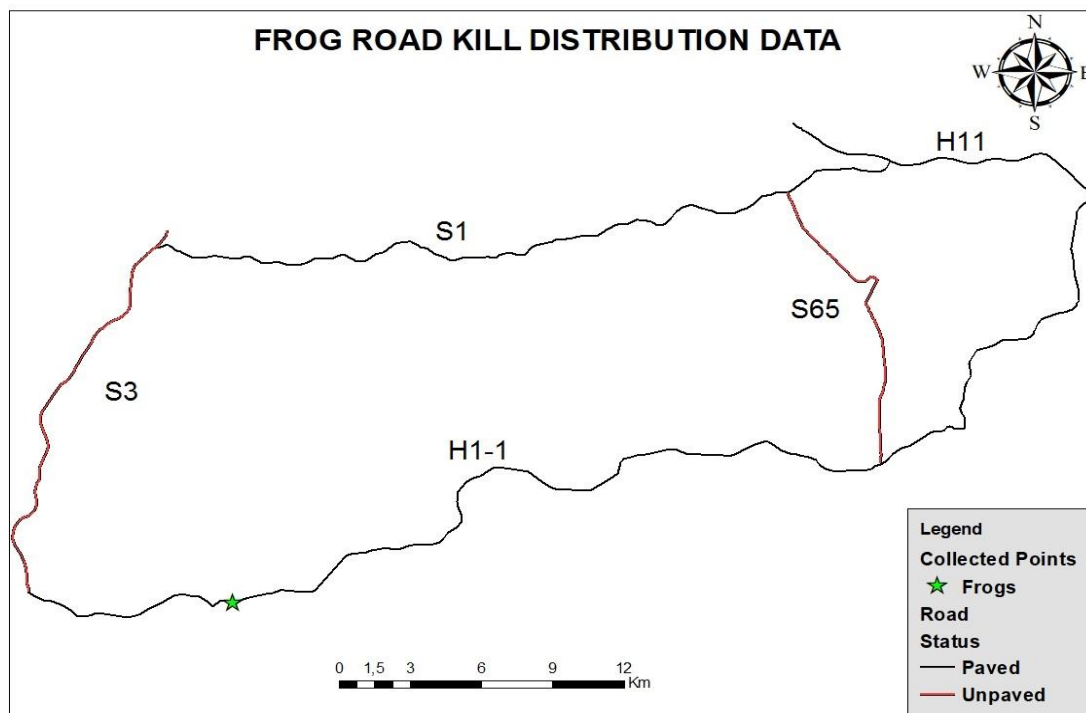
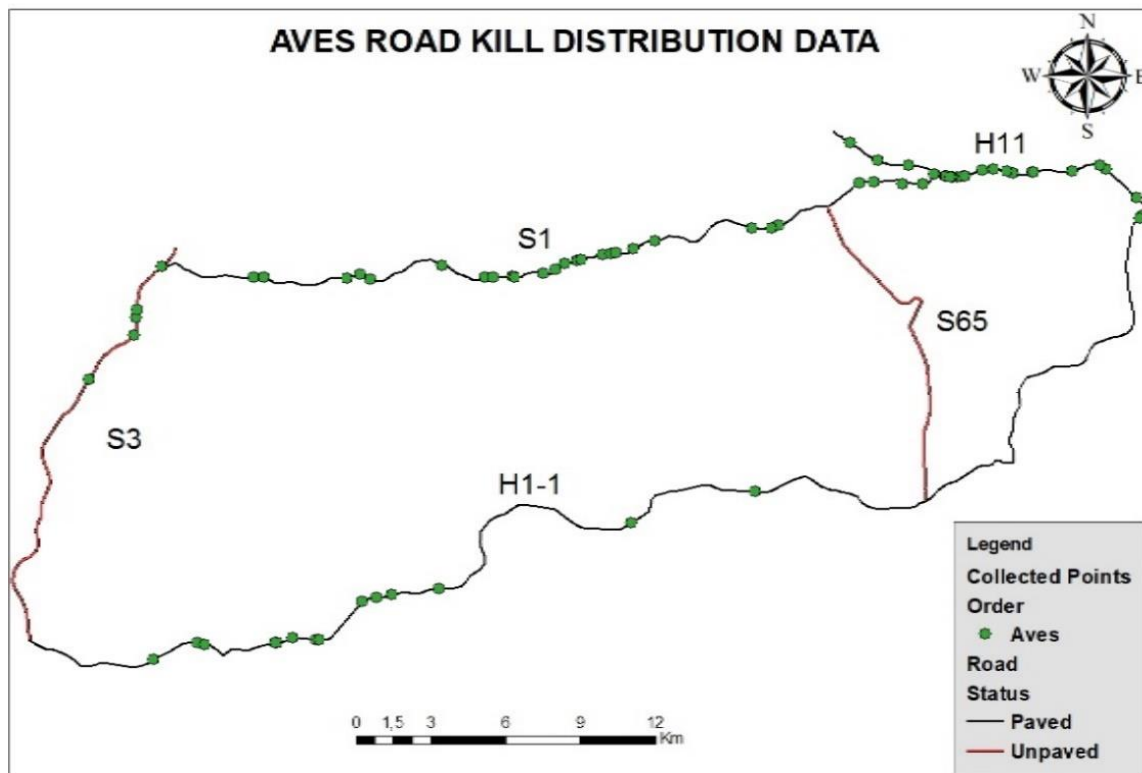
Max Peak (Distance; Value): 5558,81; 1,924152

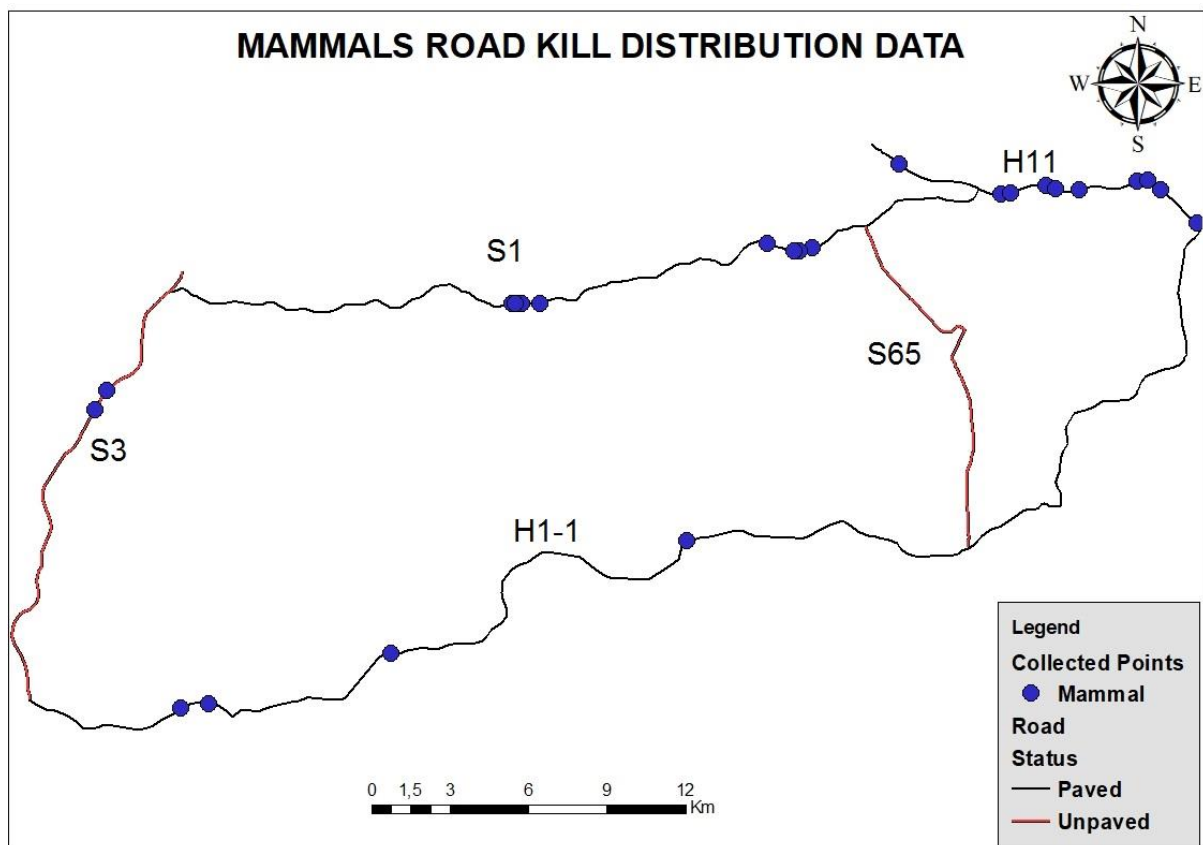
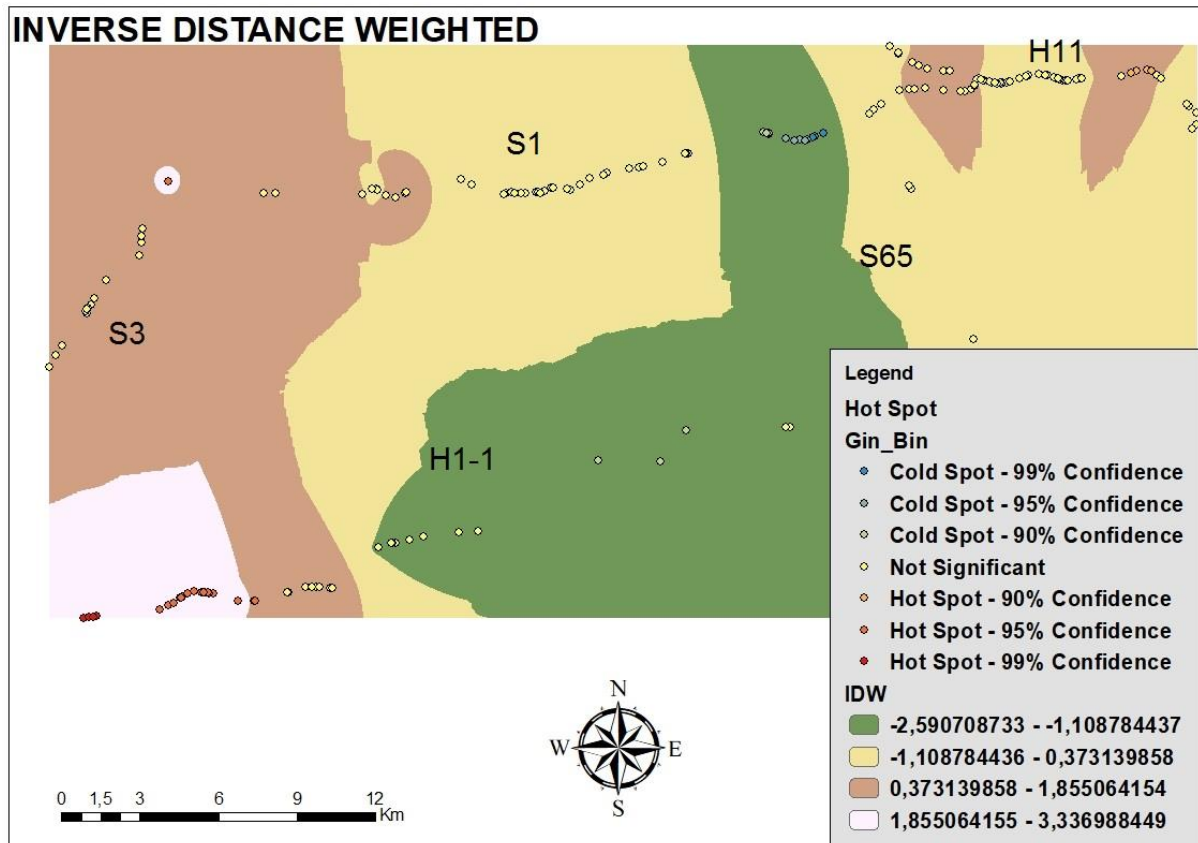
Distance measured in Meters

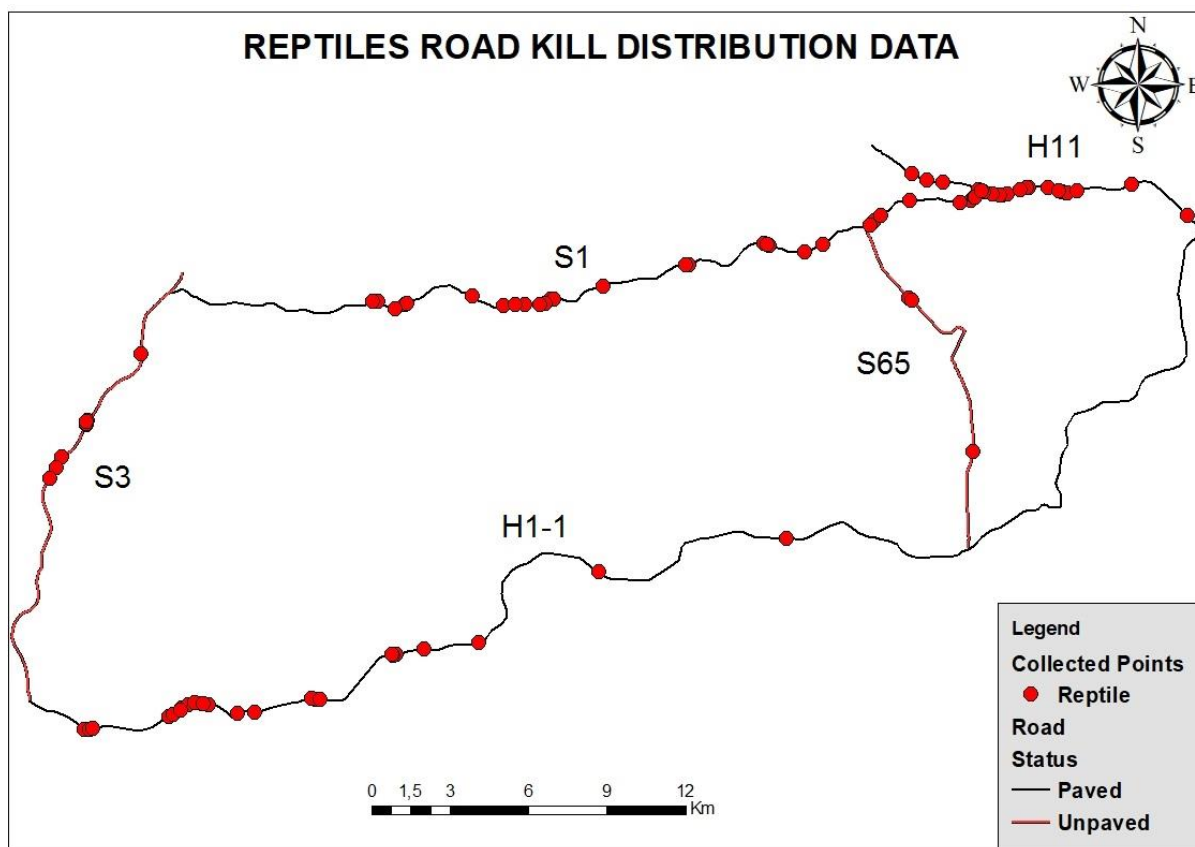
Incremental Autocorrelation Parameters

Parameter Name	Input Value
Input Features	CE
Input Field	ICOUNT
Number of Distance Bands	10
Beginning Distance	2472,000000
Distance Increment	440,972251
Distance Method	EUCLIDEAN
Row Standardization	True
Selection Set	False

Appendix 9: ArcGIS generated roadkill maps indicating different taxa on different roads in the Skukuza area, Kruger National Park South Africa.







Appendix 10: Genus frequency.

Genus	Frequency	Percent
<i>Acanthocercus</i>	1	.5
<i>Agama</i>	1	.5
<i>Amietophrynus</i>	1	.5
<i>Ardeotis</i>	1	.5
<i>Bitis</i>	1	.5
<i>Burhinus</i>	1	.5
<i>Calendulauda</i>	1	.5
<i>Dispholidus</i>	1	.5
<i>Epomophorus</i>	1	.5
<i>Halcyon</i>	1	.5
<i>Hemidactylus</i>	1	.5
<i>Lamprotornis</i>	1	.5
<i>Lanius</i>	1	.5
<i>Motacilla</i>	1	.5
<i>Naja</i>	1	.5
<i>Natrix</i>	1	.5

<i>Paraxerus</i>	1	.5
<i>Platysaurus</i>	1	.5
<i>Plestiodon</i>	1	.5
<i>Pternistis</i>	1	.5
<i>Raphicerus</i>	1	.5
<i>Rhabdomys</i>	1	.5
<i>Thelotorni</i>	1	.5
<i>Cisticola</i>	2	1.1
<i>Gerrhosaurus</i>	2	1.1
<i>Lepus</i>	2	1.1
<i>Philothamnus</i>	2	1.1
<i>Psammophylax</i>	2	1.1
<i>Trachylepis</i>	2	1.1
<i>Causus</i>	3	1.6
<i>Chamaeleo</i>	3	1.6
<i>Helogale</i>	4	2.1
<i>Paraxerus</i>	4	2.1
<i>Achatina</i>	5	2.6
<i>Dendroaspis</i>	5	2.6
<i>Dendroperdix</i>	7	3.7
<i>Kinixys</i>	8	4.2
<i>Streptopelia</i>	9	4.8
<i>Pelusios</i>	10	5.3
<i>Stigmochelys</i>	11	5.8
<i>Afrotyphlops</i>	13	6.9
<i>Unidentified</i>	16	8.5
<i>Caprimulgus</i>	20	10.6
	36	19.0
Total	189	100.0

