A STANDARDISED PROTOCOL FOR ROADKILL DETECTION AND THE DETERMINANTS OF ROADKILL IN THE GREATER MAPUNGUBWE TRANSFRONTEIR CONSERVATION AREA, LIMPOPO PROVINCE, SOUTH AFRICA

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by

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DEDICATION

This thesis is dedicated to Nairobi, Kenya, 21.08.2004, a day that gave me courage,

And Nelson.

ABSTRACT

Despite evidence suggesting that road traffic is a major threat to biodiversity loss, very little is known about its actual impact on wildlife populations in South Africa. Globally, road density and traffic volumes are increasing, and although huge budgets are devoted to the construction and upgrading of roads, there is little or no allocation to mitigation measures for protecting fauna in most countries, particularly Africa. Further, no global standardised protocol exists for the rapid assessment of roadkill or the most economical and efficient approach for assessing roadkill rates.

Using vehicle field trials, the reliability of detecting artificially deployed roadkill was assessed. Roadkill detection rates decreased significantly at speeds >50 km/h and were also significantly influenced by light conditions (i.e. detection success was greater when the sun was high) and the position of the roadkill on the road (i.e. smaller roadkill on verges were often missed). These results suggest that roadkill sampling was most effective between 1.5 h ours after dawn and 1.5 hours before dusk and that driving at slower speeds (<50 $km.h^{-1}$) was required to detect roadkill.

This protocol was implemented across three ecological seasons on a 100 km paved road and a 20 km unpaved road in the Greater Mapungubwe Transfrontier Conservation Area, Limpopo Province, South Africa. Driven daily over a 120-day period (three periods consisting each of 40 days), a total of 1,027 roadkill were recorded. These comprised 162 species from all terrestrial vertebrate groups with birds being the most commonly encountered roadkill (50% of all incidents). The high numbers of vertebrates identified as roadkill suggests that road traffic could have potentially unsustainable impacts on wildlife populations and hence the biodiversity of the area.

Seventeen variables were identified as possible determinants of roadkill occurrence with season, rainfall, minimum and maximum temperature, habitat type, grass height, grass density, fence type and vehicle type significantly influencing roadkill numbers. Significantly more roadkill were detected on the paved road (9.91/100km) than on the unpaved road (1.8/100km) probably because of greater traffic volumes and the increased speed that vehicles travelled on the paved road.

Warmer temperatures and increased rainfall in the preceding 24 hours also increased road mortality numbers as animals tended to become more active during these times. Interestingly, more roadkill was detected in open roadside habitats compared to dense roadside habitats on both the paved and unpaved roads and when grass on the roadside verge was of intermediate height. Open habitat possibly may provide a natural corridor for wildlife which ultimately end up on the road. Roadkill numbers increased when certain other physical barriers, such as cattle fences, were present, probably because these barriers were more penetrable than electric fencing.

A series of mitigation measures are proposed to reduce the impacts of roads on wildlife in South Africa. These mitigation measures highlight the need to address the balance between the development of a country's transport infrastructure and the conservation of its fauna. It is important that research on the impacts of roads becomes standardised to enable robust statistical comparisons which will provide a greater understanding of the potential threats to vertebrate biodiversity.

TABLE OF CONTENTS

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CHAPTER 1

INTRODUCTION

ROAD: *from the same root as the word 'ride', the Middle English 'rood' and Old English 'rad', meaning the act of riding*.

Collins English Dictionary (2003).

Van der Ree 2012.

Apple Records, © Kosh

1. THE HISTORY AND DEVELOPMENT OF ROADS

The Organisation for Economic Co-operation and Development (OECD) defines a road as “a line of communication open to public traffic which typically has been paved or otherwise improved to allow travel by some conveyance, including a horse, cart, or motor vehicle” (OECD 2002).

Prior to roads, trails were often simple footpaths following animal paths (Helbing *et al.* 2000), which were eventually widened to make primitive cart trails (Lay 1992). Traditionally, roads served expanding towns, linking them for trade and military purposes (Lay 1992). The world's oldest known paved road was laid in Egypt sometime between 2600 and 2200 BC (Wildord 1994) and the Roman Empire built roads that were generally straight and so durable that parts of them still remain serviceable today (Kumar & Kumar 2011). From the fall of the Roman Empire until the 19th century, European roads were generally neglected and difficult to travel. People usually walked, rode horses, or were carried in sedan chairs and goods were transported by pack animals (Lay 1992). In Great Britain, two Scottish engineers, Thomas Telford and John L. McAdam, were responsible for the development of the macadamised or tar macadam road (Chartres & Turnbull 1983). The expansion of the Industrial Revolution brought this and other road improvements to Europe. However, transport by river was still far easier, faster and more economical than transport by road (Barker & Gerhold 1995), and the emphasis was on railroad construction until after the invention of the automobile (Chartres & Turnbull 1983). With the invention and mass production of the automobile in the early twentieth century, demands for higher quality roads became paramount (Lay 1992).

Consistent uses of road type terms vary globally but roads are generally classified in a hierarchy. At the top of the hierarchy are ‘freeways’, which usually have at least two lanes in each direction, and are characterised by high speeds and traffic volumes with the sole function of allowing travelers to reach a destination as quickly and directly as possible. There is no formal definition of the English-language word ‘freeway’ and it is known by various terms worldwide, including, motorway, expressway, highway, interstate or of the equivalent foreign-language words autoroute, autobahn and autostrade that are accepted worldwide. In most cases, these words are defined by local statute or design standards (OECD 2004). Below freeways, are arterials, then distributor roads, and subsequently local roads which all have varying degrees of speed, volume, connectivity and access (Khanna & Justo 2010). Again, definitions vary worldwide with road type usages including driveway, arterial road, avenue, backroad, byway, dirt road, lane and single carriageway (Khanna & Justo 2010). At the bottom of the road hierarchy are ‘gravel’ or unpaved roads, which usually consist of irregular stones mixed with a varying amount of sand, silt, and clay. They are most common in less-developed nations, and also in the rural areas of developed nations such as the United States. They may be referred to as 'dirt roads' in common speech, but that term is used more for unimproved roads with no surface material added (Skorseth & Selim 2000).

2. THE STATUS OF ROADS IN SOUTH AFRICA

Over 32 million kilometres of road partition the earth’s surface causing enormous habitat loss and landscape fragmentation (Taylor & Goldingay 2010). The United States has the highest ownership of motor cars per 1000 people in the world, (779/1000 people). South Africa ranks at 72 (out of a world total of 143) with only 123 cars per 1000 people (Central Intelligence Agency 2012). There are approximately 789,000 km of road in South Africa (out of the country’s 1.2 million square kilometres; Karani 2008) with roughly, 18,000 km of paved national roads (administered by South African National Roads Agency Ltd (SANRAL), and 550,000 km proclaimed provincial and municipal roads that are unpaved. There are an additional 221,000 km of un-proclaimed access roads made of gravel or earth, and not falling within the official maintenance responsibility of any tier of the government (Ross & Field 2007).

Recent budget allocation of US$42 billion (Karani 2008) is intended for building, upgrading and maintaining roads in South Africa, but no offset is mentioned for the indirect and direct effects of roads or their cumulative effects on local fauna (Karani 2008). Furthermore, the South African population is estimated at 51 million people, and with a positive economic growth of 4%, pressure is anticipated on all modes of transport (Karani 2008; Statistics South Africa 2012).

Roads are critical to economic development and, in the developing world, roads are often seen as a way to improving a country's socio-economic status by providing access to primary health care, education and markets (van der Hoeven *et al.* 2009). Furthermore, roads are a necessity for industrial development as a means to transport natural resources such as timber or minerals. In South Africa, around 75% of freight is transported by road (Karani 2006).

3. THE IMPACT OF ROADS ON WILDLIFE

Despite recognition of roads being a threat to biodiversity, road density continues to increase and huge budgets are devoted to the construction and upgrading of roads with little or no allocation to mitigation measures to protect biodiversity (van der Ree *et al*. 2011). Growing concern about the ecological effects of roads has led to the emergence of a new scientific discipline called road ecology (Forman *et al.* 2002; Fahrig & Rytwinski 2009). The goal of road ecology is to provide planners with scientific advice on how to minimise or mitigate negative environmental impacts of transportation (Balkenhol & Waits 2009).

Malo *et al.* (2004) noted that the number of collisions with large mammals is increasing in developed countries and may be of the order of several millions each year. Collisions with animals can have negative consequences besides the obvious ending of a life, such as, vehicle damage, harm to endangered species, injury to or death of pets, injury to, or death of vehicle occupants.

A Road Traffic Management Report (RTMC 2008) for South African accident statistics recorded 11,577 fatal road accidents in 2008. Animal-vehicle collision did not rate as a category for describing the type of collision, but came under the heading of 'other' or 'unknown', of which 714 could have been due to animal-vehicle collision. Around US$150 million is spent each year on accident insurance claims in South Africa, with US$92 million devoted to possible animal-vehicle collisions. The Insurance Institute for Highway Safety (2010) estimates US$200 billion a year in costs to vehicular damage from vehicle-wildlife collisions with deer (Cervidae)/car collisions being the number one insurance claim in North America. Whilst these claims compensate vehicle owners, there is no benefit from these claims to ameliorating the negative impacts on animals. In short, the reports examined the cost to human-life but not the cost to biodiversity, despite road traffic being a known cause of wildlife deaths (Ray *et al.* 2005).

Transport infrastructures are a common presence everywhere humans have settled and it is now becoming widely accepted that roads affect many aspects of ecosystems (Forman 2000; Jaegar *et al.* 2005, Peschak 2008). Roads and traffic are destructive in two ways to animal populations; indirectly, by fragmenting a population's habitat, with this threat only apparent over a period of time (Hels & Buchwald, 2001), and directly, roads impact wildlife via mortality (i.e. roadkill; Clevenger *et al.* 2003), and is of immediate impact. Roads therefore pose a threat not just to the survival of individual animals but also to populations.

Of 153 peer-reviewed studies that examined road effects, I found 47 assessed the indirect effects, whilst 62 observed the direct impacts of roads on wildlife. The remaining 44 studies examined mitigation measures (e.g. Clevenger *et al.* 2001; Malo *et al.* 2004) as well as how roadkill can be used to further our knowledge of animal behaviour. For example, roadkill can be used to monitor some populations (Baker *et al*. 2004) or to compare the health of roadkill individuals to death through other causes (Richini-Pereira *et al.* 2011; Bujoczek *et al*. 2011).

3.1 The indirect impacts of roads and traffic on wildlife

Indirectly, roads may create unstable meta-populations by fragmenting habitat which restricts animal movement and increases the functional isolation of populations (Dodd *et al*. 2004; Holderegger & Di Guilo 2010; Taylor & Goldingay 2010). Whilst some wildlife can negotiate these potential obstacles, mortality from vehicle collisions can be high (Dodd *et al*. 2004). Roads can alter animal behaviour, with many animals being attracted to roads (Long *et al.* 2010). For example, snakes and other ectotherms habitually bask on asphalt, birds consume spilt grain from roadsides and some birds use roadside gravel to aid digestion (Jackson 2003). Similarly, deer (Cervidae) and other browsing herbivores are attracted to the dense vegetation or so called 'green curtain' of roadside edges (Noss 2002). This attraction often results in direct mortality and a cascade effect along the trophic hierarchy where scavenging animals seek out roadkill and often become roadkill themselves (Antworth *et al*. 2005; Dean & Milton 2009). Some species avoid roads altogether (e.g. Oxley *et al.* 1974) and may shift home ranges, feeding sites and nesting areas away from the roads (Strasburg 2006). Additionally, it has been noted that animals avoid crossing roads due to noise avoidance which in turn can impact their migratory routes (Hogan 1973; Forman & Alexander 1998; Jaeger *et al*. 2005).

Roads are designed and built for primary use by vehicular and pedestrian traffic and have long been recognised as a chief source of pollution. For example, motor vehicle emissions contribute to air pollution (Delfino 2002), whilst rainwater run-off tends to pick up gasoline, motor oil, and other pollutants and may result in water pollution, and indirectly impact wildlife populations (Seawell & Agbenowosi 1998; Burton & Pitt 2001).

3.2 The direct impacts of roads and traffic on wildlife

Road mortality is probably the best known and visible impact of roads on wildlife (Santos *et al.* 2011). Many definitions exist for animals that are killed on roads; animal-vehicle-collision (AVC; Malo *et al.* 2004), MVC (moose-vehicle-collision; Seiler 2003), road-kill/roadkill (Russell *et al.* 2009; da Rosa & Bager 2012), vehicular homicide (Schwartz 1998), wildlife fatality (Ramp *et al*. 2005), wildlife road mortality (Siegfried 1965), wildlife road traffic accident (WRTA; Putnam 1997), wildlife traffic casualty (Møller *et al*. 2011), wildlife-vehicle-collision (WVC; Markolt *et al.* 2012). By contrast, Braunstein (1998) argues that the word ‘roadkill’ implies that the road is the lone assailant on killing wildlife, when it is actually ‘us’ in our cars that are the cause. Therefore, a more apt description may be ‘carkill’ although this then implies some sort of ownership from our side as human beings, and to do that, would mean taking some form of responsibility (Braunstein 1998).

3.2.1 Roadkill

Roadkill only became common with the advent of the car in the 1920s (Georgano 2000); there may well have been incidents from carts and wagons, but it would have been rare due to the slow speed of these vehicles. One of the earliest reports to recognise road traffic accidents as a significant cause of wildlife mortality comes from Stoner (1925) who referred to the automobile as “creating a serious impact on native mammals, birds and other forms of wildlife.” In almost 100 years roads have dominated the landscape, but animals do not appear to have evolved to understand the cues that may save them on roads (Woodside 2011). This is why there is a critical obligation to mitigate the risks to wildlife from roads.

Dreyer (1935) estimated that 7,350 animals were killed daily in the 1930s on the roads in North America. The Humane Society of the US and the Urban Wildlife Research Centre state that one million (large; >20 kg) animals are killed each day on highways in the United States (Noss 2002). These statistics do not account for animals that crawl off the road to die after being hit, and nor do they account for all species; it may be as high as two million mortalities a day (Gerow *et al.* 2010). On an average day in Michigan, a car runs down a deer once every 8 minutes (Havlick 2004).

Clevenger *at al*. (2003) noted that roadkill rates increase with traffic volume and road width. It is clear that the wider the road, the more time animals need to cross. Thus, the probability of a successful road crossing decreases. Moreover, wider roads usually carry higher traffic volumes and allow for higher speeds (van Langevelde & Jaarsma 2004).

There is evidence from other countries that roadkill is a real threat to the persistence of a variety of species (Coffin 2007; Taylor & Goldingay 2012). This is in contrast to South Africa, where studies have either been taxa-specific or localised (Dean & Milton 2009; Bullock *et al*. 2011). Further, no standardised protocol exists for roadkill data collection.

Roadkill signals a threat to biodiversity that can have long-term effects on ecosystems (Bartels & Kotze 2006). With populations of many species coming under increasing pressure, the need for fast, efficient ways of understanding the potential threat caused by roadkill is becoming more urgent (Erritzøe *et al.* 2003).

AIMS

The broad aims of this study were to:

- *Develop a means to rapidly and effectively assess the impact and frequency of wildlife road traffic accidents on biodiversity in South Africa.*

- *Establish the determinants of roadkill in an important conservation area, namely the Greater Mapungubwe Transfrontier Conservation Area (GMTFCA), Limpopo Province, South Africa.*

- *Develop recommendations for mitigation that can reduce the occurrence of roadkill in South Africa.*

CHAPTER 2

Description of the study site

"At last he came to the banks of the great grey-green, greasy Limpopo River, all set about with Fever Trees."

Rudyard Kipling (1902). The Elephant's Child, Just So Stories.

1. DESCRIPTION AND HISTORY OF THE STUDY AREA

The study area is located in the Limpopo River Valley of South Africa in the Limpopo Province. The confluence of the Limpopo and Shashe Rivers is approximately 15 km to the north of the study area (22°13'59.14"S, 29°28'2.21"E) and borders Botswana and Zimbabwe. The nearest towns are Musina (approximately 80 km to the east) and Alldays (120 km to the south). The area falls within latitude 22°14'S; 22°19"S and longitude 29°17'E; 29°18'E.

The study area also forms part of the Greater Mapungubwe Transfrontier Conservation Area (GMTFCA) and was recognised as an important area for conservation when it was declared a World Heritage Site in 2003 (Figure 2.1).

In 2006, a Trilateral Memorandum of Understanding (MoU) between South Africa, Botswana and Zimbabwe established the Limpopo-Shashe Transfrontier Conservation Area (now known as Greater Mapungubwe Transfrontier Conservation Area). The total area included in the proposed TFCA is approximately 5,000 km^2, with South Africa contributing 2,000 km^2, Botswana 1,500 km^2 and Zimbabwe 1,500 km^2. The GMTFCA also forms part of the Vhembe Biosphere Reserve (VBR) which was formed in 2000 (Carruthers 2006; Mapungubwe National Park, Park Management Plan 2008) and includes other high biodiversity centres within the region. With the development of the GMTFCA, the planned removal of fences will open up larger tracts of land to aid in the dispersal and movement of wildlife populations (Mapungubwe National Park, Park Management Plan 2008).

The GMTFCA comprises an area of approximately 4,900 km^2. Land use currently includes nature conservation, heritage site conservation, tourism, agriculture and infrastructure related to diamond and coal mining (Deacon *et al.* 2010; Figure 2.2). From the 1940s until the 1980s, the land was used primarily for livestock ranching. Farms were heavily stocked with cattle (*Bos primigenius*) and goats (*Capra aegagrus hircus*), resulting in soil and vegetation degradation (MacGregor & O'Connor 2002). Livestock was removed from a substantial portion of the GMTFCA (345 km^2) when De Beers Consolidated Mines Ltd. purchased land between 1981 and 1986, and the area was established as a nature reserve and indigenous herbivores reintroduced (Nel & Nel 2009).

Figure 2.1: A topographical map indicating the Greater Mapungubwe TFCA formerly known as the Limpopo/Shashe TFCA. The circle indicates the study area. GIS data source: Peace Parks Foundation (2010). (ArcGIS 9.3; map units: decimal degrees; not projected).

In the 1980s, a diamond-bearing kimberlite pipe was discovered on the farm Venetia (22°26'45.20"S; 29°18'55.34"E), situated 25 km south of where the international borders of Botswana, Zimbabwe and South Africa intersect (Figure 2.2). In conjunction with the landowners, Anglo Vaal and De Beers established a diamond mine on the property and Venetia Mine opened in 1992. It is currently the largest producer of diamonds in South Africa, yielding approximately 40% of South Africa's total annual diamond production. The mine is currently an open-pit operation, but is expected to be converted to an underground mine between 2018 and 2021(Brown & Erasmus 2004).

In addition, the Limpopo Coal Company (Pty) Ltd acquired the prospecting rights to prospect for coal on four farms along the Limpopo River which border Zimbabwe (22°13'21.26"S; 29°38'53.41"E; Figure 2.2). Mining by Coal of Africa (Pty) Ltd (CoAL) commenced in 2012 with an opencast and underground coal mine planned on the four properties (Nel & Nel 2009). Mining is a large and predominant contributor to the GDP of the Province with several areas ear-marked for exploration. The prospect of excessive traffic by way of labour, transport and other heavy vehicles on the eastern fringe of the GMTFCA is likely to be cause for concern for their impact on wildlife.

With the GMTFCA having the potential to become a major tourist destination in Southern Africa, tourist-borne traffic is likely to also increase. Existing tourist infrastructure is already in place, with a number of privately run lodges in Botswana (which already attract about 20 000 visitors each year; (SANParks 2010) and a growing number in South Africa (SA Tourism 2012). SA Tourism reported a 22% increase in national and 9% international visitors to northern Limpopo since 2005 (Parliamentary Monitoring Group minutes October 2010*).*

The core area for my study comprised paved and unpaved roads within the South African section of the GMTFCA, surrounding the Venetia Limpopo Nature Reserve (VLNR) and the privately owned land to the west, south and east of VLNR (Figure 2.2). These properties are all managed as game farms with a livestock component, mainly comprising goats and cattle. Mapungubwe National Park is situated north of VLNR and is managed by South African National Parks (SANParks).

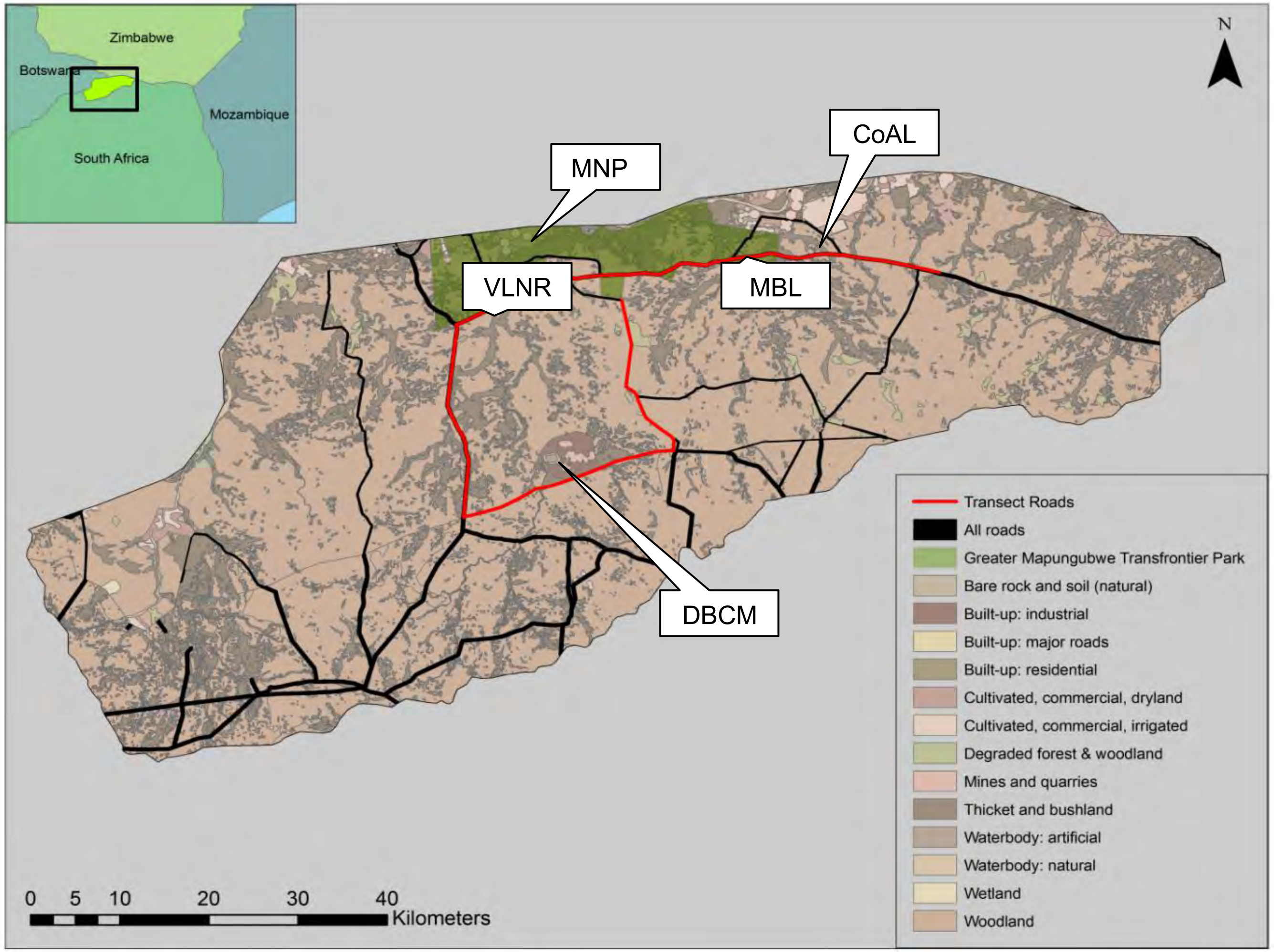

Figure 2.2: A topographical map illustrating the land cover in the GMTFCA. The paved and unpaved roads of the study are highlighted in red. (MNP = Mapungubwe National Park; VLNR = Venetia Limpopo Nature Reserve; DBCM = De Beers Consolidated Mine (Venetia Mine); CoAL = Coal of Africa (Pty) Ltd.) and MBL = Mopane Bush Lodge. GIS data source: GeoNetwork (2000); Peace Parks Foundation (2010). (ArcGIS 9.3; map units: decimal degrees; not projected).

2. TOPOGRAPHY AND GEOLOGY

The GMTFCA is unique in that it accommodates a portion of a biological convergence zone where the West Arid Biome and South West Arid Biome converges with the Subtropical Biome (Rutherford 1997; Deacon *et al*. 2010). The area comprises a semi-arid landscape with varied geology (Brandl 1981; Deacon *et al*. 2010). There is the extensive carbon-rich sedimentary rocks of the Karoo system which contain the reserves of coal that are currently being intensively mined in the area (Nel & Nel 2009).

The topography of the area is predominantly flat with elevations of between 600 m and approximately 900 m. The highest peak in the area is Dongolakop, measuring 896 m.a.s.l. (22°15'13.74"S; 29°41'13.92"E; Figure 2.3).

Sandstone is the dominant underlying bedrock beneath (>2 m) colluvial soils (Nel & Nel 2009). The occasional rocky sandstone outcrop interrupts the landscape (Figure 2.4), together with two major seasonal rivers, the Kalope (flowing south to north) and the Setonki (west to north). Alluvial soils are found adjacent to the rivers (O'Connor 1992).

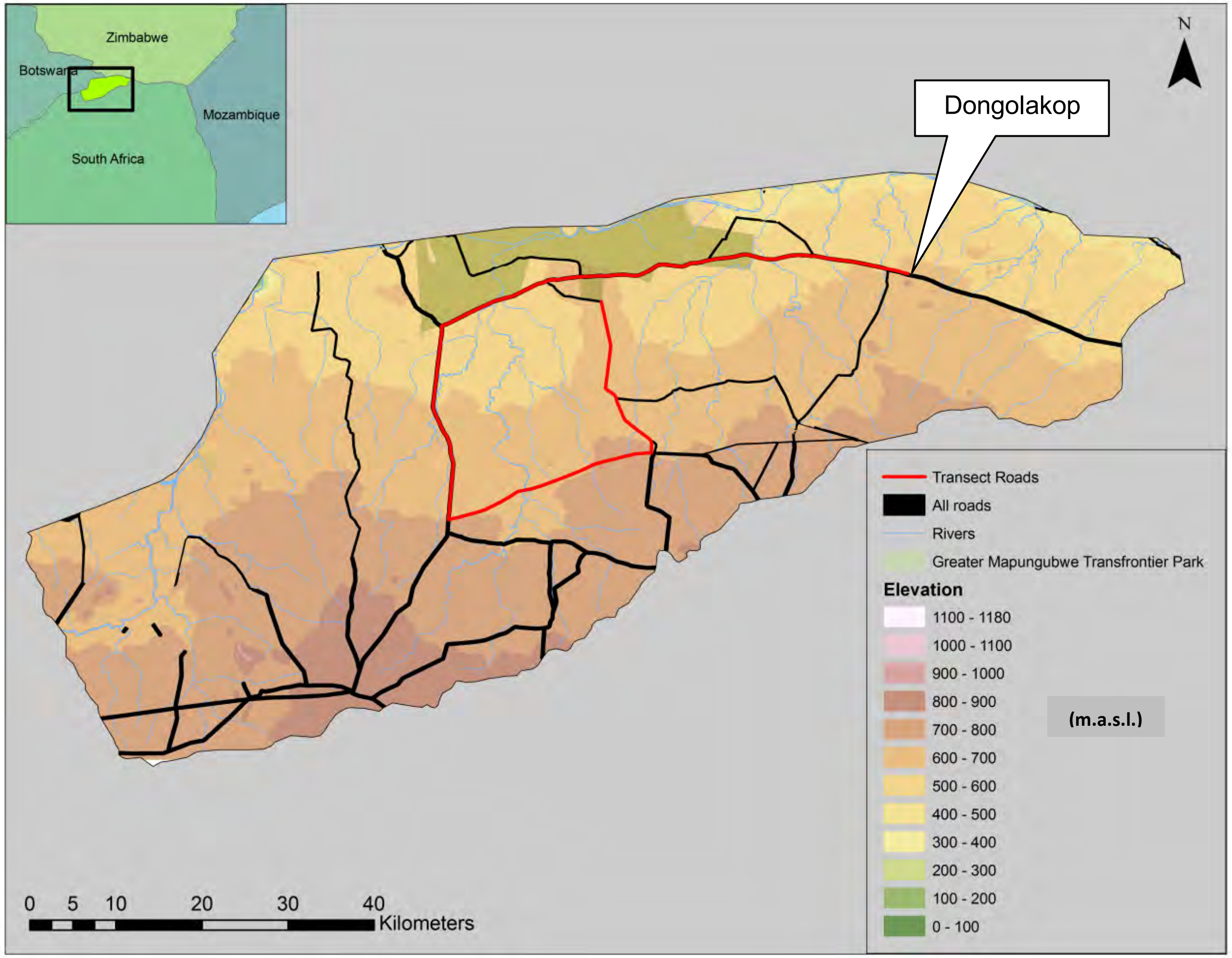

Figure 2.3: A topographical map illustrating elevation in the GMTFCA. The paved and unpaved roads of the study are highlighted in red. GIS data source: GeoNetwork (2000); Peace Parks Foundation (2010). (ArcGIS 9.3; map units: decimal degrees; not projected).

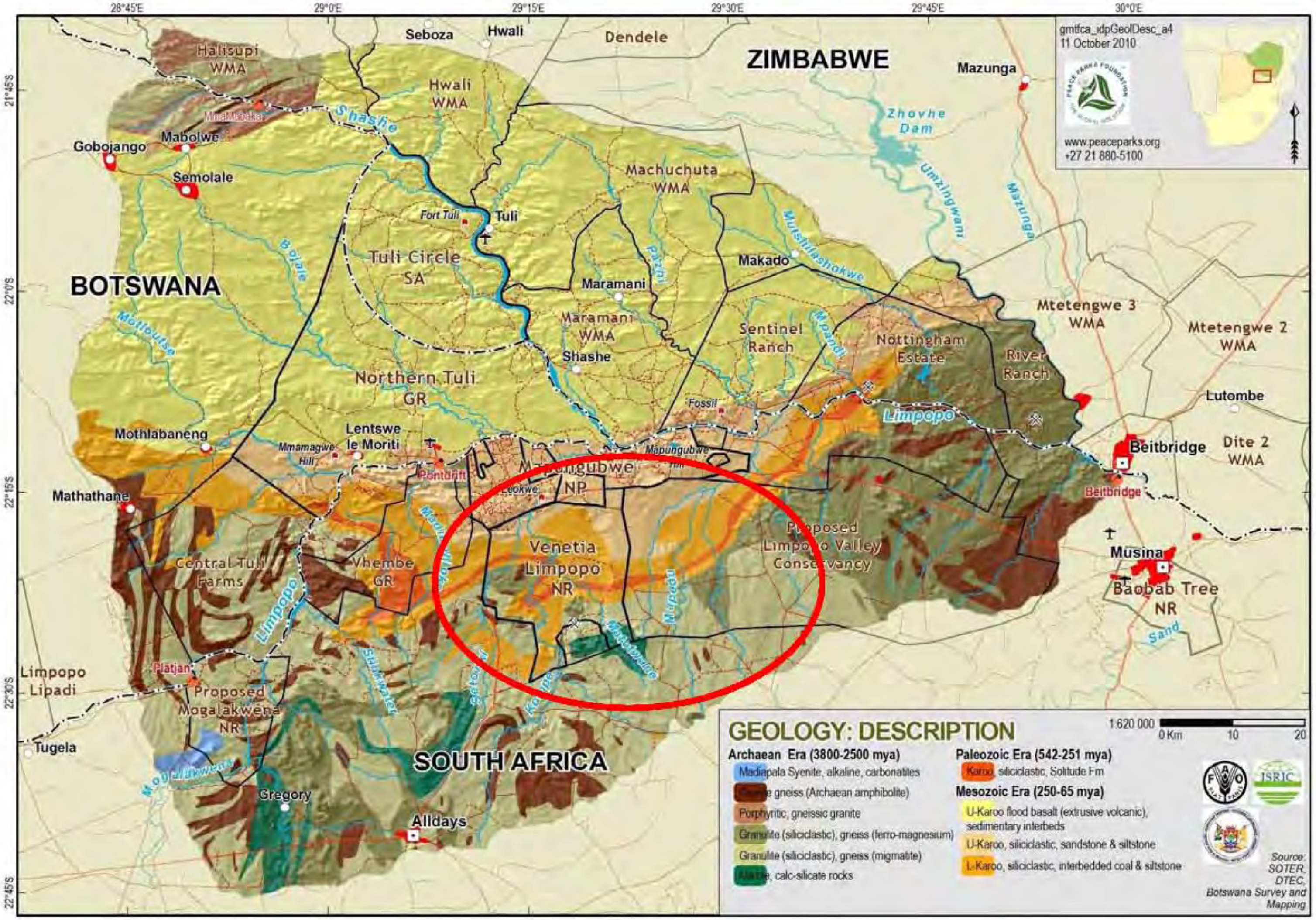

Figure 2.4: A topographical map illustrating the geology of the GMTFCA. The circle indicates the study area. GIS data source: Peace Parks Foundation (2010). (ArcGIS 9.3; map units: decimal degrees; not projected).

3. CLIMATE

The study area is characterised by hot summers (average temperatures range between 17 °C and 27 °C) and mild (4 - 20 °C) winters with frost occurring only occasionally (Figure 2.5; Deacon *et al.* 2010). The mean annual temperature is 22.5 °C with the extreme maximum and minimum temperatures measured as 43.5 °C and -3.8 °C, respectively (Nel & Nel 2009). Evaporation from free-standing water surfaces is in excess of 2,500 mm per year (Nel & Nel 2009).

The area has relatively low rainfall with high variability in periodicity (Figure 2.6). The mean annual rainfall for the Goeree (Dongolakop) weather station (22°15'13.74"S; 29°41'13.92"E) is 278 mm but this can be as low as 154 mm during dry years and as high as 451 mm per annum during wetter years (Nel & Nel 2009). The rainy season is predominantly from November to March (summer) when the Province receives 90% of its total annual rainfall (M'Marete 2003; Deacon *et al*. 2010). The driest months are between May and September when less than 7 mm per month of rain can be recorded (van Rooyen 2008). Cloud cover is at its peak from December to February, with July to August being the sunniest months (Nel & Nel 2009). Relative humidity is highest between February and July (Nel & Nel 2009).

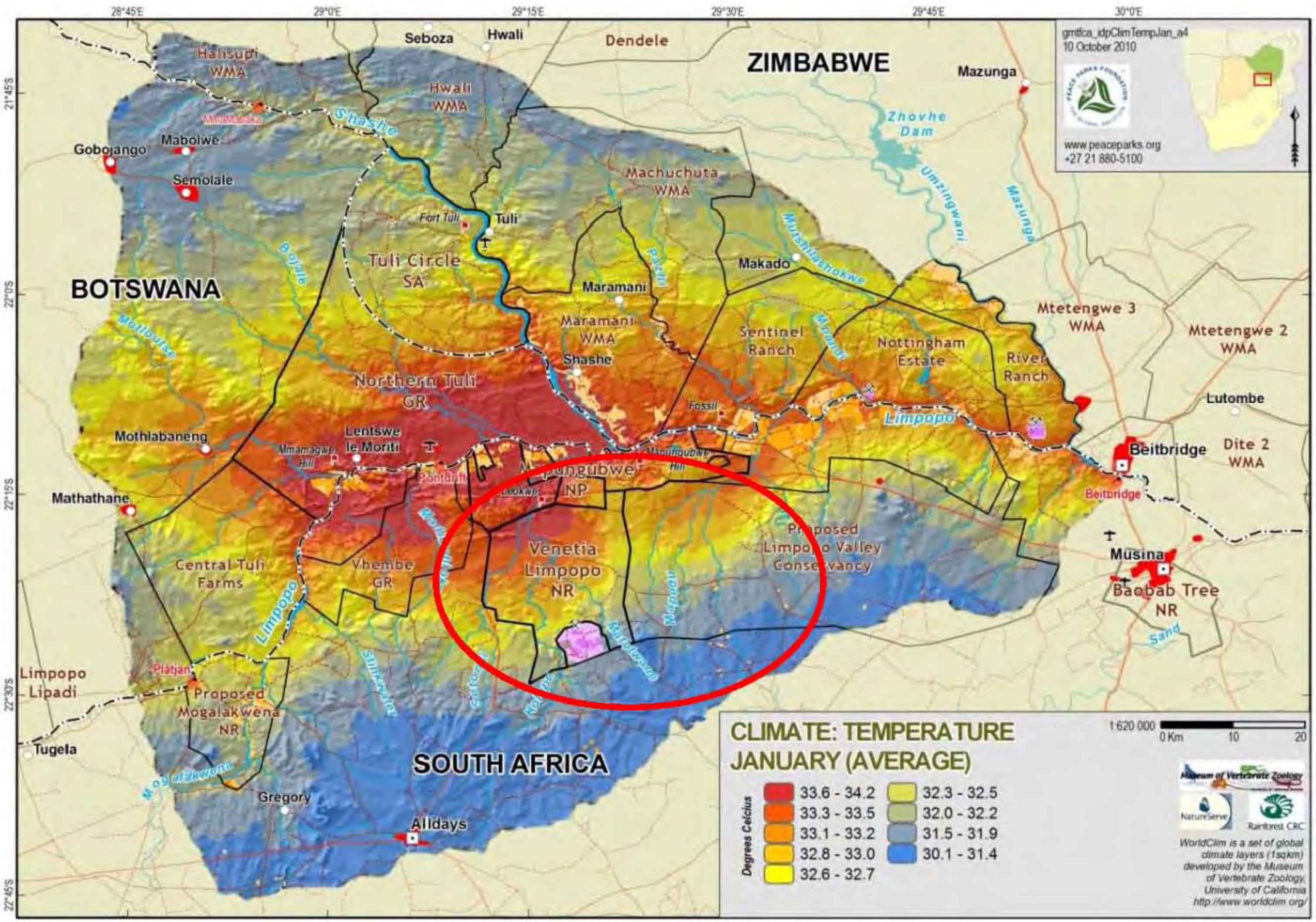

Figure 2.4: A topographical map illustrating the climate of the GMTFCA. The circle indicates the study area. GIS data source: Peace Parks Foundation (2010). (ArcGIS 9.3; map units: decimal degrees; not projected).

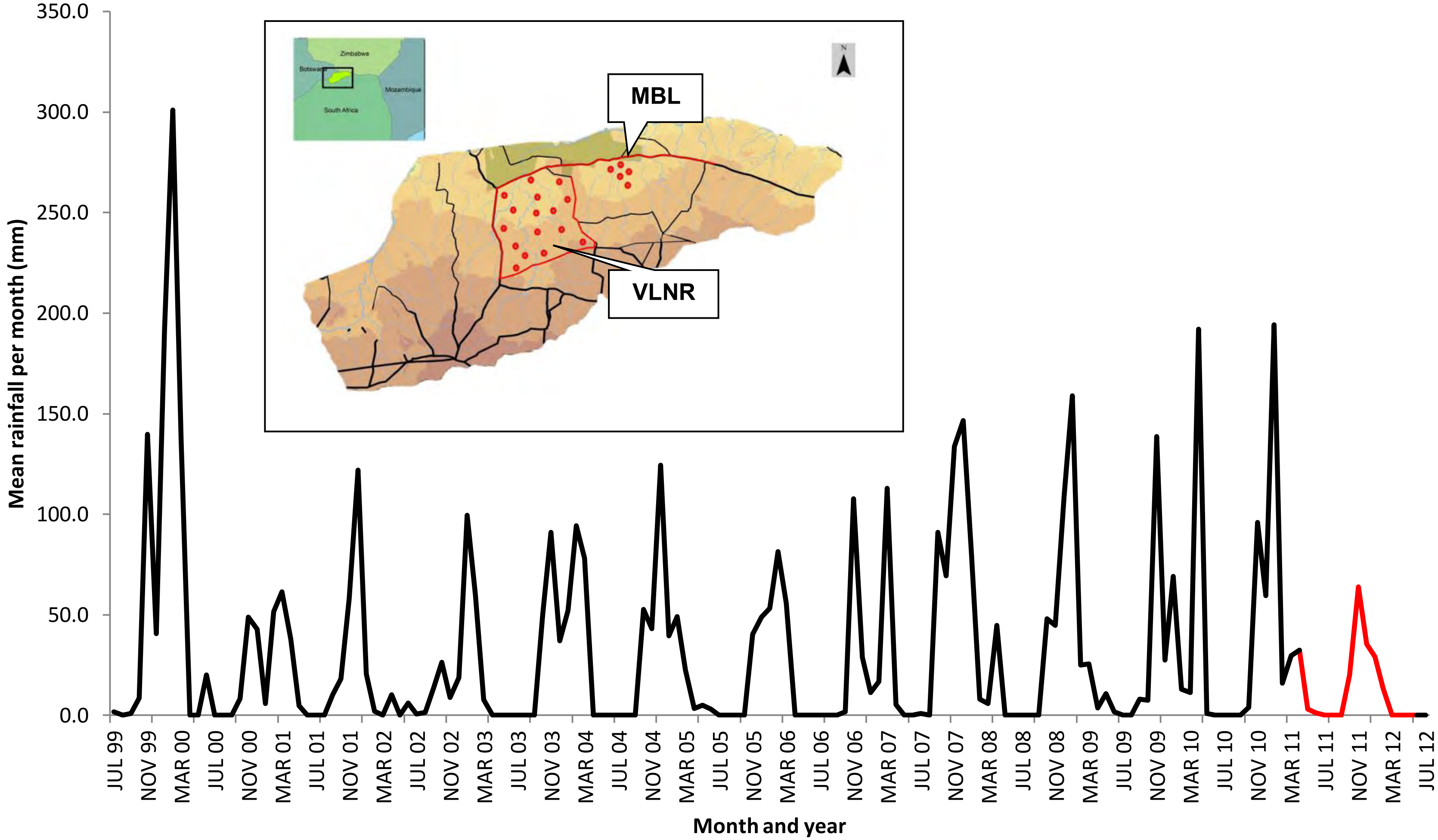

Figure 2.6: The mean monthly rainfall (taken from the mean of 21 rain gauges) over 12 years in the study area of the GMTFCA, South Africa. The study period is highlighted in red. (Data provided by De Beers Venetia Limpopo Nature Reserve (VLNR) Ecology Division and Mopane Bush Lodge (MBL)). The red circles on the map insert shows the location of the 21 rain gauges in the study area, with the road transects highlighted in red.

4. FLORA

The Limpopo Province is situated in a dry savanna subregion within the Savanna Biome, which is the largest biome in South Africa (Mucina & Rutherford 2006). It is characterised by a grassy ground layer, with intermediate stages of growth (neither low growing nor tall and dense; Low & Rebelo 1996) and scattered trees and bushes, and is known locally as Bushveld (Mucina & Rutherford 2006). The study area falls within the Mopane Bioregion and is the smallest bioregion in the Savanna Biome, consisting of two vegetation units; Musina Mopane Bushveld and Limpopo Ridge Bushveld (Mucina & Rutherford 2006). Sixteen of the 18 vegetation types which occur in the region are dominated by this species, with short (~1.5 m) *Mopane* woodland (*Colophospermum mopane)* being most common (O'Connor 1992). Within the riparian zone, *Mopane* trees can reach heights of up to 10 m (O'Connor 1992). It is classified as Mopane Veld and found on sandy, loamy to rocky soils derived mainly from gneiss (Acocks 1988; Figure 2.7).

The foliage of the *Mopane* is an important browse for many herbivores in the area, including African elephant (*Loxodonta africana*), eland (*Tragelaphus oryx*), Greater kudu (*Tragelaphus strepsiceros*), and impala (*Aepyceros melampus*; Styles 1993; Skinner & Chimimba 2005). In addition, the mopane caterpillars (of the emperor moth *Imbrasia belina*) favour this tree species as a food source (Picker *et al*. 2003; De Nagy Koves Hrabar 2006). This in turn leads to large outbreak populations of mopane caterpillars during the summer season and provides for numerous predators, often at ground and road level (Styles 1995). The tree layer is characterised by mixtures of *Mopane* and Red Bushwillow (*Combretum apiculatum)*, Knobthorn (*Vachellia nigrescens)*, Baobab (*Adonsonia digitata*), Corkwood spp. (*Commiphora* spp.), Shepherd's Tree (*Boscia albitrunca),* White Seringa (*Kirkia acuminate),* Raison Bush spp. *(Grewia* spp.) and Umbrella Thorn (*Vachellia tortilis).* The shrub layer consists of *Grewia* spp., Stunted Plane (*Ochna inermis),* Common Star-Chestnut *(Sterculia rogersii*) and Sickle Bush (*Dichrostachys cinerea)* making this the most diverse Mopane Veld in South Africa (Mucina & Rutherford 1996).

The grass layer comprises Nine-awned Grass (*Enneapogon cenchroides),* Blue Buffalo Grass *(Cenchrus ciliaris*), Silky Bushman Grass (*Stipagrostis uniplumis*), Tassel Three-awn (*Aristida congesta*) and Sand Quick (*Schmidtia pappophoroides*; van Oudtshoorn 1999).

The most common economic uses for the vegetation in this area are game and cattle farming, ecotourism and agriculture (citrus, tomatoes; *Solanum lycopersicum* and maize; *Zea mays*) along the Limpopo River (Nel & Nel 2009).

5. FAUNA

The study area is an area rich in species diversity for three of the four terrestrial vertebrate classes, Reptilia, Aves and Mammalia (Branch 1998, Hockey *et al*. 2005, Skinner & Chimimba 2005). With 480 species, Southern Africa is considered to have the highest reptile diversity in Africa (Branch 1998) and 25% of these reptile species occur in the GMTFCA. Of the 858 species of birds that occur in South Africa (Clements *et al.* 2012), at least 50% of them are found in the GMTFCA (Hockey *et al.* 2005), as are at least 32% of South Africa's mammals (Skinner & Chimimba 2005); only two of the 28 medium to large mammal species which could potentially occur in the area fall into the IUCN's red data category. These are the black rhinoceros (*Diceros bicornis)* which is globally rated as 'critically endangered', and the African wild dog (*Lycaon pictus)* which is globally rated as 'endangered'. By contrast, of the 115 species of amphibian that occur in South Africa (Carruthers & du Preez 2011), only 10% have been accounted for in the GMTFCA (Braack 2009).

Data from three different legislation categories (National Forest Act 1998; Limpopo Environmental Management Act 2003; Threatened or Protected Species Act 2007) and the IUCN red data list (Friedman & Daly 2004) state that of the vertebrate species occurring in the area, six are considered 'endangered', 12 are 'vulnerable', and 11 are protected species.

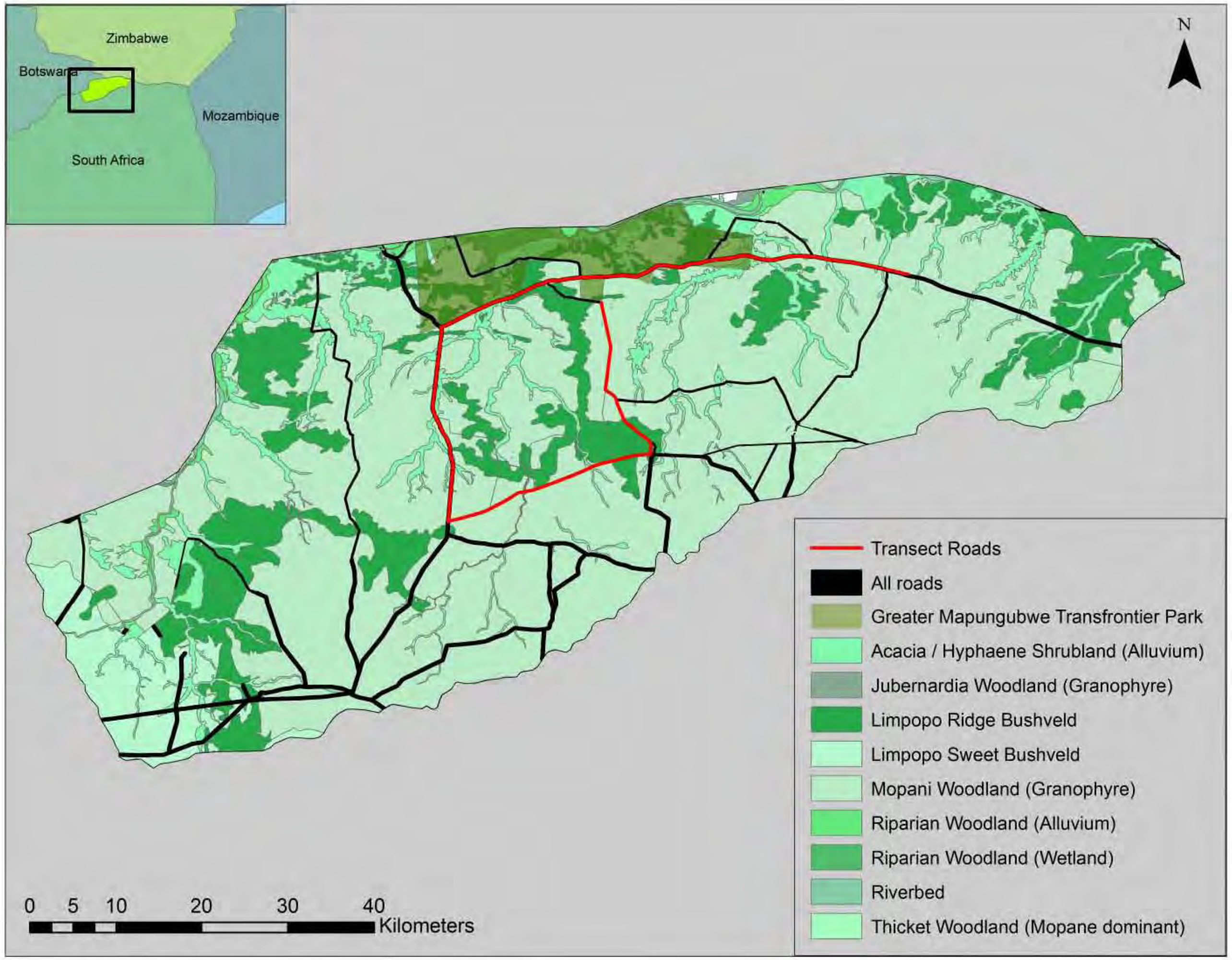

Figure 2.7: A vegetation map of the GMTFCA. The paved and unpaved roads of the study are highlighted in red. GIS data source: GeoNetwork (2000); Peace Parks Foundation (2010). (ArcGIS 9.3; map units: decimal degrees; not projected).

6. SITE DESCRIPTION

Paterson (1987) defines paved roads as engineered structures whilst unpaved roads are more primitive and usually follow existing tracks. I have used the definition of road surfaces as described by Paterson (1987) and will refer to the two road surfaces as either paved or unpaved.

The paved road (Figure 2.8a) in the study area consists of an asphalt surface laid on a gravel base and comprises sections of the R572, R521 regional highways and an unnamed paved road (southern paved road), which was constructed by De Beers Consolidated Mines (DBCM) in the 1990s. The unpaved road (Figure 2.8b) is a 'sandy' surface which overlays the soil group, Arenosol (Batjes 1995; FAO ISRIC 2003) and is a section of the Nieuwelust District Road, which forms the eastern boundary of the Venetia Limpopo Nature Reserve and divides the reserve from private farms to the East.

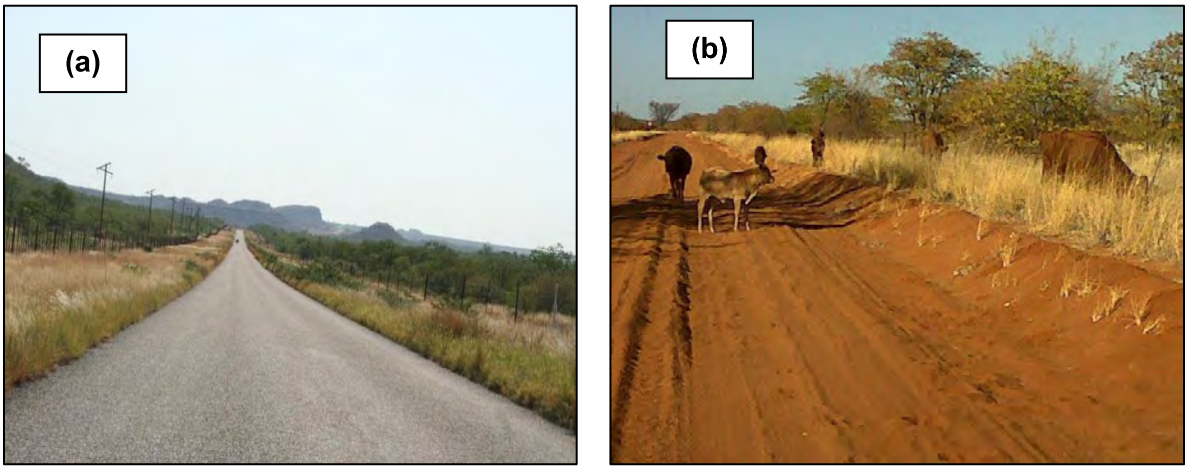

Figure 2.8: Photographs showing examples of the (a) paved road surface and (b) unpaved road surface.

Both roads are single-lane roads with an average width of 6 m (minimum width 4 m / maximum width 8 m). There are no road markings on the unpaved road and markings on the paved road are intermittent, with not all sections having a central dividing line or verge markings. Many sections of the paved R521 were in a poor state of repair with large potholes. Consequently, repairs were regularly conducted to the road surface and speed restrictions imposed.

The roads are bordered on either side by fences which consist of electric, game, cattle, or cattle/electric combined (Figure 2.9).

Two properties are fenced by electric fencing which comprise 29% of the study area on the paved and unpaved roads; Mapungubwe National Park (SANParks), and Venetia Limpopo Nature Reserve (VLNR). There is currently no formal national guideline pertaining to the design of electrified game fences in South Africa. There are, however, a number of documents, which outline proposed minimum requirements for the efficient containment of game species (Beck 2010). The electric fencing conforms to the South African Bureau of Standards (SABS 2012; SANParks 2012) and is described as an ‘electrified predator-proof big game fence’. It measures 2.4 m in height, has 23 strands of high strain steel wire, with four live wire strands installed at 300 mm, 800 mm, 1400 mm and 2300 mm above ground level (inside) and 300 mm above ground level on the outside with two live/earth offset brackets (SABS 2012). The output voltage is 7000 volts. A 3 km section of electric fencing in the north-western corner of the VLNR has been supplemented with a Bonnox (Bonnox 1962) or diamond mesh apron and a low-level live strand set between 50 mm and 100 mm above the ground, known as a tripwire (Beck 2010). No electric tripwire is present on the SANParks and the rest of the VLNR as these wires have been shown to cause most of the electric fence induced mortalities (Beck 2010). Where possible, and in problem areas, rock packing along the base of the fence had been carried out to prevent warthogs (*Phacochoerus africanus*) from digging beneath fences and opening up holes (Davies-Mostert 2009). Herbicide applications controlled herbaceous vegetation on either side of the fence and were sprayed 500 mm on either side of the fence during the study (SANParks 2012).

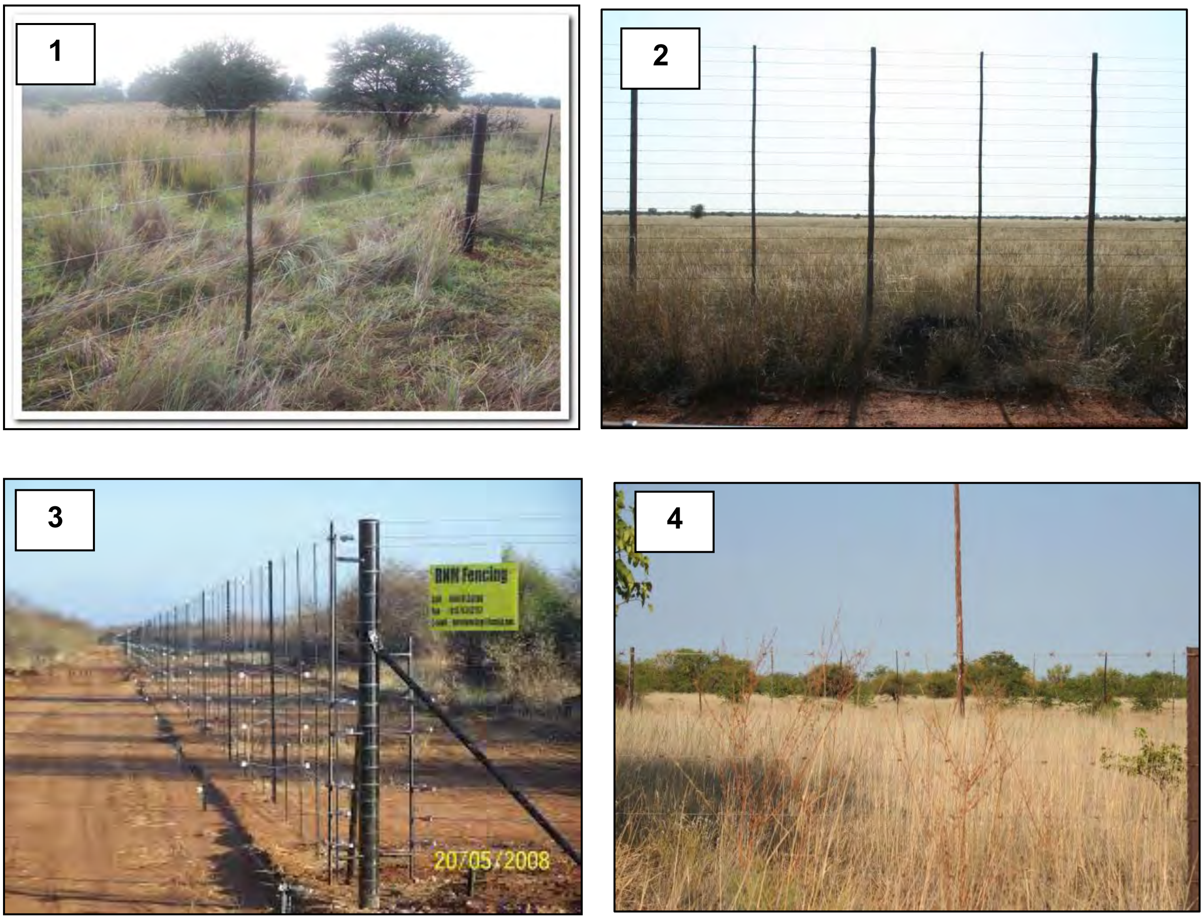

Figure 2.9: Photographs representing the four different fence types (1) cattle (C), 2), game (G), (3), electric (E), (4), cattle/electric combined (CE) along the transect roads in the GMTFCA, South Africa.

Game fencing was found along 50% of the paved and unpaved roads in the study area and was also 2.4 m high with 19 wire strands (BNM 2012); cattle fencing was found along 19% of the transect distance and varied between three and six strands and was ~1.2 m in height. The cattle/electric fence combined consisted of a cattle fence ~one metre from the road verge and an electric fence ~20 m further away (which enclosed private land). This combination was not encountered very regularly (2% of total transect distance).

CHAPTER 3

DETECTING FLATTENED FAUNA: designing a standardised protocol for the detection of roadkill

"As a killer of men, the automobile is more deadly than typhoid fever and runs a close second to influenza…….. not only is the mortality among human beings high, but the death-dealing qualities of the motor car are making serious inroads on our native mammals, birds and other forms of animal life."

Stoner (1925)

1 INTRODUCTION

Roads have been recognised as a threat to biodiversity for almost 100 years (Stoner 1925) in North America and Europe (e.g. Dodd *et al.* 2004; Antworth *et al.* 2005). However, there is a paucity of data available for road ecology in Africa and only four of these studies focus on roadkill in South Africa (Siegfried 1965; Eloff & van Niekerk 2005, 2008; Bullock *et al.* 2011). Much data for human-road-casualties are available in South Africa (Craighead *et al.* 2001; Botha 2005) with wildlife often viewed as a contributor to traffic accidents as opposed to roads being a threat to wildlife (Conover *et al.* 1995). There is therefore little known about the impacts of roads on South African wildlife (Eloff & van Niekerk 2005). Africa is the third most biologically diverse country on Earth (Bartels & Kotze 2006; IUCN Red List 2012) with populations of many vertebrate species coming under increasing pressure from human development (Dodd & Smith 2003). The demand for quick, resourceful methods of recognising the latent threat caused by roads is becoming more urgent (Erritzøe *et al.* 2003).

A search on Google Scholar using the words 'vertebrate roadkill surveys' revealed 1,450 results and the first 10 pages were reviewed. From 62 peer-reviewed studies that involved roadkill surveys (Table 3.1), the majority of the roadkill studies took place in North America (38%) with 33% in Europe, 11% in South America, 7% in Australia/New Zealand and 7% in Southern Africa. Three studies were from other countries.

The majority of the roadkill assessment studies (83%) were conducted between 2000 and the present day with only 10% being conducted between 1980–1999. Consequently, studies that document roadkill as a threat to biodiversity have increased in the last decade.

Roadkill studies in Europe and North America have demonstrated that there is more global interest for roadkill outside of South Africa (e.g. Seiler *et al.* 2004; Sutherland *et al.* 2010) even though all indications suggest that roadkill could have significant impacts on terrestrial diversity (Bartels & Kotze 2006). However, the methodology of previous assessments of wildlife road traffic accidents are not directly comparable as there is, at present, a lack of effective methodologies (Evink 2002; Erritzøe *et al.* 2003) and no standardised protocol for the collection of data on wildlife that have been killed on roads (Erritzøe *et al*. 2003; Barthelmess & Brooks 2010; Bager & da Rosa 2011). Consequently, there are no international or national comparative statistics documenting roadkill (Shyama Prasad Rao & Saptha Girish 2007). Santos *et al.* (2011) suggested that existing studies rely primarily on estimates of wildlife road mortality which are often based on a particular sampling scheme designed for a particular species. This raises questions about the accuracy and utility of such studies for comparative purposes due to variations in the protocol used. A number of studies state a pressing need to develop methods to investigate the factors influencing the location of roadkill for a wide variety of species (Erritzøe *et al*. 2003; Ford & Fahrig 2007; Kolowski & Nielson 2008). Thus, there is a need for a standardised protocol to assess the impact and frequency of roadkill on biodiversity in South Africa.

This chapter examines the existing methods used globally for the study of roadkill and incorporates them into the design of a standardised protocol to detect roadkill rates. Components from the methods of existing studies were selected to devise four hypotheses for sampling roadkill. These included (and are described in detail below);

1 The detection probability of roadkill decreases at higher speeds.

2 Driving later in the day (i.e. after sunrise) rather than earlier (i.e. sunrise) increases the detection probability of roadkill.

3 Increasing the number of observers increases the detection probability of roadkill.

4 The detection probability of roadkill increases as replication and distance travelled increases.

The mean speed of 28 of the 62 peer-reviewed roadkill detection studies was 53 $km.h^{-1}$. I therefore predicted that to drive faster than this speed would mean that the detection probability of roadkill would decrease (Taylor & Goldingay 2004). I tested eight different speeds (20, 30, 40, 50, 60, 70, 80 and 100 $km.h^{-1}$) at which to detect roadkill. I also predicted that the detection probability will be influenced by the position of the sun in relation to the observer. Despite a low sun angle improving contrast between light and shade (Stander 1998), the low sun angles at sunrise/sunset may shine directly into an observer's eyes if driving towards the sun, or into sideview and rearview mirrors when driving away from the sun (sun blinding; Haby 2012) and therefore reduce visibility. Thus, driving later in the day (after sunrise) will likely increase the detection probability of roadkill.

I predicted that the number of observers used would influence the detection probability of roadkill, and that more observers will lead to higher rates of detection. Therefore, a minimum of two people should be present in the vehicle. Safety to other road users as well as increased detections would suggest that two observers are better than one, and to drive and observe at the same time, may result in missed roadkill due to focusing on driving. However, it may be more cost effective to have a single person (as driver and observer; Adams & Geis 1983; Ramp *et al.* 2005).

Detection probability would increase with replication and distance travelled. These two parameters would also increase the number of species detected and localities of higher frequency (Clevenger *et al.* 2003; Litvaitis & Tash 2008). However, excessive replication and distances may result in driver fatigue (Dukette & Cornish 2009).

AIM

The aim of this chapter was to establish a means to rapidly and effectively assess the frequency of roadkill on biodiversity in South Africa.

OBJECTIVE

- *To develop a standardised protocol for collecting data on roadkill in South Africa.*

2 MATERIALS AND METHODS

2.1 A review of previous studies and methods

The 62 peer-reviewed studies that involved roadkill surveys (Appendix A) were reviewed to compare previously employed techniques of detecting roadkill and their characteristics; these included speed driven, time of day when transects were driven, the number of observers used, sampling distance and the frequency of sampling (Appendix A). Of the 62 previous roadkill assessment studies, only 45% provided the speed at which the transect was driven, 31% stated how many observers were used, and 32% stated the time of the day that the transects were conducted. Whilst all studies provided information on sampling frequency and distance, there was little explanation as to how the technique evolved (Appendix A).

Surveys were conducted on various road types, from highways to unpaved roads (Appendix A). However, terminological inconsistencies between studies complicate any comprehensive review of techniques. For example, some studies referred to major roads as highways, whilst others used the term ‘motorway’ or ‘freeway’. The same was true for unpaved, gravel and dirt roads. The assumption is that these definitions all mean the same road type, but the terminology varies from country to country. To avoid misinterpretation of the definitions, I have used the road terminology ‘paved’ and ‘unpaved’ (see chapter 2), with paved roads split into a further two categories, ‘major’ and ‘other’. Sixty-one per cent of the surveys were conducted on major roads (i.e. highways/freeways/motorways) and 30% on ‘other’ paved roads (i.e. national/tarmac/secondary roads). The remaining 9% were conducted on unpaved roads (i.e. gravel and dirt).

For this review, only vertebrate roadkill studies were examined (Appendix A). The most studied taxa were mammals (48%) followed by birds (16%), reptiles (8%) and amphibians (5%). The remaining studies were less species-specific (23%) and examined a combination of vertebrate taxa.

Different speeds were driven depending on the taxon of interest and road transects were conducted at several different times of the day (Table 3.1; Appendix A). The average speed (of 28 of the 62 peer-reviewed roadkill detection studies) was 53 $km.h^{-1}$ (range 15–100 $km.h^{-1}$). However, 34 of the 62 studies did not provide details of the speed driven. In addition, the majority of the studies (67%) did not specify the time of day when sampling commenced. However, 14% specified that data were collected during daylight hours and 3% that transects were conducted during the night.

Some of the studies (19%) used two observers for conducting transects, while 9% used just one observer (Table 3.1; Appendix A). Very few of the studies (3%) used a combination of both one and two observers. However, 69% of the studies did not state how many observers were used to collect data.

The frequency of sampling varied considerably amongst the studies from driving daily, to weekly, to monthly, whilst different transect lengths (km) were also selected ranging from 0.6 km to 223 km (Table 3.1; Appendix A). The mean sampling distance was 104.2 km (n=38) whilst the median sampling distance was 41 km (n=38). The time spent sampling ranged from one month to fourteen years (Table 3.1; Appendix A), with the median frequency being 24 months (n=47). However, whilst the length of the study was usually documented, it was not always clear how often data were collected during that period.

Other methods used to assist with the collection of roadkill data involved; on-foot surveys to sample the road verges in the event that an animal had either crawled off the road and died or if the impact with the vehicle had thrown the roadkill off the road (n=5); assistance from volunteers or work crews to record data; animal-vehicle-collision (AVC) data taken from insurance company reports (n=9); video surveillance, and opportunistic surveys (Appendix A).

Table 3.1: A summary of the 62 peer-reviewed studies showing the mean and median speeds driven, the number of observers used, the sampling frequency, the mean sampling distance, and the number of transects driven (taken from a search on Google Scholar using the words ‘vertebrate roadkill surveys’).

Technique	n of 62 studies	Mean/median
Mean speed ($km.h^{-1}$)	28	53
Median speed ($km.h^{-1}$)	28	51
Mean/median observers	21	2
Mean sampling frequency (months)	47	29
Median sampling frequency (months)	47	24
Mean sampling distance (km)	38	104.2
Median sampling distance (km)	38	41
Mean number of transects	42	4
Median number of transects	42	2

2.2 Experimental methods

2.2.1 Speed trials

Speed trials were implemented to assess the optimum speed at which to detect roadkill. Twenty artificial roadkill were fabricated from squares of painted rubber sprinkled with sand and gravel to resemble flattened carcasses (Figure 3.1).

Using the international paper size standard, ISO 216 (Kuhn 2006), two sizes, one of A5 (148 mm x 210 mm) and the other of A7 (74 mm x 105 mm) were used. A5 was judged to be similar to a large bird roadkill (e.g. Spurfowl; *Pternistes swainsonii*) whilst A7 was judged to be similar in size to a rodent roadkill (e.g. Bushveld gerbil; *Tatera leucogaster*). These were termed ‘large’ and ‘small’ and there were 10 replicates of each.

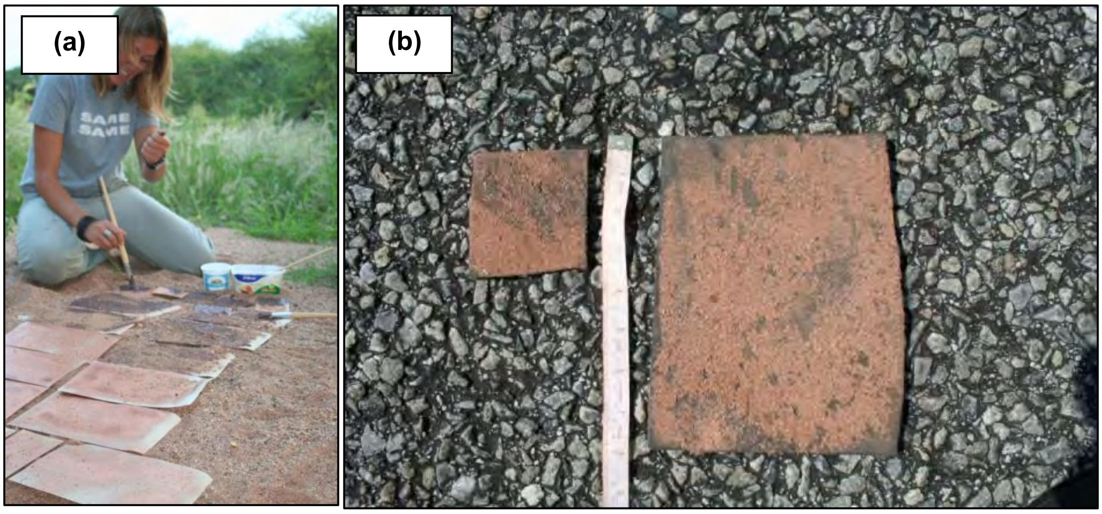

Figure 3.1: Photographs to demonstrate the stages of creating the artificial roadkill (a) preparing the artificial roadkill using sand, gravel, glue and paint to create a mottled surface, (b) final artificial roadkill product, showing ‘small’ and ‘large’ examples.

Artificial roadkill were deployed along a 1 km stretch of straight paved road and the road width was separated into seven zones, each being one metre apart (Figure 3.2). Zone 0 started at the left-hand verge edge (in relation to the driving direction), with Zone 3 being the centre of the road, and Zone 6 being the right-hand verge edge. Road width was, on average, 6 m, from verge to verge (Table 3.2; Figure 3.2).

Table 3.2 Artificial roadkill zones, with each zone measuring 1 m in width. Road width was, on average, 6 m in total width from verge to verge.

Zone	Position on road	Description	Code
0	Verge	Verge Left	VL
1	1 metre from verge	Middle Verge Left	MVL
2	2 metres from verge	Centre Middle Left	CML
3	Centre of road	Centre	C
4	2 metres from verge	Centre Middle Right	CMR
5	1 metre from verge	Middle Verge Right	MVR
6	Verge	Verge Right	VR

Figure 3.2: A photograph showing the seven positions on the road where the artificial roadkill was placed, with the average width of road (6 m).

Using a random number generator (RNG, Microsoft Office Excel 2010) to determine the position along the 1 km transect and location across the road, large and small roadkill were placed at specified points along the 1 km transect (Figure 3.3). The transect was then driven 15 times at each of the following speeds: 20, 30, 40, 50, 60, 70, 80, and 100 $km.h^{-1}$. These speeds were selected with the minimum speed of 20 $km.h^{-1}$ recorded for transect sampling (Stander 1998) and 60 $km.h^{-1}$ being the maximum speed limit on South African unpaved roads and 120 $km.h^{-1}$ being the maximum for South African national roads (Arrive Alive 2011).These speeds were also based on the speeds driven in other roadkill detection studies (Appendix A). The artificial roadkill were re-positioned after each 1 km trial was driven once.

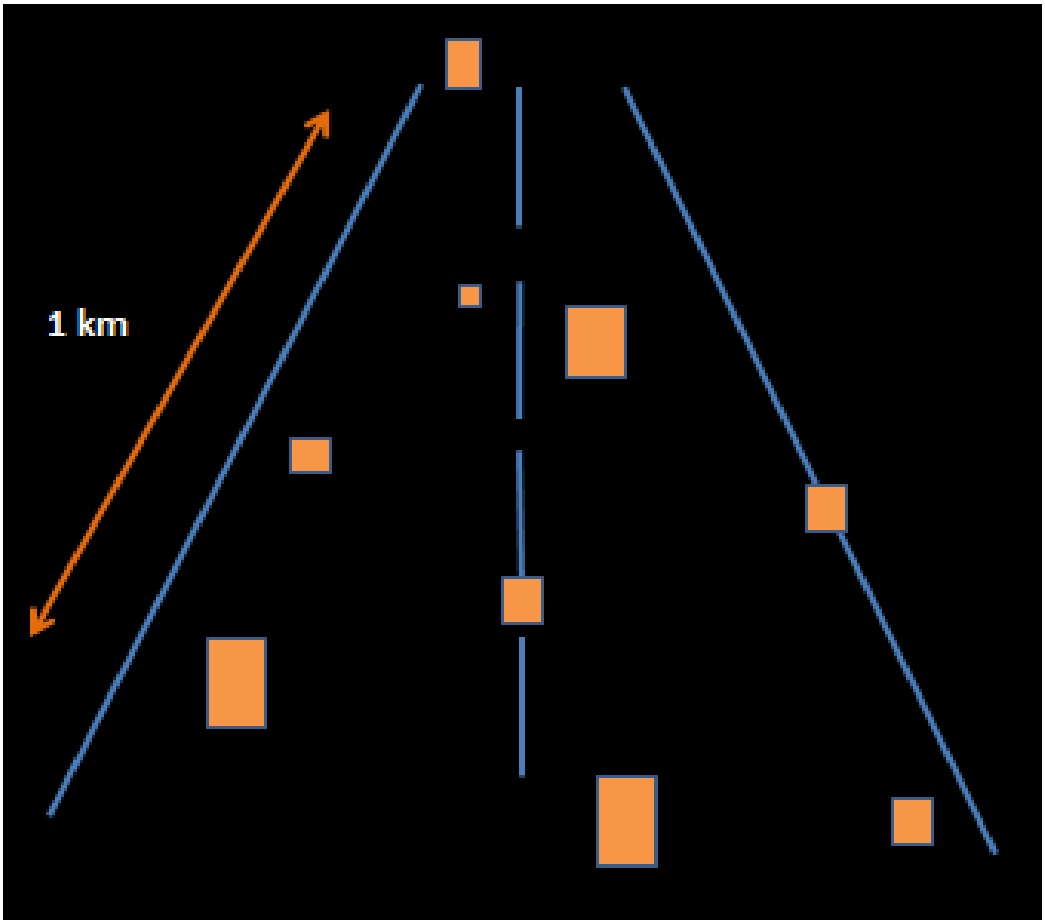

Figure 3.3: A diagrammatic representation of the 1 km stretch of road with random positions of the artificial roadkill in the seven different zones of the road.

Three standard observers (being the same three people) conducted all of the trials, two laid out the course and collected the artificial roadkill each time and the third detected the roadkill. This was conducted fifteen times at each speed with the 'driver-as-the-observer' and fifteen times at each speed with the 'passenger-as-the-observer' to determine any difference in detection ability between observer type (Clevenger *et al.* 2003; Barrientos & Bolonio 2009). Both the driver- and passenger-as-observer were considered 'trained' in the detection of roadkill due to replication of the trials. A third observer type (untrained) completed one trial for three different speeds (20, 60 and 100 km.h^{-1}) as the passenger. This was to allow comparison between trained observer types, with the trained observer expected to detect more roadkill than the untrained. A scribe sat with the observer and recorded either 'large' or ‘small’ when one of the artificial roadkill was detected during each replicate (Table 3.3).

This procedure was repeated on a 1 km stretch of unpaved (gravel) road at speeds of 20, 40, and 60 $km.h^{-1}$. All of the speed trials (paved and unpaved roads) were conducted at different times of the day (dawn to dusk) and driven in two different directions (east-to-west and west-to-east) to assess if light conditions affected detection rates (Table 3.3). A right-hand-drive vehicle was used for the trials with the road driven on the left-hand side of the roadway, according to South African road regulations (Arrive Alive 2011).

Table 3.3: The variables tested during the 1 km speed trials, with speed (km.h^{-1}) as the dependent variable, observer type, artificial roadkill size, light (time of day) and the location of the roadkill on the road as the independent variables. The range of speeds tested for each observer type is given against the independent variables (and their range).

Dependent variable	Observer type	Speed (km.h^{-1}) driven on road type		Independent variable	Range of independent variable
		Paved road	Unpaved road		
Speed (km.h^{-1})	Driver-as-the-observer (trained)	20, 30, 40, 50, 60, 70, 80, 100	20, 40, 60	1. Artificial roadkill size	1. Small and Large
	Passenger-as-the-observer (trained)	20, 30, 40, 50, 60, 70, 80, 100	20, 40, 60	2. Light (time of day)	2. Sunrise to sunset
	Untrained observer	20, 60, 100	20, 60	3. Location	3. Seven zones on the road (verge-to-verge)

2.2.2 Field transects

Field data were collected (using the protocol which resulted from the speed trials described above) during the hot/wet season, which is when vertebrate species are most active and when migratory species were most likely to be present (Branch 1998; Hockey *et al*. 2005; Skinner & Chimimba 2005; Carruthers & du Preez 2011). To assess the optimal distance and frequency of sampling to adequately assess roadkill rates, a 90 km (67 km paved road and 23 km unpaved road) transect was driven each day for a month. This transect was conducted on sections of roads in the Greater Mapungubwe Transfrontier Conservation Area (GMTFCA; Figure 3.4) and consisted of three paved road sections (19.2 km, 23.7 km and 24 km, respectively) and one unpaved road (23.1 km). Two observers (with one of the observers also being the driver) conducted this part of the survey. The transect was driven at speeds of between 40 – 50 km.h^{-1}. The same direction was driven each day, travelling anti-clockwise, and it covered all four cardinal directions.

A photograph, the position on the road, and a GPS reading (using a Garmin eTrex) was taken of each carcass to avoid recounts on consecutive days.

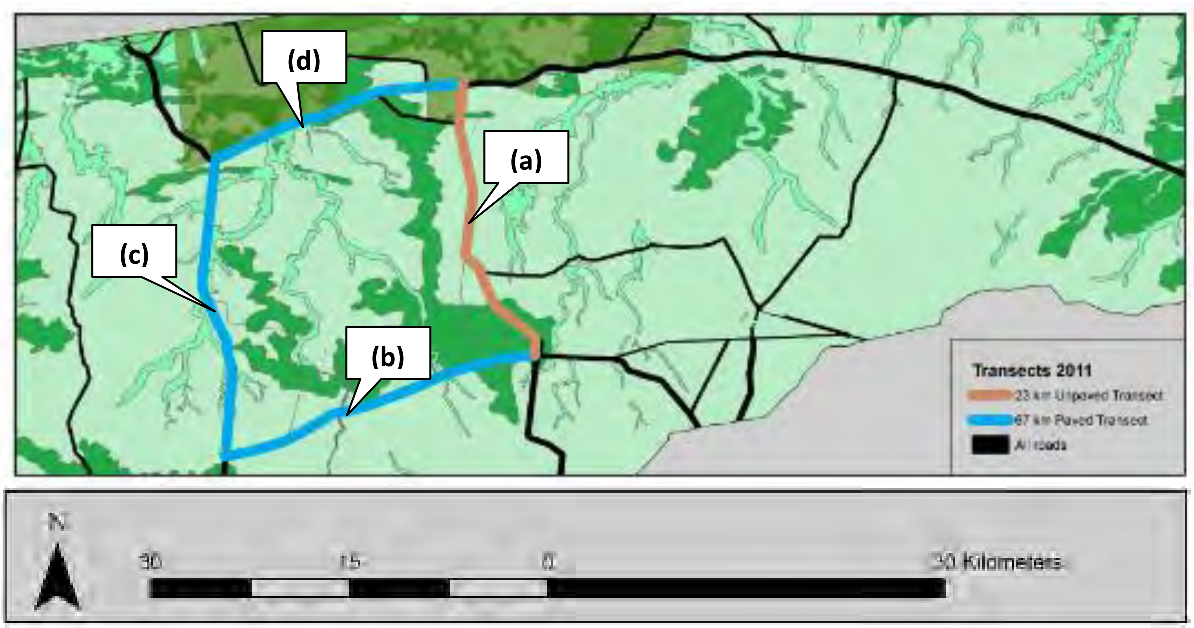

Figure 3.4: Map of the Greater Mapungubwe Transfrontier Conservation Area (GMTFCA) formerly known as the Limpopo/Shashe TFCA depicting roads sampled during the field trials (a) Nieuwelust unpaved road (23.1 km) (b) un-named paved road (24 km) (c) R521 regional road (23.7 km) (d) R572 regional road (19.2 km). GIS data source: GeoNetwork (2000); Peace Parks Foundation (2010). (ArcGIS 9.3; map units: decimal degrees; not projected).

2.3 Statistical procedures

2.3.1 Speed trials (1 km transect)

The difference between the artificial roadkill detected on paved and unpaved roads and the speed driven was tested using a two-way ANOVA (STATISTICA, version 10, 2011) where tests were considered significant at $p < 0.05$ (Fowler *et al*. 2009). Vehicle speed and road surface type were categorical factors and the number of artificial roadkill detected per vehicle speed category as the dependent variable. A Scheffé's post-hoc range test was used to examine differences among means when the p-value ($p < 0.05$) was significant.

Since roadkill-animal body size is likely to interact with vehicle speed and influence detection, this interaction was tested using a two-way ANOVA with vehicle speed and roadkill-animal body size as categorical factors and the number of roadkill detected per vehicle speed category as the dependent variable.

A two-way ANOVA was also used to test whether vehicle speed and three observer types (i.e. the driver as the experienced observer, the passenger as the experienced observer – with the experienced observer being the same person in both these cases - and an untrained observer as a passenger) produced a difference in the number of roadkill detected per vehicle speed category. Two vehicle speeds (20 and 100 $km.h^{-1}$) were used to compare the detection rate of all three observer types. Since using an untrained observer is unlikely, I further compared roadkill detection at a wider range of vehicle speeds by using only the driver as the experienced observer and the passenger as the experienced observer; these speeds were 20, 30, 40, 50, 60, 70 80, and 100 $km.h^{-1}$.

Several vehicle speeds were pooled together to form two categories that compared the influence of direction driven and the position of the sun on detection rate; slow (20-50 $km.h^{-1}$) and fast (60-100 $km.h^{-1}$). A mean value for slow and fast speeds was generated for each category and was tested in a two-way ANOVA with vehicle speed and light as categorical factors. Light relates to the angle of the sun and its impact on visibility whilst driving and was divided into three 'time of day' categories; 'sun in eyes' (driving east up to three hours after dawn/driving west less than three hours before sunset), ‘sun behind’ (driving east more than three hours after dawn/driving west more than three hours before sunset, and ‘sun above’ (driving east/west three hours from dawn/dusk).

A two-way ANOVA was used to assess whether zone (where the artificial roadkill was positioned on the road), and vehicle speed produced a difference in the number of roadkill detected per vehicle speed category with vehicle speed and zone as categorical variables (Table 3.2).

2.3.2 Field transects (90 km transect)

To adequately assess roadkill rates, the optimal distance and frequency of sampling were examined using species accumulation curves for each group of vertebrate taxa (Amphibia, Reptilia, Aves and Mammalia) using EstimateS 8.2 (Colwell 2009). After driving the road transects (90 km) for 30 days, the observed species richness (Mao Tau) (Magurran 2004; Magurran *et al.* 2010) was used to construct species accumulation curves for each taxon (Chazdon *et al.* 1998; Magurran 2004; Magurran *et al.* 2010). Species richness of specific groups can be classified in two ways; the observed species richness (Mao Tau), which represents a simple count of the number of species observed during sampling (Magurran 2010) and true species richness, which refers to the total number of species actually present during sampling (Magurran 2010). Observed species richness is often biased towards the species that are easy to observe (Magurran 2010) and are usually lower than the true species richness as not all species are likely to be sampled (Magurran 2010). As a species detection method, the sampling of roadkill is unlikely to saturate a species accumulation curve because recording roadkill is always going to be biased towards certain species that are predisposed to becoming roadkill (Magurran 2004; Magurran *et al.* 2010; Bager & da Rosa 2011). Nevertheless, adequate sampling was defined as the point when the rate of species accumulation (observed species richness) over 5 sampling intervals fell below 0.10 (Taylor 2007; Parker 2008; Chao *et al.* 2009). This approach was adopted for both the frequency (i.e. number of sampling days required) and transect length (km).

3 RESULTS

3.1 Speed trials

3.1.1 Vehicle speed, road surface type and artificial roadkill size

Artificial roadkill detection was significantly influenced by the vehicle speed travelled ($F_{7,224}$ = 03.55, p <0.05; Figure 3.5) and by the body size of the artificial roadkill on the paved roads ($F_{1,224}$ = 5.7, p <0.05; Figure 3.5). There was no significant interaction between vehicle speed and body size ($F_{7,224}$ = 0.8, p = 0.6; Figure 3.5). The number of artificial roadkill (large and small combined) observed at 100 km.h^{-1} was significantly lower than at 20 km.h^{-1} ($F_{7,\ 232}$ = 3.4, p <0.05; Figure 3.5). Additionally, the number of artificial roadkill observed at 60 km.h^{-1} on the unpaved road was significantly lower than at 20 and 40 km.h^{-1} ($F_{2,87}$ = 7.8, p <0.05; Figure 3. 6).

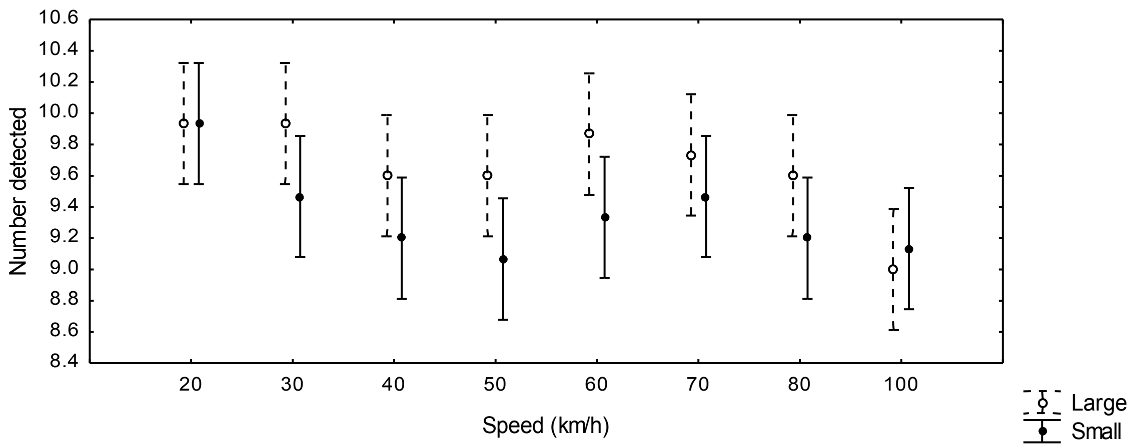

Figure 3.5: The mean (± 95% CI) number of large and small artificial roadkill (see text 2.2.1) detected at eight speeds during experimental testing along a 1 km section of paved road in the GMTFCA, South Africa.

Both vehicle speed and body size had a significant effect on roadkill detection on the unpaved road (speed; $F_{2,84}$ = 10.6, p <0.05; size; $F_{1,\ 84}$ = 32.9, p <0.05; Figure 3.6), although there was no interaction between the two variables ($F_{2,\ 84}$ = 0.1, p = 0.9; Figure 3.6). Artificial roadkill was detected ~20% more at vehicle speeds of between 20 and 40 km.h^{-1} than 60 km.h^{-1} (Figure 3.6).

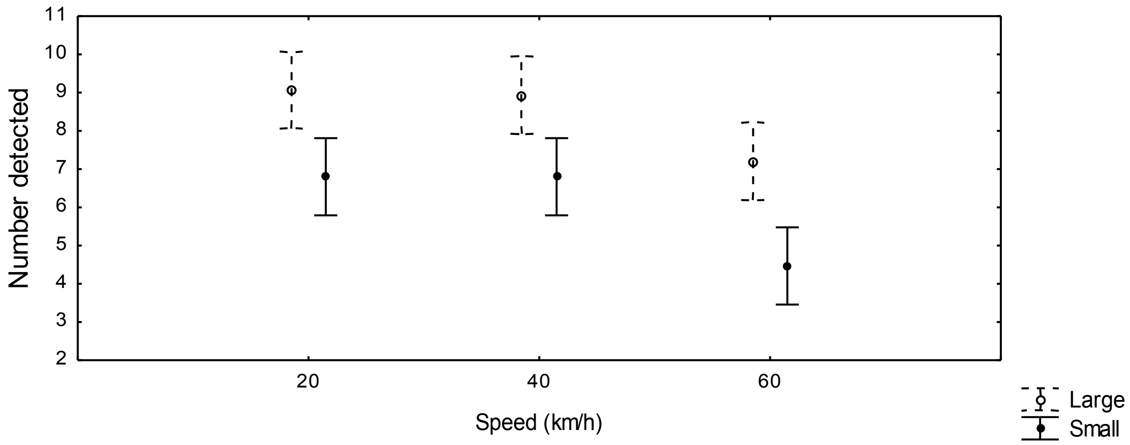

Figure 3.6: The mean (± 95% CI) number of large and small (see text 2.2.1) artificial roadkill detected at three speeds during experimental testing along a 1 km section of unpaved road in the GMTFCA, South Africa.

3.1.2 Vehicle Speed and observer type

Vehicle speed ($F_{1,84}$ = 59.8, p <0.05; Figure 3.7) and observer type ($F_{2,84}$ = 3.8, p <0.05; Figure 3.7) significantly influenced the number of artificial roadkill detected on the paved road. However, there was no significant interaction between the two variables ($F_{2,84}$ = 2.8, p = 0.07). At 20 $km.h^{-1}$, there was no difference in the number of artificial roadkill detected among the three observers (Figure 3.7). However, detection by the untrained observer at 100 $km.h^{-1}$ was significantly lower than that of the experienced observers (Figure 3.7).

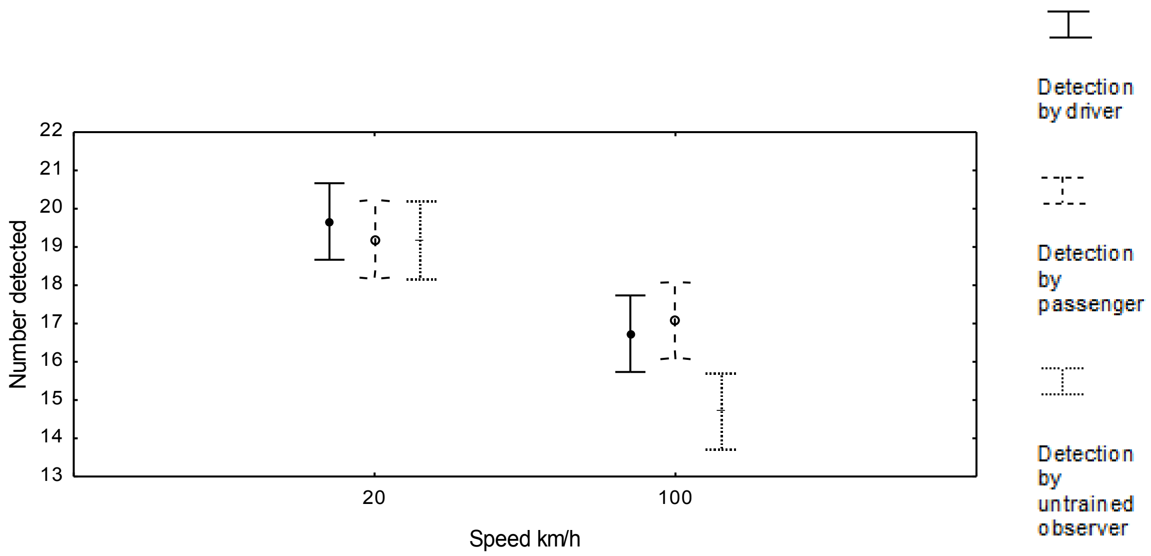

Figure 3.7: The difference between observer experience and detection rates interaction between three categories of observer and roadkill detected at two speeds during experimental testing along a 1 km section of paved road in the GMTFCA, South Africa. Data are means (± 95% CI) for both large and small roadkill (see text 2.2.1).

Significantly fewer artificial roadkill were detected by all observers at 100 km.h^{-1} compared to the number of detections at 20 km.h^{-1} ($F_{1, 84}$ = 59.8, p <0.05; Figure 3.7). There was no significant difference between the number of detections made by the observer/driver and the passenger as the observer ($F_{5,169}$ = 1, p = 0.41; Figure 3.7).

At all vehicle speeds, there was no significant difference in the detections made by the observer whether driving and observing or just observing on the unpaved road ($F_{1,168}$ = 0.49, p = 0.5; Figure 3.8a). However, both observer types (the driver as observer and the passenger as observer) detected significantly fewer artificial roadkill at 100 km.h^{-1} than at slower speeds ($F_{5,168}$ = 14.9, p <0.05; Figure 3.8a). There was no significant interaction between vehicle speed and observer type ($F_{5,168}$ = 1, p = 0.4; Figure 3.8a). However, the untrained observer detected significantly fewer artificial roadkill than the experienced observer at both 20 and 60 km.h^{-1} ($F_{2,27}$ =13, p <0.05; Figure 3.8b).

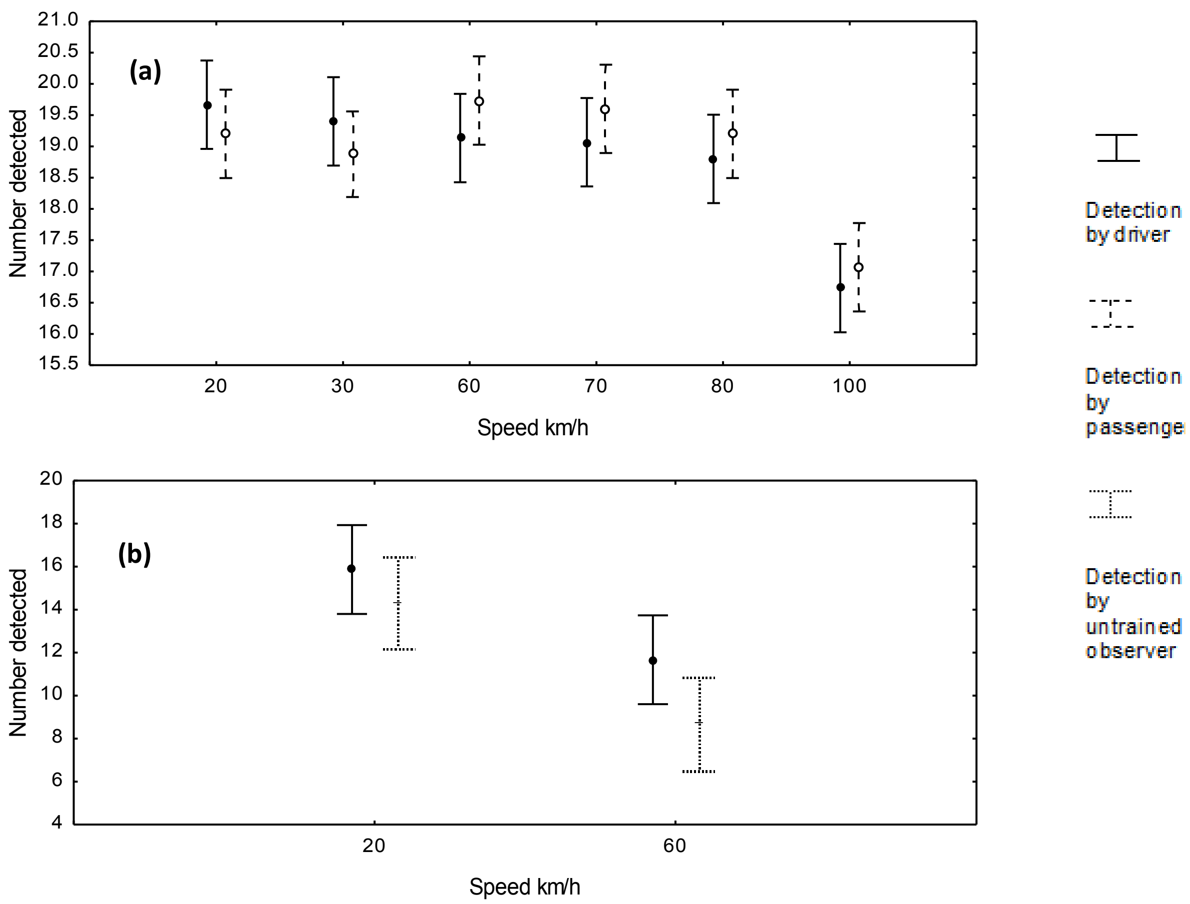

Figure 3.8: Detection rates during experimental testing along a 1 km section of unpaved road in the GMTFCA, South Africa. Data are means (± 95% CI) for both large and small roadkill (see text 2.2.1) (a) the difference between driver and passenger detection rates (at six vehicle speeds) (b) the difference between driver experience (with two different observers) and detection rates at two speeds.

3.1.3 Vehicle speed and light

The position of the sun had no significant effect on the detection of artificial roadkill ($F_{2, 18}$ = 0.7, p = 0.5; Figure 3.9). However, fewer roadkill were missed when the 'sun was above', i.e. driving east/west >1.5 hours from dawn and <1.5 hours from dusk (Figure 3.9).

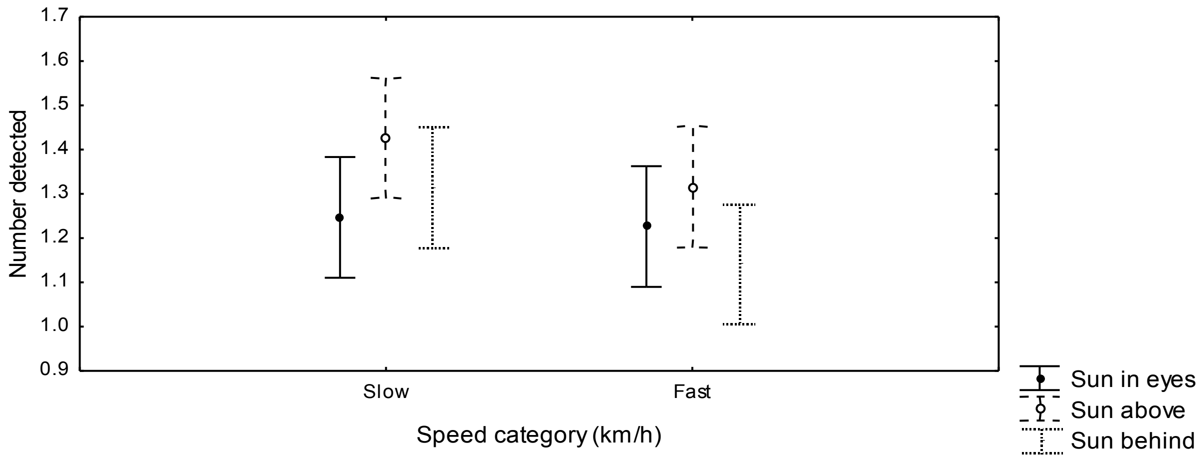

Figure 3.9 The difference between the position of the sun and the mean (± 95% CI) number of large and small (see text 2.2.1) artificial roadkill detected at two pooled speeds (slow: 20-50 $km.h^{-1}$/ fast: 60-100 $km.h^{-1}$) during experimental testing along a 1 km section of paved road in the GMTFCA, South Africa.

3.1.4 Vehicle speed and zone

The detection of artificial roadkill was not affected by its position on the road, irrespective of size (small = $F_{40,\ 2}$ =6.3, p = 0.14; large = $F_{40,\ 2}$ = 6.7, p = 1.4). However, most detection errors were for artificial roadkill positioned on the verges and the far left-hand side of the vehicle (i.e. fewer roadkill were detected in the zone furthest from the driver/observer).

3.2 Speed trials summary

To accurately detect roadkill for all vertebrate taxa across a range of body sizes (~4 cm^2 minimum), the recommendations listed in Table 3.4 were adopted when conducting the field transects (Table 3.4).

Table 3.4: A summary of the results of speed trials conducted on a 1 km section of paved and unpaved road to assess the optimal methods at which to detect roadkill.

Trial	**Recommendation**
Vehicle speed	40-50 km.h^{-1}
Time start	1.5 hours after sunrise
Time stop	1.5 hours before sunset
Number of observers	1 (driver as the observer)
Observer skill level	Trained

3.3 Observer type

The null hypothesis was that all 20 artificial roadkill, both large and small would be detected along the 1 km stretch of road across a variety of speeds. The trial was repeated 15 times across eight different speeds to minimise Type I errors (i.e. missing true effects; Fowler *et al*. 2009). As faster speeds were driven, more mistakes were made in detecting roadkill, with it either being missed or a large roadkill being mistaken for a small, and vice versa. No Type I errors were recorded until 70 km.h^{-1} after which it became difficult for the recorder to accurately note cases of whether a small roadkill should have been a large one. This was possibly due to the close placement of the artificial roadkill over the 1 km stretch. Of roadkill detected between speeds of 70 and 100 km.h^{-1}, 0.5% (n=900) were misidentified as small when in fact they were large roadkill. Type I errors were also more common with the untrained observer who mistakenly identified roadkill size, and counted extra ‘objects’ on the road as roadkill (more than 20/20) at lower speeds than the trained observer. The untrained observer detected an extra 0.6% roadkill when driving at 20 km. This increased to 1.3% extra detections at 50 km.h^{-1}. Therefore, to overcome this, a trained observer was used during field transects, with a speed of less than 50 km.h^{-1}.

3.4 Field transects

A total of 374 individual roadkill were observed during 30 repeated samples of the 90 km transect (total distance = 2,700 km). These comprised 81 species from all terrestrial vertebrate groups. The number of hours spent sampling was 118.7 (daily average = 3. 4; n=30).

3.4.1 Species richness versus number of days driven.

The sampling effort was considered to be adequate (for the number of days driven) when the rate of species accumulation over five sampling intervals fell below 0.10 (Colwell 2009). Whilst 20 days was adequate for amphibian sampling (Table 3.5; Figure 3.10), the sampling frequency would need to be extended to adequately sample the remaining three groups in future surveys.

Table 3.5 Sampling effort over a 30-day period on a 90 km transect (using the Mao Tau method) showing the sampling frequency required for each taxa.

Taxon	Frequency (# of days)
Amphibia	20
Reptilia	>30
Aves	>30
Mammalia	>30

By using the most diverse vertebrate group (Aves), it was calculated that, on average, 1.3 fewer bird species were detected every five days of sampling. Therefore, a further 10 days would be required to ensure adequate sampling of the Aves group in my study area. In the case of future monitoring of all vertebrate roadkill species, it is recommended that a sampling period of 40 days be implemented for future surveys.

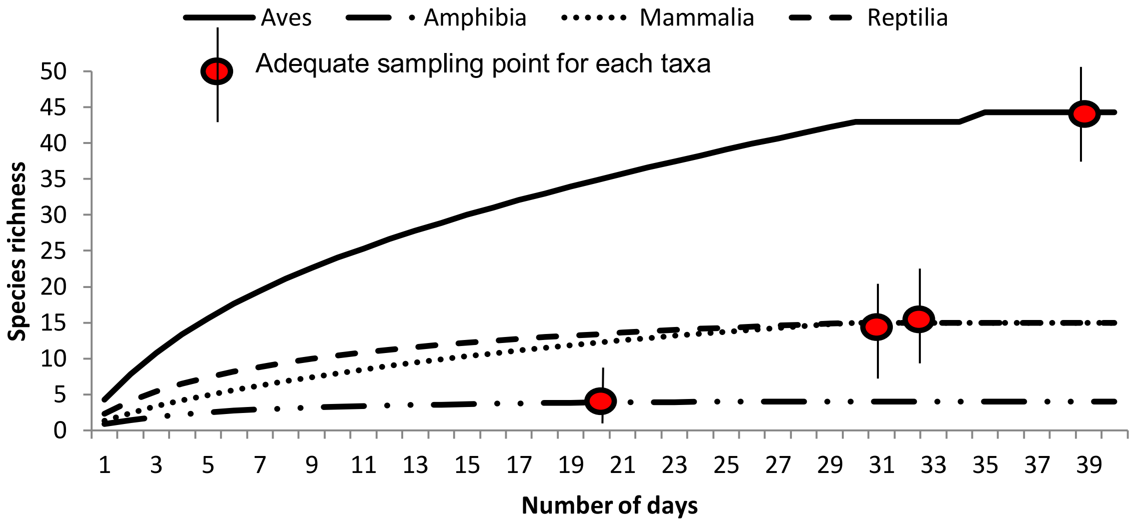

Figure 3.10 Species accumulation curves showing observed species richness (Mao Tau) for each taxon over a 30-day period / 90 km transect. Sampling was deemed adequate at the point where the rate of species accumulation over 5 sampling intervals fell below 0.10.

3.4.2 Species richness versus distance driven

After 30 repeated samples of the 90 km transect on the paved and unpaved roads only three taxa had been adequately sampled (Amphibia, Reptilia and Mammalia; Table 3.6/Figure 3.11) with the Aves group requiring more sampling (i.e. more km).

Table 3.6 Sampling effort over a 30-day period on a 90 km transect (using the Mao Tau method) showing the sampling frequency required for each taxa.

Taxon	Distance (km)
Amphibia	26
Reptilia	88
Aves	>90
Mammalia	89

By using the most diverse vertebrate group (Aves), it was calculated that, on average, 2.2 fewer bird species were detected every five km of sampling. Therefore, a further 10 km (to extend the transect from 90 km to 100 km) would be required to ensure adequate sampling of the Aves in my study area. In the case of monitoring all vertebrate roadkill species, a sampling distance of 100 km in future studies for time and frequency is recommended (Figure 3.11).

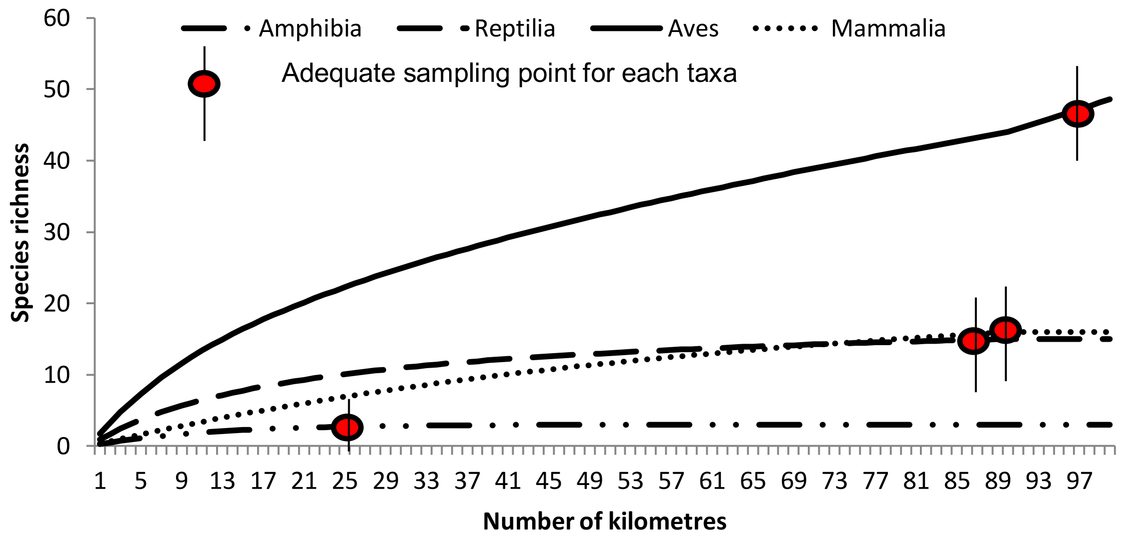

Figure 3.11 Species accumulation curves showing observed species richness (Mao Tau) for each taxon over a 30-day period / 90 km transect. Adequate sampling was defined as the point where the rate of species accumulation over 5 sampling intervals fell below 0.10.

4 DISCUSSION

4.1 Speed trials

4.1.1 Summary of the speed trials

Using vehicle speed trials, the results showed that artificially deployed roadkill was detected most reliably at speeds of between 40 and 50 km.h^{-1}. Despite a second observer possibly being more time effective, there was no significant difference between having one or two observers for roadkill detection in this study. I therefore recommend using one observer as it is likely more cost-effective and demonstrates that detection rates are not significantly affected. Detection rate was influenced by light conditions with detection success greatest when the sun was high. Smaller roadkill on verges were often missed and increased effort by driving at slower speeds (<50 km.h$^{-1)}$ is required to detect roadkill in these positions. The results suggest that roadkill sampling was most effective between 1.5 hours after dawn and 1.5 hours before dusk.

4.1.2 Vehicle speed

Hypothesis: The detection probability of roadkill decreases at higher speeds.

Some studies recommend driving at speeds slower than 30 km.h^{-1} to detect roadkill (Jackson 2003; Gomes *et al.* 2009; Grilo *et al*. 2009; Carvalho & Mira 2011; Santos *et al*. 2011). Others suggest slightly faster (45-55 km.h^{-1}) speeds (Mackinnon *et al*.2005; Barrientos & Bolonio 2009; Bager & da Rosa 2010; da Rosa & Bager 2012; Guinard *et al*. 2012), while others recommend travelling at speeds that are greater than 55 km.h^{-1} (Romin & Dalton 1992; Meunier *et al*. 2000; Antworth *et al*. 2005; Ramp *et al.* 2005; Conrad & Gipson 2006; Barthelmess & Brooks 2010). Whilst it may be considered more desirable to drive at slower speeds for species-specific studies that focus on smaller vertebrate roadkill, this does not always appear to be necessary. Mackinnon *et al*. (2005) drove at speeds of between 40-60 km.h^{-1} for detecting snake and turtle roadkill, and Sutherland *et al.* (2010) drove at speeds of up to 56 km.h^{-1} for the detection of amphibian roadkill. Brockie *et al*. (2009) drove at a speed between 50-100 km.h^{-1} but concluded that counts were limited to animals of at least 'rat size'. A possible explanation is that higher speeds were driven to cover greater distances and a larger sample area. The effectiveness of these speeds is difficult to determine since the data represents the counting of carcasses, and lacks any analysis of the method (Erritzøe *et al.* 2003). Thus, high roadkill detection rates may not be as important for determining the speed travelled during roadkill assessments. In fact, other factors, such as driver safety, may be more important when determining the most appropriate speed to travel. Clevenger *et al.* (2003) recommended driving at a speed of 10-20 km.h^{-1} below the posted speed limit for the safety of other drivers.

In my study, artificially deployed roadkill was most reliably detected at speeds of up to 50 km.h^{-1}, with detection rate decreasing at faster speeds. Previous studies which have focused on small to medium-sized mammals (less than 10.0 kg) such as rabbits (*Oryctolagus cuniculus;* Barrientos & Bolonio 2009), polecats (*Mustela putorius;* Barrientos & Bolonio 2009) and snakes (*Lampropeltis triangulum;* Mackinnon *et al.* 2005) employed similar speeds during their roadkill assessments. By contrast, the studies that quantified the prevalence of larger species such as mule deer (*Odocoileus hemionus;* Romin & Dalton 1992), raptors (Meunier *et al.* 2000) and medium-sized mammals (1.0-10.0 kg; Barthelmess & Brooks 2010) travelled at higher speeds (60-72 km.h^{-1}). This suggests that the larger the target species, the faster one may drive.

Ultimately there will be a trade-off between the speed driven and the distance sampled. The faster a transect is driven (more than 40-50 km.h^{-1}), the more ground can be covered. This may be more suitable when needing to travel greater distances, but the detection rates may not be as accurate since smaller species are more likely to be missed (<10.0 kg; Barrientos & Bolonio 2009). Driving slower than 40-50 km.h^{-1} may increase the detection rate but reduce the sampling distance. For example, Carvalho & Mira (2011) drove at a speed of 20 km.h^{-1} over a distance of 26 km when collecting roadkill data for the four vertebrate taxa (Amphibia, Reptilia, Aves and Mammalia). However, Bager & da Rosa (2011) drove at a higher speed (50 km.h^{-1}) and covered a greater distance (117 km) for the detection of all vertebrate roadkill. Faster speeds (>50 km.h^{-1}) may be applicable for quantifying larger-bodied species-specific road mortalities (e.g. Moose *Alces alces*; Haikonen &

Summala 2001). However, roadkill surveys for specific rare or endangered species that are small in size (e.g. Western Leopard Toad *Amietophrynus pantherinus)* may need to consider speeds less than the recommended 50 $km.h^{-1}$ since maximum detection of endangered species may be more critical to determine the roadkill rates.

It is difficult to compare many sampling methods as some mention the sampling distance but not the speed (e.g. Caro *et al*. 2000; Bright *et al.* 2005), whilst others mention neither (e.g. Mohammadi *et al*. 2011; Santos *et al*. 2011).

Although my detection rates remained high at faster speeds, driving faster is not recommended due to the risks involved in having to stop and possibly reverse to the site to identify the carcass. Also, the recommended speed may not be consistent with conditions on the survey road, especially if there is a set speed limit or high traffic volumes which may endanger other drivers (Clevenger *et al.* 2003). My results demonstrate that detection rates decrease significantly at speeds faster than 50 $km.h^{-1}$ and therefore this protocol recommends that, where possible, a maximum speed of 50 $km.h^{-1}$ be driven to obtain cost and time-effective data.

4.1.3 Position of the artificial roadkill on the road and detection

Although not significant, roadkill detection rate during the speed trials was influenced by the position of roadkill on the road (i.e. roadkill on verges were often missed). Increased effort is required to detect roadkill on road verges, particularly on the driver's 'blindside'. Santos *et al*. (2011) suggested that the most accurate method of sampling roadkill was to sample 'on foot'. Similarly, Slater (2002) detected five times more roadkill when walking compared to driving. However, this is more time consuming, resulting in shorter overall sampling distances being covered. By contrast, Hels & Buchwald (2001) stated that monitoring amphibian roadkill by foot was surprisingly inefficient with variations in reporting that ranged from 7 to 67% of roadkill detected. However, Guinard *et al*. (2012) noted that roadkill surveys by vehicle were as efficient as surveys by foot although less efficient for carcasses on verges. Therefore it is recommended that roadkill transects be conducted by vehicle with further study conducted on-foot to look for roadkill that may have gone undetected or to target specific locations where small-bodied species (e.g. Western Leopard Toad *Amietophrynus pantherinus)* may occur.

4.1.4 Number of observers

Hypothesis: Increasing the number of observers increases the detection probability of roadkill.

This study is the first to formally quantify the effect number of observers have on rates of detection. Whilst it would be beneficial to have as many observers as possible for detecting roadkill, it is not always practical or within the budget of a project. Many of the reviewed studies did not state the number of observers used (e.g. Case 1978; Sanz 2001; Serrano *et al*. 2002; Antworth *et al.* 2005; Bullock *et al*. 2011), and of those that did, the majority opted for two people in the vehicle (one as the driver and the other as the observer; Clevenger *et al*. 2003; Russell *et al*. 2009). There was no significant difference between one or two observers for roadkill detection in my study, and it is likely more cost effective to have one person (with the driver also being the observer). Of 62 roadkill studies reviewed, only five stated that one person was in the vehicle. Comparing the speed driven in these five studies to this study, shows that two drove at a slower speed (30 $km.h^{-1}$; Gomes *et al.* 2009; Grilo *et al.* 2009), one drove at a faster speed (60 $km.h^{-1}$; Ramp *et al.* 2005), two did not mention the speed (Adams & Geis 1983; Ciesiolkiewicz *et al.* 2006). Apart from Ciesiolkiewicz *et al.* (2006), who sampled smaller taxa (i.e. snakes), the other studies all sampled species that were larger in size (i.e. ≥5 kg; owls (Strigiformes), carnivores, and mammals) and were therefore more likely to be visible at faster speeds.

Because the majority of roadkill studies do not mention the number of observers used (e.g. Saeki & MacDonald 2004; Markolt *et al*. 2012), comparison with my study is limited. The assumption, in some cases, is that there was more than one person present (e.g. Case 1978; Smit & Meijer 1999) since some of the roadkill surveys were conducted by road service crews. Guinard *et al.* (2012) used the same two people when conducting their roadkill transects, but it was unclear from some of the other studies whether it was always the same observers (e.g. Coelho *et al.* 2008;

Quintero-Angel *et al*. 2012). There was a significant difference between having a trained and an untrained observer in my study. The untrained observer failed to detect more artificial roadkill than the trained observer, which suggests that for roadkill data collection to be consistent, the observer should always be the same person.

4.1.5 Light conditions

Hypothesis: Driving later in the day (i.e. after sunrise) rather than earlier (i.e. sunrise) increases the detection probability of roadkill.

Although not significant, roadkill detection success tended to be greater when the sun was high. This suggests that roadkill sampling is most effective between 1.5 hours after dawn and 1.5 hours before dusk.

Stander (1998) recommends performing transects at dawn when conducting spoor count surveys. This is due to the angle of light which creates shadow on a concave shape in the earth. When there are no shadows, the chance of detecting spoor decreases due to the reduction in contrast between light and shade. In contrast, roadkill is a convex shape on the ground, and visibility of the roadkill is less easy due to early or late sunlight shadow (pers.obs.) with the low sun angles at sunrise/sunset (i.e. sun blinding; Haby 2012) also reducing visibility. The location of the sun in the sky affects light penetration, with the best light levels occurring around noon (Rossier 2012). The further the sun sinks on the horizon, the smaller its angle of incidence and the worse the visibility for contrasting shapes (i.e. the convex shape of a roadkill against a flat road surface) (Rossier 2012).

Nine roadkill studies conducted their transects at dawn (Hels & Buchwald 2000; Meunier *et al*. 2000; Slater 2002; Clevenger *et al.* 2003; Ciesiolkiewicz *et al*. 2006; Russell *et al.* 2009; Seshadri *et al.* 2009; Barthelmess & Brooks 2010; da Rosa & Bager 2012). Meunier *et al.* (2000) adopted an *ad hoc* process of conducting a roadkill assessment of raptors, and started transects 1-2 hours after dawn but did not state why this time was selected. Clevenger *et al.* (2003) and Barthelmess & Brooks (2010) also conducted dawn surveys but made no reference in their study as to why they had selected this time. Reasons for starting roadkill surveys as early in the day as possible may be because traffic volumes are usually lower at dawn due to general working hours (pers.obs.). Consequently, there is likely to be less damage to and/or removal of the roadkill carcasses. With fewer vehicles on the road, it is likely to be safer for the observers to be stopping/starting during their transects (Clevenger *et al.* 2003).

There is little data to support reasons for selecting the time of day for roadkill transects (Clevenger *et al.* 2003; Erritzøe *et al.* 2003; Mackinnon *et al.* 2005; Ramp *et al.* 2005). Consequently, it would appear that there is no single ‘best fit’ recommended method to detect multi-vertebrate roadkill surveys. However, the timing of some species-specific transect sampling seem to be based on the activity budgets of the target species, rather than because of the angle of the sun. For example, Jackson (2003) surveyed at night to examine the impact of roads on nightjars (Caprimulgidae) which are nocturnal, and Russell *et al*. (2009) surveyed at dawn and dusk when surveying a number of bat species. By comparison, Hels & Buchwald (2000) started sampling amphibian roadkill at dawn as they believed that this would minimise the removal of carcasses by daytime scavengers.

Whilst data in my study did not show any significant differences in the time of day selected for surveying, there were fewer detection errors when the sun was higher. Therefore, multi-species roadkill sampling should ideally be conducted between 1.5 hours after dawn and 1.5 hours before dusk.

4.2 Field trials

Hypothesis: The detection probability of roadkill increases as replication and distance travelled increases.

4.2.1 Sampling frequency

Whilst many of the studies state the time length of the study, for example, one year (Seiler *et al.* 2004), and two time periods, nine years apart (Carvalho & Mira 2011), it was not always clear how the sampling frequency within the time frame had been selected (Erritzøe *et al.* 2003). For example, Ramp *et al*. (2005) sampled mammal roadkill ‘on a mostly daily basis’ for five years, as opposed to Serrano *et al*. (2002)

who sampled medium to large-sized mammals weekly over two years. Bright *et al.* (2005) conducted monthly mammal surveys based on decomposition estimates of roadkill carcasses and as a result, volunteers were instructed not to repeat journeys within a 30-day period in case carcasses were ‘double-counted’. In contrast, Sutherland *et al.* (2010) sampled daily for two months over two years for amphibians whilst Hels & Buchwald (2000) sampled for seven months over three years (with the assumption that there was daily sampling). Both these sampling periods were when the amphibians they were targeting were most active. Quintero-Angel *et al*. (2012) sampled snake roadkill once every two weeks and this was based on estimates of how long snakes remained on the road after they had been hit by a vehicle.

Of the studies that have sampled all vertebrates and were therefore most similar to mine, some collected daily data (Smit & Meijer 1999; Clevenger *et al* 2003; Ciesiolkiewicz *et al.* 2006; Santos *et al.* 2011), some sampled weekly (Taylor & Goldingay 2004; Barthelmess & Brooks 2010; Bager & da Rosa 2011), some sampled bi-monthly (Barrientos & Bolonio 2009; Carvalho & Mira 2011; Quintero-Angel *et al.* 2012), whilst others sampled monthly (Vestjens 1973; Coelho *et al*. 2008). Bager & da Rosa (2011) who sampled weekly over two years, for vertebrates stated that weekly sampling did not attain sampling sufficiency when all classes were considered together, but was adequate for reptiles and medium-sized mammals. Further sampling to twice a week, showed that birds still had not been adequately sampled (Bager & da Rosa 2011) due to the high richness of bird species in the area. Santos *et al.* (2011) state that based on the higher removal rate of roadkill, surveys of vertebrate roadkill should be conducted daily, even for larger species (>10 kg).

The huge variation in time frames, sampling frequency and consequently fragmentation of the data makes it difficult to assess and therefore to make comparisons between sampling frequencies (Erritzøe *et al.* 2003).The results of my study align with the recommendation of daily sampling to detect all vertebrate roadkill (Bager & da Rosa 2011; Santos *et al.* 2011). The data show that 40 days is adequate to sample all four taxa, with birds being the most diverse group, and therefore requiring the greatest sampling frequency.

4.2.2 Transect length

It is apparent from some roadkill surveys that shorter distances were likely selected for either species specific reasons or because of localised conditions. Hels & Buchwald (2000) sampled a distance of 0.6 km for amphibians, whilst Gerht (2002) conducted a 41.8 km roadkill survey to obtain indices for raccoon (*Procyon lotor*) populations. This formed part of a larger study of monitoring raccoon population demographics that covered an area of 32.39 km^2. Loughry & McDonough (1996) sampled a 5 km stretch of road to measure Armadillo (*Darypus novemcinctus*) roadkill and compared this population with a live population at another site. Further, Snow *et al*. (2011) sampled six segments of road totaling 32.2 km which were sampled 4-7 times per week over 29 months. The study site was on an island measuring approximately 34 km long and 6.5 km wide, which would suggest that the road transect length was selected based on the size of the island. However, the criteria used for selecting the number of sampling days were not clear. In contrast, Haikonen and Summala's (2001) study in Finland examined the impacts of roads on the country's population of Moose (*Alces alces*) and White-tailed deer (*Odocoileus virginianus*), covering all roads and a greater distance (300,000 km^2).

Of the studies that sampled all vertebrates and were therefore most similar to mine, three sampled distances less than 40 km (34 km; Antworth *et al.* 2005; 32 km; Hell *et al*. 2005; 26 km; Carvalho & Mira 2011), two sampled over 100 km (195 km; Coelho *et al.* 2008; 117 km; Bager & da Rosa 2011). Clevenger *et al.* (2003) sampled two transects totalling 248.1 km. Dreyer (1935) and Dickerson (1939) recorded vertebrate roadkill whilst travelling in America and covered distances of 75,000 and 1,500 km respectively. Malo *et al*. (2004) used data collected from a traffic collision database on a 3,253 km stretch of highway over 13 years, whilst Smit & Meijer (1999) used data collected by traffic inspectors on unspecified distances on Dutch highways.

As with sampling frequency, the huge variation in sampling distance of existing methods (e.g. Bager & da Rosa 2011; Carvalho & Mira 2011) made them difficult to compare (Erritzøe *et al.* 2003). My study proposes a sampling distance of 100 km to adequately sample the four vertebrate taxa, with birds being the most diverse group, and therefore requiring the greatest sampling distance. For data to be comparable in future global roadkill detection research, and for surveys sampling all vertebrate taxa, further modelling covering various distances is recommended.

4.3 Implications of the results

None of the 62 peer-reviewed roadkill studies examined all of the variables required to detect roadkill for a multi-species study. This is not to say that the components of the other studies are flawed, but that the methods were not always fully reported and were therefore incomplete or unclear. For example, da Rosa & Bager (2012) included all of the discussed variables in their method. However, there was no reference to how each variable was determined (e.g. how the best driving speed was determined to most reliably detect roadkill). Similarly, Coelho *et al*. (2008) when sampling vertebrates, and Barrientos & Bolonio (2009) when sampling polecat (*Mutela putorius* L) both drove at a similar speed to this study (50 $km.h^{-1}$), but both sampled longer distances (195 km and 246 km respectively) and used two observers. This would seem to be both more costly and less time effective than my study, and questions whether their greater sampling distance and frequency were in fact necessary. However, the assumption is that polecat occur at low densities with large home ranges, and therefore to target a specific roadkill species, a further distance needs to be sampled. My results align and improve upon components of other studies since all of the variables required to detect roadkill were examined.

During my field transects, data were not collected for roadkill found on the road verges since this data collection was likely to lead to inconsistences in roadkill numbers. Some of the off-road roadkill were highly visible due to the absence of grass or dense habitat, whilst in places where the habitat and grass were denser, off-road roadkill was likely to be missed due to hampered visibility. One million animals (large mammals) are killed each day on highways in the United States (Noss 2002), with up to one third remaining undetected (Baker *et al.* 2004). This is either because they crawl off the road to die after being hit by a vehicle or the impact of the collision throws them onto the road verge (Slater 2002; Taylor & Goldingay 2004; Ramp *et al.* 2005). Consequently, this raises the hypothesis that the threat to wildlife from roads could be far greater than realised, and that future roadkill transects should include walking surveys along the road verge as suggested by Santos *et al*. (2011).

Further limitations of this study involve the effect of scavenging and the rate at which a carcass disappears or is removed from the road (Rodda 1990; Guinard *et al.* 2012). Barthelmess & Brooks (2010) conducted an experiment to examine how long a carcass remained on the road and suggested that only 20.7% of the likely total of roadkilled mammals was detected on a 100 km transect. This did not take into account any animals that had died away from the road. Equally, Myers (1969) reported that 15% of deer (Cervidae) hit by vehicles in Colorado moved far enough off the road so that their carcasses were not found. Antworth *et al.* (2005) suggest that road surveys may be biased due to the removal of carcasses from roads. They found between 60-97% of carcasses had been removed by scavengers within 36 hours, whilst Taylor & Goldingay (2004) noticed 30-50% of birds and mammals removed within a week. Whilst my study attempted to address this by sampling each day at the same time, it is still likely that some roadkill had disappeared within 24 hours and therefore remained undetected especially as scavenging rates are often highest during daylight hours (Antworth *et al*. 2005). Future surveys should exercise a degree of caution when interpreting roadkill data and should therefore recognise that the numbers collected are likely to be underestimated and every attempt should be made to measure detection errors when conducting road surveys (Hels & Buchwald 2001; Antworth *et al*. 2005; Guinard *et al*. 2012).

5 CONCLUSION

The results provide a standardised protocol, which to my knowledge, no other studies examine all of these variables in detail. Therefore, the recommendation for a standardised protocol for the sampling of multi-vertebrate roadkill is as follows (Table 3.7):

Table 3.7: A summary of the results of the speed trials and the field transects to assess the most cost and time effective method at which to detect roadkill.

Trial	**Recommendation**
Speed	40-50 $km.h^{-1}$
Time start	1.5 hours after sunrise
Time stop	1.5 hours before sunset
Number of observers	1
Observer skill level	Trained
Distance to be driven	100 km
Number of days to be sampled	40

It is important that future research on roads become more standardised to enable a statistical analysis of different studies. Typical road stretches should be chosen in a study, and each stretch should have a set length to allow for easier analysis and later comparison. The conservation implications of this protocol are far-reaching since roads are important for economic development and yet a significant proportion of biodiversity is under threat as a result.

CHAPTER 4

HIT AND RUN: the determinants of roadkill in the Greater Mapungubwe Transfrontier Conservation Area, Limpopo Province, South Africa.

"In the end, we will conserve only what we love. We will love only what we understand. We will understand only what we are taught."

Bada Dioum, (1968) Senegalese Ecologist

1 INTRODUCTION

Roads have gruesomely been described as 'long, narrow slaughterhouses' (Spellerberg 2002) and likened to predators (Bujocek *et al.* 2010). According to the Optimal Foraging Theory (MacArthur & Pianka 1966), predators will select prey by choosing weaker individuals from the population (Møller & Erritzøe 2000; Bujocek *et al.* 2010). A predator is defined as 'an organism that lives by preying on other organisms' or 'one that selectively plunders or destroys' (Collins 2003). Therefore, if roads are selective they too should lead to the elimination of individuals that are in poor nutritional condition and hence more vulnerable to vehicles (Bujocek *et al.* 2010). However, a study conducted in Poland which compared the body condition of birds killed by vehicles to birds killed by natural predation showed that roadkill birds were in better nutritional condition than those taken by predators (Bujocek *et al*. 2010). Roads are therefore neither predators nor selective (Jaarsma *et al.* 2006) and can randomly eliminate healthy individuals from a population, thus weakening the population (da Rosa & Bager 2011).

There are two main schools of thought in terms of what influences roadkill. Firstly, that roadkill is randomly distributed (e.g. MacKinnon *et al.* 2005; Quintero-Angel *et al.* 2012) and secondly, that roadkill is not random and is spatially clustered, linked to specific vegetation types and adjacent land uses, with variation between taxa and species and their distribution patterns (e.g. Clevenger *et al.* 2003). MacKinnon *et al.* (2005) suggested that roadkill is 'random' for snakes and not influenced by surrounding vegetation and reported no clustering around specific habitats. The absence of spatial patterning was likely a reflection of the relative abundance of snakes in the study area as well as the species being active in all sections of the road monitored (Quintero-Angel *et al.* 2012). Other studies concur that roadkill is distributed randomly with respect to landcover type (e.g. Jackson 2003; Smith-Patten & Patten 2008). However, most peer-reviewed studies support the theory that roadkill tends to be clustered. For example, roads near wetlands and ponds are likely to have increased roadkill rates (Forman & Alexander 1998; Puky 2005; da Rosa & Bager 2012; Langen *et al*. 2012) as are artificial waterholes near to roads (Mkanda & Chansa 2010) or roads crossing drainage lines (Forman & Alexander 1998; Saeki & MacDonald 2003). Owl (Strigiformes) fatalities were detected in clusters in Portugal rather than being randomly distributed (Gomes *et al*. 2009) and more roadkill, particularly ungulates, were located at 'fence ends' (e.g. where the fence line terminated or altered; Clevenger *et al*. 2001).

Assuming that roadkill is not random, there is a pressing need to understand the factors influencing wildlife mortality on roads (Kowlowski & Nielson 2008) and there have been many studies around the globe that have investigated the possible determinants of roadkill (e.g. Stoner 1925; Bright *et al.* 2005; Snow *et al.* 2011). A search conducted by Taylor & Goldingay (2010), using the Web of Science database, produced 244 peer-reviewed studies that examined vertebrate roadkill between 1998-2008. Of these 244 studies, Taylor & Goldingay (2010) observed geographical bias with 51% were from North America, 25% were from Europe, 17% were from Australia, and only 7% from the rest of the world. Few studies have been conducted in Africa (e.g. Drews 1995; Bognounou *et al*. 2009; Van der Hoeven *et al*. 2009; Mkanda & Chansa 2010; Haas 2011), and South Africa, in particular, is under-represented among global studies. One of the earliest studies in South Africa recorded bird roadkill in the Northern Cape Province (Siegfried 1966). Later studies included surveys in the Eastern Cape (Eloff & van Niekerk 2008), Nama-Karoo (Dean & Milton 2009), and the Southern Kalahari (Bullock *et al.* 2011) and unpublished data have been kept by many National Park managers and other conservation agencies (pers.comms.; McDonald, I., Percy FitzPatrick Institute of African Ornithology, University of Cape Town 2012; Mutayoba, S.K., Sokoine University, Tanzania 2012; Vernon, C., East London Museum 2012).

Taxonomic bias was also present among the 244 studies reviewed (Taylor & Goldingay 2010), with 53% of studies involving mammals (of which 19% focussed on ungulates, the most frequently studied taxonomic group), with less for birds (10%), amphibians (9%), and reptiles (8%). Multi-species studies accounted for the remaining 20%. Taylor and Goldingay (2010) suggest that most of the studies reflected the interest and appeal to the researcher of a particular taxon, rather than the need for study.

In Australia, traffic collisions have placed the survival of populations of koalas (*Phascolarctos cinereus)*, and swamp wallabies (*Wallabia bicolour)* at risk (Seabloom *et al.* 2002), and roads and traffic account for an approximate 30%

reduction in European hedgehog (*Erinaceus eurpaeus)* densities across the Netherlands (Barthelmess & Brooks 2010). Similarly, in the United Kingdom, roads are believed to kill more than 66% of post-emergent Eurasian badger cubs (*Meles meles)* annually (Clarke *et al.* 1998). In addition, mortality on roads accounts for about 10% of the mortality of the endangered Iberian wolf (*Canis lupus signatus)* population in Spain (Ferreras *et al.* 1992; Grilo *et al.* 2002; Grilo *et al*. 2009) and has caused a 70% decrease in the Barn Owl (*Tyto alba)* population over the last 10 years in Portugal (Carvalho & Mira 2011). Importantly, these statistics do not account for animals that escape to die later, nor do they account for all species (Noss 2002).

The determinants of roadkill can be broadly arranged into three distinct categories; biophysical, environmental and physical, with a further category that includes external factors not fitting into the other three categories (e.g. driver awareness and animal speed; Figure 4.1). Not all roadkill studies have assessed all biophysical, environmental and physical determinants and are often limited to only a few specific variables. For example, van Langevelde *et al.* (2009) examined the impact of traffic on wildlife in the Netherlands, with limited data on any environmental and biophysical factors. Other studies only provide roadkill counts (e.g. Baker *et al.* 2004; Balakrishnan & Afework 2008; Barthelmess & Brooks 2010). These limitations potentially confound any meta-analyses aimed at identifying the most influential factors (Groot Bruinderink & Hazebroek 1996). Furthermore, simply counting the number of dead animals on the road will not contribute to understanding whether roads and vehicles are endangering the existence of populations or species (van der Ree *et al*. 2011).

The biophysical variables

Biophysical variables such as rainfall, minimum and maximum temperature, humidity, cloud cover and moon phase influence roadkill numbers (Clevenger *et al*. 2001). However, according to Kolowski & Nielson (2008), the extent and direction of their effects are difficult to quantify due to the paucity of data in existing studies. Higher rainfall is likely to cause an increase in roadkill since many animals become more active when it rains (e.g. amphibians; Carruthers & du Preez 2011). In addition, rain water on roads causes increased run-off onto verges, which, in turn, flourish and become more attractive to grazers (Forman & Alexander 1998). This increases the likelihood of animals being hit by vehicles as they wander from the roadside verge onto the road (Mkanda & Chansa 2010). Moreover, after prolonged periods of rain, water sources in more arid areas become replenished and may result in roadkill 'hotspots' if they are near to roads (Mkanda & Chansa 2010).

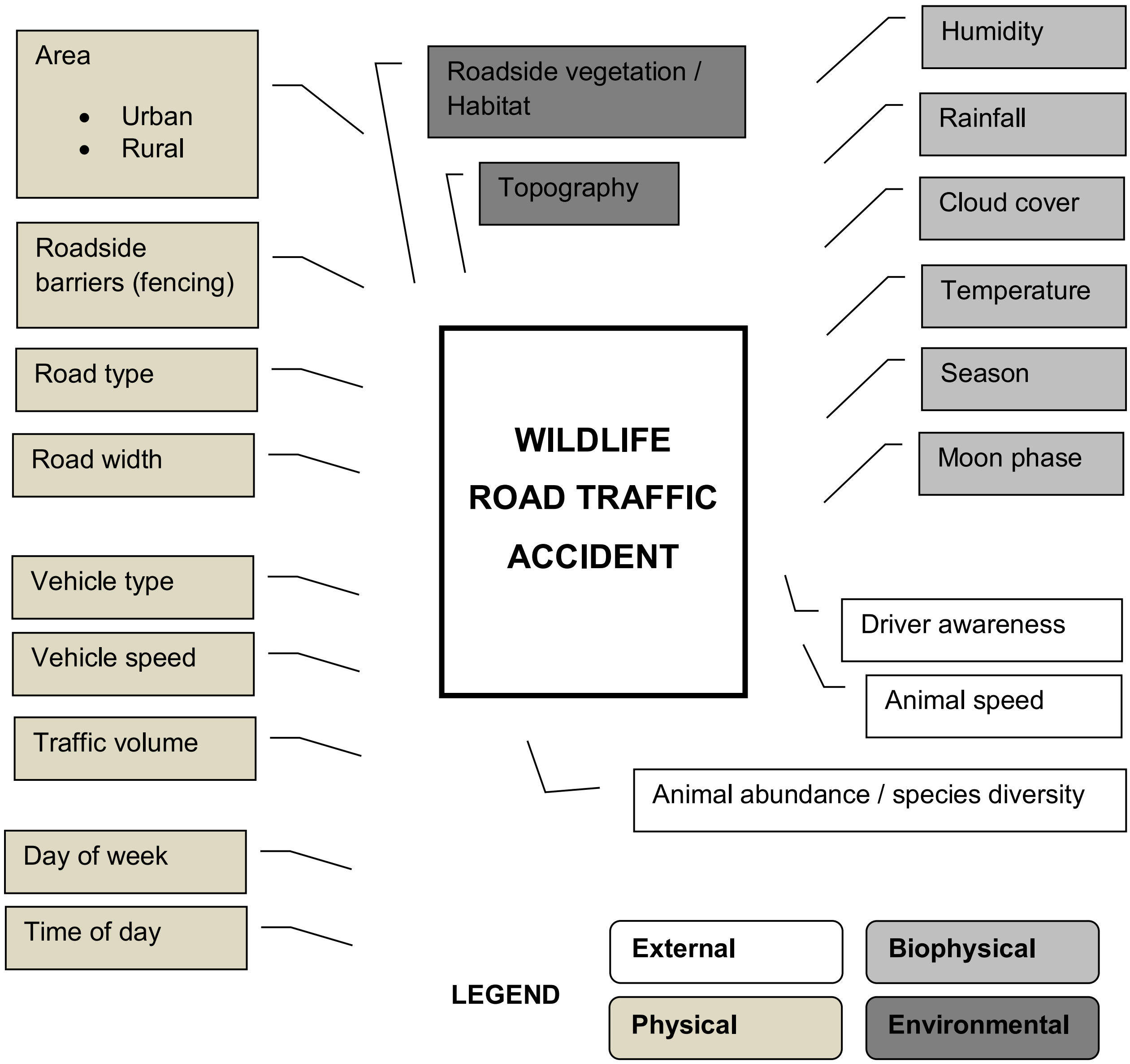

Figure 4.1: A diagram illustrating the interrelationship between variables (external, physical, biophysical and environmental) that have been implicated in determining the number of individual animals that are killed by vehicles (adapted from Litvaitis & Tash 2010).

Variations in temperature also cause a fluctuation in roadkill rates. Many reptiles bask on roads when it is warmer and therefore are killed by vehicles (Branch 1998; Sutherland *et al.* 2010). Some mammals become less active when temperatures increase (de Boer *et al.* 2012) and are therefore likely to be less mobile and be less prone to becoming roadkill (Skinner & Chimimba 2005; Feldhamer *et al*. 2007). The combination of high temperatures and rainfall often sees an increase in humidity, and consequently an indirect influence on road mortality. Humidity is one of the main abiotic factors that define animal activity (Hogan 2010). For example, certain amphibian species rely on specific timings of rainfall and optimum temperature for reproductive success (Hogan 2010), which will result in an increase in activity and movement (Carruthers & du Preez 2011).

Eloff & van Niekerk (2005) found roadkill numbers for kudu (*Tragelaphus strepsiceros*) increased when there was greater cloud cover than no cloud although they did not suggest why this was the case. It may be due to changes in animal activity brought about by differences in cloud cover as it alters light levels. For example, birds will often pause from their ‘singing’ during the dawn chorus in response to less light due to cloud cover (Hutchinson 2002).

Gerbils (*Gerbillus allenbyi* & *G. pyramidum*) also tend to be less active when cloud cover restricts moonlight (Kotler *et al.* 1993). By contrast, roadkill may increase when there is more moonlight since certain diurnal and crepuscular species may become more active at night when there is more light (Creel & Creel 1995; Eloff & van Niekerk 2005). For example, kudu (*Tragelaphus strepsiceros*), usually a diurnal species, may browse at night (Eloff & van Niekerk 2005), and the African wild dog (*Lycaon pictus*; a crepuscular species) will often hunt when the moon is full (Creel & Creel 1995; Davies-Mostert 2010). Several studies have reported increased roadkill at night, particularly as driver visibility decreases (Clevenger *et al.* 2003; Puky 2005; Ramp *et al.* 2005; Rowden *et al.* 2008; Bullock *et al*. 2011).

Linked to rainfall and temperature, season has a major influence on road mortality (Clevenger *et al.* 2001) since it catalyses many species that synchronise their life history behaviour in accordance with season (Hockey *et al*. 2005; Skinner & Chimimba 2005; Carruthers & du Preez 2011). A search on Google Scholar using the words ‘vertebrate roadkill’ produced 152 peer-reviewed studies that examined the determinants of roadkill. All showed that season played an important role in influencing roadkill numbers, with higher rates detected during the spring and summer (e.g. Siegfried 1966; Clevenger *et al.* 2001; Taylor & Goldingay 2010).

The environmental variables

Roads fragment habitat and may divide populations (Forman & Alexander 1998; Clevenger *et al.* 2003) and animals will cross roads if they bisect part of their home ranges and territories (Dodd *et al*. 2004). Clevenger *et al.* (2003) found that habitat had a significant effect on roadkill and identified species-specific patterns of road casualty distribution that were linked to certain landscape characteristics. Greater concentrations of roadkill were detected in gaps or openings between denser vegetation or where shrub cover was >7 m high compared to shorter, denser vegetation with no gaps in cover (van der Hoeven *et al.* 2009). The ability of drivers to see wildlife is generally impeded by denser roadside habitats and can result in more collisions (Caro *et al*. 2000; Ansara 2004; Eloff & van Niekerk 2005). In addition, roadside verges often create micro-habitats (Gubbi *et al.* 2012) and are home to smaller species such as rodents (Bellamy *et al.* 2000), seed-eating birds and hedgerow specialists (Coelho *et al.* 2008; Orlowski 2008). Consequently, when grass is in-seed, road mortalities of seed-eating species increases as they are more active on the roadside verges and are more likely to be killed when attempting a road crossing (Forman & Alexander 1998; Dean & Milton 2003). Animals that prey on these smaller species often become roadkill themselves (Barrientos & Bolonio 2009).

The distance from road verge to vegetation is known to significantly influence roadkill (Dickerson 1939; Ansara 2004; Malo *et al.* 2004; Seiler 2005). More roadkill is generally detected when vegetation (> 1 m tall) is closer to and/or extends to the road edge (Ansara 2004).

The physical variables

Fencing deters animals from crossing roads (Patterson 1977; Dodd *et al.* 2004) and a number of studies have examined the effectiveness of fences in reducing roadkill numbers (see Jackson & Griffin 2000; Lesbarrieres & Fahrig 2012). For example, wildlife road mortality was compared between areas with and without roadside fencing in Canada and 80% fewer ungulate-vehicle collisions were observed in fenced areas compared to unfenced sites (Clevenger *et al.* 2001). However, fences are also known to fragment habitat and cause population isolation (Seiler 2005). They disrupt individual daily movements and should be considered carefully for their role in impeding events essential to species persistence such as dispersal and range expansion (Gadd 2012).

Despite fencing being a deterrent, many animals will dig under, push through, or jump over fences (McAtee 1939; Owen-Smith 1985) and consequently, collide with vehicles (Eloff & van Niekerk 2005). Kudu and impala (*Aepyceros melampus*) can jump over electric fences up to 2.4 m in height (Vosloo *et al*. 2005). South Africa is a country with a ‘fence culture’ and has thousands of kilometres of different types of fencing dividing farms, national parks and individual properties (i.e. cattle fencing for domestic livestock, game fencing for wild game, and electric fencing for protected areas; Fencing Act No. 31 of 1963; Bond *et al.* 2004). Few studies have compared the effect of fence type on roadkill and the diversity of fence types in South Africa provides an opportunity to examine the effectiveness of each fence type.

Characteristics of a road, such as the presence of bridges, bends and junctions also influence road mortality (Malo *et al.* 2004). Fifty percent less roadkill was detected in Spain at a crossroads and when the embankments on either side of the road were more than 2 m high (Malo *et al.* 2004). A study in Canada found that ravens (*Corvus* sp.) were less likely to be killed where there are embankments on either side of a road, as they can fly over the road at a greater height than a vehicle and avoid being pulled into the vehicle’s down-draught (Clevenger *et al*. 2003; Møller *et al.* 2011). In addition, more mammal roadkill was detected on bends on roads in the United Kingdom, possibly because of reduced visibility (Bright *et al.* 2005; Kociolek *et al.* 2011). However, Joyce & Mahoney (2001) found that 79% of moose (*Alces alces)* casualties occurred on straight road sections in Canada, while Møller *et al.* (2011) found more roadkill on hills in Denmark, most likely because vehicles travel downhill faster.

Different road types will have different traffic volumes and speed limits, and therefore the occurrence of roadkill will also vary (Seiler 2005; Bullock *et al.* 2011). Vehicles on unpaved roads are more likely to travel slower than on paved roads due to the substrate of the road surface (Oxley *et al.* 1974). More mammal roadkill were detected on paved than unpaved roads in a study conducted in the USA, with 8.60 mammal roadkill per 100 km on the paved road and 3.65 mammal roadkill per 100 km on the unpaved road (Smith-Patten & Patten 2008). Few other studies have examined the differences between paved and unpaved roads (da Rosa & Bager 2012).

Many animals avoid crossing roads as wide as two-lanes (Noss 2002) since wider roads require more time to cross and are therefore more likely to result in mortality (Forman & Alexander 1998; Smith-Patten & Patten 2008; Barrientos & Bolonio 2009; van Langevelde *et al.* 2009). Smaller animals are frequently more vulnerable on wider roads as they need more time to cross than larger species (van Langevelde & Jaarsma 2004). Barrientos & Bolonio (2009) found more European polecat (*Mustela putorius* L.) roadkill in areas where the road was wider (i.e. two lanes on either side compared to single-lanes). However, traffic volume had a greater effect than road size as road size alone could not explain the increased road mortality (Jaeger *et al.* 2005).

Studies that examine the impacts of traffic volume on wildlife in other parts of the world are either highly variable or non-existent. Of 62 peer-reviewed studies, only 45% compared traffic volumes to the number of roadkill detected (e.g. Case 1978; Clevenger *et al.* 2003; Chapter 3), and 40% of these obtained data from national road agencies using an Average Daily Traffic count (ADT) (e.g. Clark *et al*. 2010; Berthinussen & Altringham 2012). Only 5% of the studies conducted traffic counts during the study using either sensor or observational counts (e.g. Bright *et al.* 2005; Snow *et al.* 2011; Chapter 3). Importantly, Bright *et al*. (2005) suggest that to rely on mean daily traffic flow data does not always consider the traffic counts at the time of the study and provides an oversimplified measure.

A strong positive correlation was noted between roadkill and traffic volume (Fahrig *et al.* 1995; Clevenger *et al.* 2003; Saeki & MacDonald 2003). The relationship between roadkill rate and traffic volume differs either side of ~5,000 vehicles per day (Figure

4.2), with roadkill numbers decreasing when traffic volume is greater than or less than 5,000 vehicles per day, but remaining high in the range from 2,500-10,000 vehicles per day (Seiler 2003; Seiler 2005; Coelho *et al*. 2008; Brockie *et al*. 2009). Animals can therefore learn to avoid roads when traffic volumes are higher because high traffic volume effectively acts as a barrier to wildlife crossing roads (Baker *et al.* 2004; Seiler 2003; Seiler 2005; Grilo *et al.* 2009).

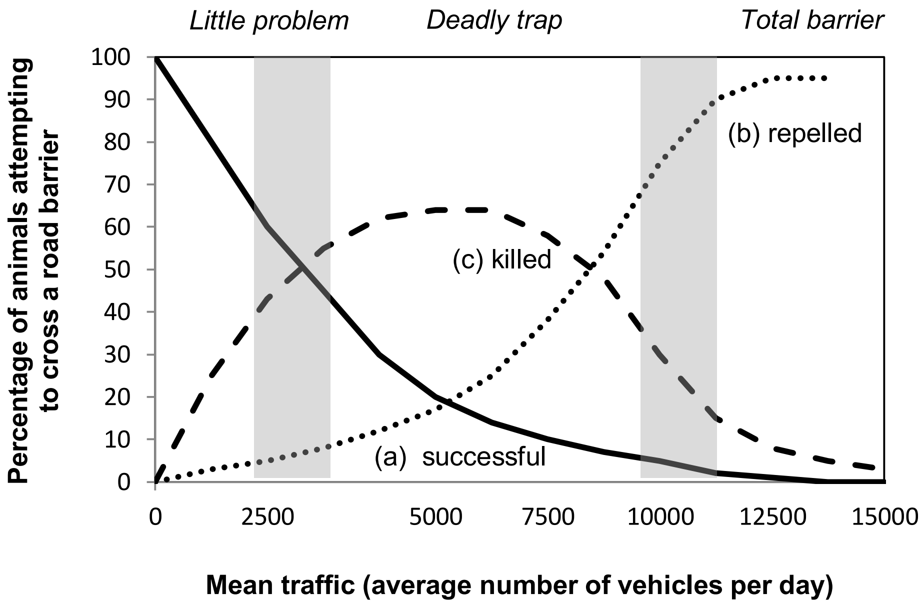

Figure 4.2: A conceptual model demonstrating the effect of traffic volume on the percentage of animals that can (a) successfully cross a road, (b) those that are repelled by traffic noise and vehicle movement, (c) or those that get killed as they attempt to cross (modified from Seiler 2003).

More roadkill generally occurs at ‘intermediate’ speeds (i.e. 90 $km.h^{-1}$) with less roadkill when vehicles travel at slower or faster speeds (Taylor & Goldingay 2004; Seiler 2005; Rowden *et al.* 2008). However, some studies have found no relation between traffic speed and roadkill numbers (e.g. Case 1978; Bullock *et al*. 2011). More European polecat *(Mustela putorius*) were killed when vehicles travelled at faster speeds although this speed was not specified (Barrientos & Bolonio 2009). In addition, more polecat roadkill were observed with low frequencies of heavy vehicles (Barrientos & Bolonio 2009) compared to passenger vehicles (i.e. cars). The opposite was found to be true for elk (*Cervus elaphus)* roadkill, which increased with higher volumes of larger vehicles (trucks) than passenger vehicles (Gunson *et al.*

2003). More roadkill were also observed at weekends, when traffic flow is usually higher (Bautista *et al*. 2004).

AIMS

This study aims to contribute to filling several gaps in the understanding of factors that affect roadkill by looking at all vertebrate taxa and by recording data for a range of biophysical, environmental and physical factors. The study site (The Greater Mapungubwe Transfrontier Conservation Area (GMTFCA)) was selected for several reasons. As a conservation area it is home to a wide range of vertebrates, some of which are endangered (e.g. African wild dog; *Lycaon pictus*, and Pels Fishing Owl; *Scotopella peli*). It is crisscrossed by numerous roads and it is expected that the recent development of a coal mine and increased tourism will result in greater use of the roads. This chapter examines the determinants of roadkill in the GMTFCA in South Africa.

The specific aims of this chapter were to:

1 *Implement the standardised protocol (as designed in chapter 3) as a systematic approach to detect roadkill.*

2 *Obtain baseline rates for roadkill for all vertebrate species in the Greater Mapungubwe Transfrontier Conservation Area (GMTFCA), South Africa.*

3 *Investigate and assess whether roadkill is randomly distributed or clustered spatially.*

4 *Establish the determinants of roadkill and to better understand the potential threats of roads on wildlife.*

2 MATERIALS AND METHODS

2.1 Transect sampling

Four transects were selected to enumerate for roadkill (Table 4.1). The vehicle used was a Suzuki Jimny, 1.4. A single observer, also the driver, occupied the vehicle and drove at speeds of between 40-50 km.h^{-1} (see chapter 3).

a) The detection of roadkill over a 100 km transect on the paved road

The primary transect was 100 km in length and was driven daily for 40 consecutive days commencing 1.5 hours after sunrise (see chapter 3). The transect comprised three paved roads (Figure 4.3a; un-named paved road = 23.7 km, R521 Regional paved road = 23.4 km and, R572 Regional paved road = 52.9 km).

b) The detection of roadkill over a 20 km transect on the unpaved road

To allow comparison of the occurrence of roadkill on paved and unpaved roads, a 20 km transect was sampled once daily during each 40-day period (Figure 4.3; Table 4.1d). This was driven in addition to the 100 km transect and commenced 1.5 hours after sunrise, as part of the primary transect.

c) Sub-transects to determine the time of day of roadkill occurrences over a 20 km transect on the paved road

A 20 km sub-transect of the primary transect was driven twice a day starting 1.5 hours before sunrise (pre-dawn; Figure 4.3b, Table 4.1c), and again 1.5 hours after sunset (post-dusk; Figure 4.3b, Table 4.1d). The sub-transect started at the 60 km point of the 100 km transect, since it was closest to my place of residence, and therefore more economical to use as a starting point.

The sub-transects were included to cover a wider range of times and to allow an analysis of the effect of time of day on the occurrence of roadkill.

The initial sampling procedure required that data were collected for the full primary transect and the pre-dawn and post-dusk sub-transects over the same 40-day period. However, driver fatigue resulted in the pre-dawn sub-transects being driven for only 20 days.

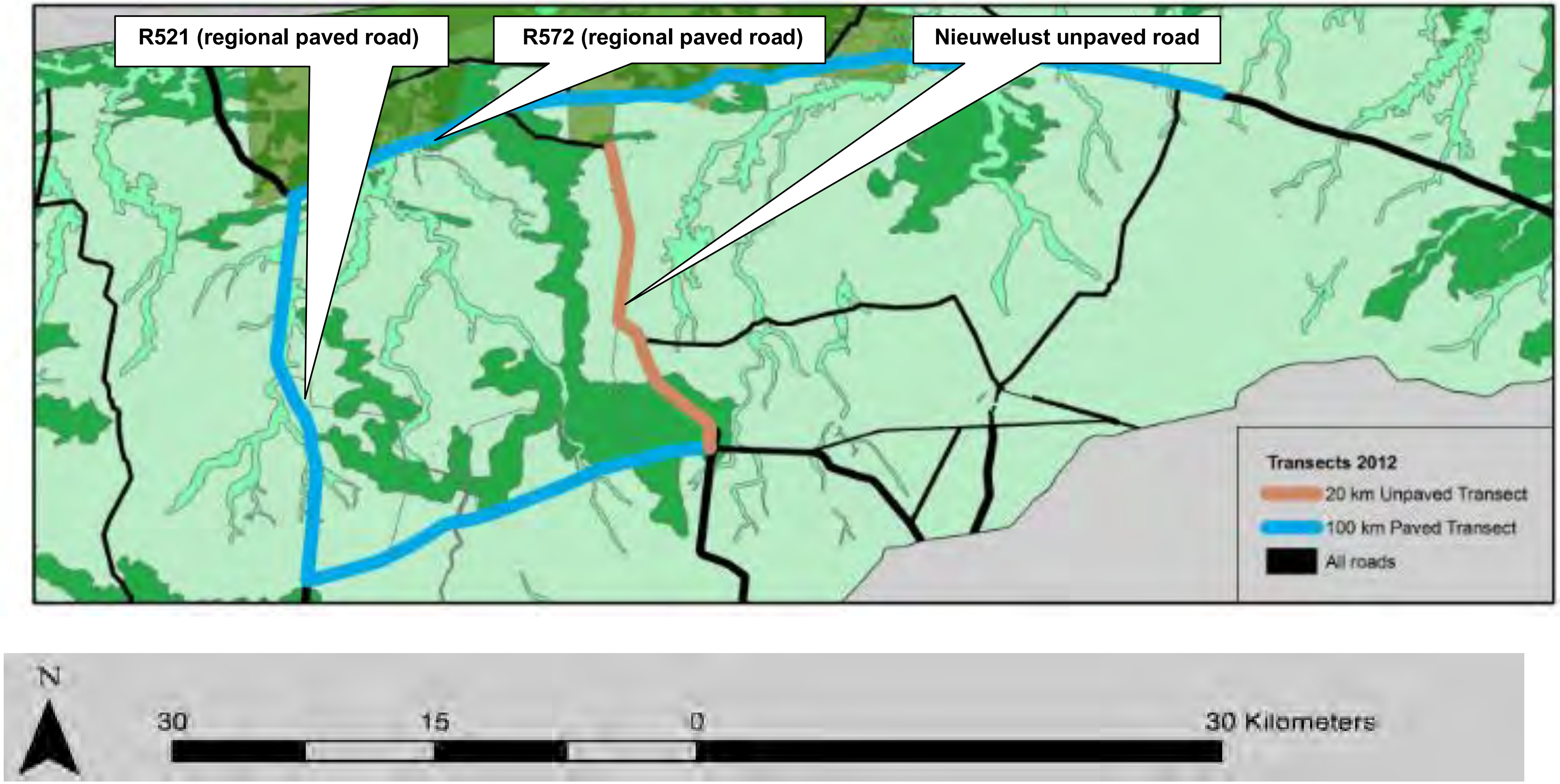

Figure 4.3a: A map of the study area showing the 100 km paved road and 20 km unpaved road. GIS data source: GeoNetwork (2000); Peace Parks Foundation (2010). (ArcGIS 9.3; map units: decimal degrees; not projected).

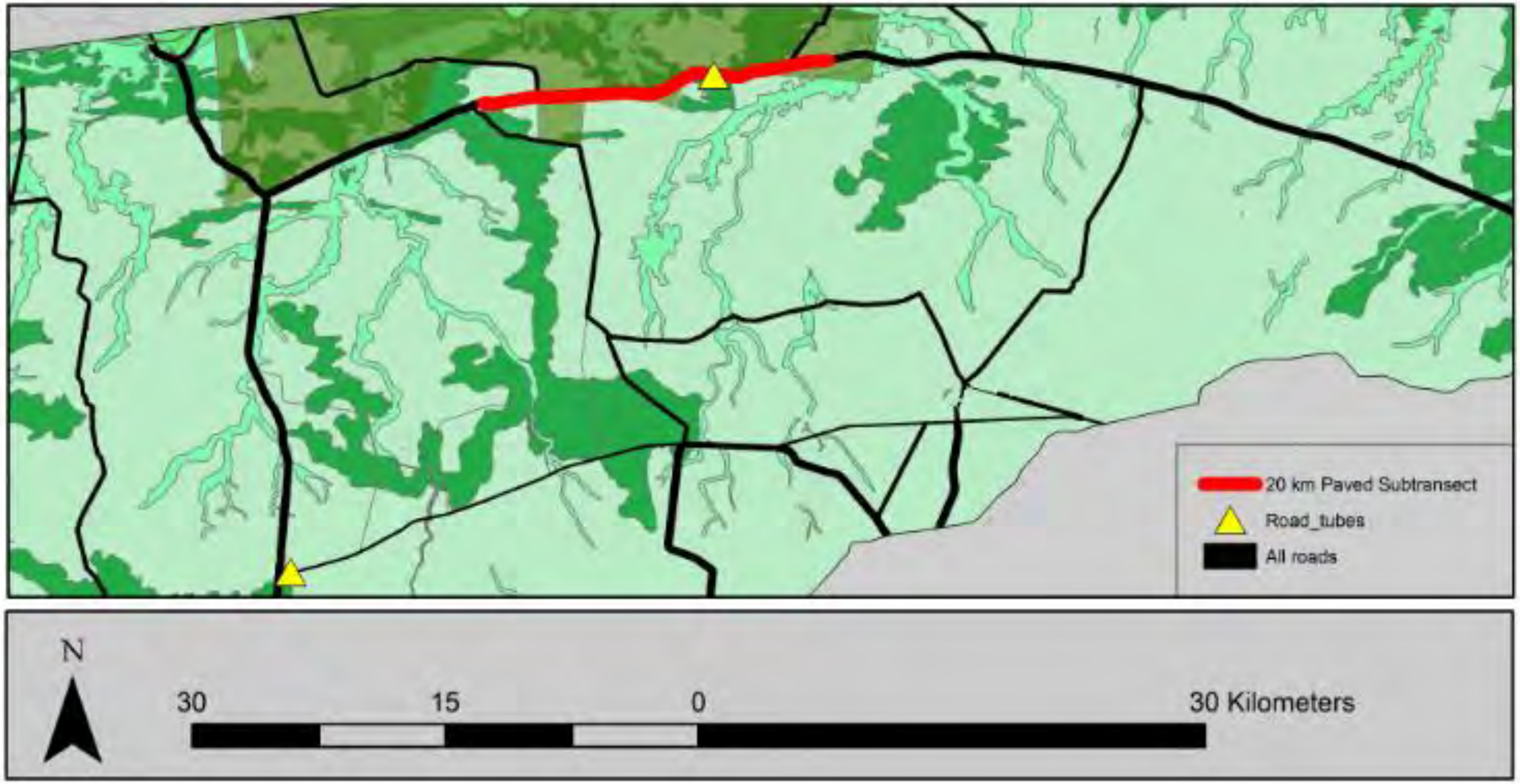

Figure 4.3b: A map of the study area showing the 20 km subtransect highlighted in red. The yellow triangles on 4.3b illustrate the position of the traffic counters (section 2.1.4). GIS data source: GeoNetwork (2000); Peace Parks Foundation (2010). (ArcGIS 9.3; map units: decimal degrees; not projected).

Table 4.1: The transect types, distances (km) and number of days driven across three ecological seasons on paved and unpaved roads in the GMTFCA, South Africa.

Transect	Transect type	Transect time	Road surface	# of days (per season)	Distance driven per day (km)
a	Primary paved transect	Post-dawn (1.5 hours after sunrise)	Paved road	40	100
b	Unpaved transect	Post-dawn (1.5 hours after sunrise)	Unpaved road	40	20
c	Sub-transect	Pre-dawn (1.5 hours before sunrise)	Paved road	20	20
d	Sub-transect	Post-dusk (1.5 hours after dusk)	Paved road	40	20

South Africa does not generally experience four distinct seasons and autumn and spring tend to be very short (South African Weather Service 2011). Typically, a season is a division of the year that is marked by changes in ecology, weather and hours of sunlight. In temperate and sub-polar regions, the four meteorological seasons (namely spring, summer, autumn and winter) are well-defined whereas in tropical and subtropical regions, seasons are usually expressed as either wet or dry (Schulze & McGee 1978), with a further three-way division into hot, wet and cold season often used (Schulze & McGee 1978).

The study area comprises three ecological seasons; the hot/dry, hot/wet, and cold/dry, as opposed to the four meteorological seasons An ecological season was defined as the period of the year in which only certain types of floral and animal events occur. For example, amphibians are generally less active during the cold/dry season when they estivate, but more active during the hot/wet season (Carruthers & du Preez 2011). Ecological seasons were selected over meteorological seasons as changes in animal behaviour were considered more likely to influence roadkill rates. The transects were sampled in each of the three ecological seasons (modified from Viljoen 1989; Viljoen *et al.* 2008; Table 4.2) and the full suite of seventeen variables were recorded at each roadkill and outlined below (Table 4.3).

Table 4.2: Timing of the three ecological seasons used in the study.

Ecological season	Range	Sampling months
Hot / Dry	September – January	October/November
Hot / Wet	February - May	February/March
Cold / Dry	June – August	June/July

Based on the literature review and knowledge of the study area, seventeen variables were identified as possible determinants of roadkill. These were placed into three categories; biophysical, environmental and physical. The effects of each of these variables were examined on paved and unpaved roads in the GMTFCA.

Table 4.3: Variables used to determine the biophysical, environmental and physical factors that influenced the number of roadkill on paved roads and unpaved roads in the GMTFCA, South Africa.

Variable	**Brief description**	**Type of factor**	**Type of data**
Season	Three ecological seasons (hot/wet, hot/dry, cold/dry)	Biophysical	Categorical
Cloud cover	Nine cloud categories (0-8, with ‘0’ being when no cloud was present, and ‘8’ being overcast)	Biophysical	Categorical
Moon phase	Eight moon phases (new moon, waxing crescent, first quarter, waxing gibbous, full moon, waning gibbous, last quarter, waning crescent)	Biophysical	Continuous
Rainfall (mm)	Data collated from 21 separate rain gauges in the study area	Biophysical	Categorical
Minimum temperature (°C)	Recorded daily at 12:00	Biophysical	Continuous
Maximum temperature (°C)	Recorded daily at 12:00	Biophysical	Continuous
Humidity (%)	Recorded daily at 12:00	Biophysical	Continuous
Habitat type	Nine vegetation communities identified in the study area	Environmental	Categorical

Grass density	Photographic index of grass density (scale 1-9, with 1 being the least dense)	Environmental	Categorical
Grass seed	Presence or absence of grass seed	Environmental	Categorical
Grass height (cm)	Average of three grass heights obtained on the road verge at 1 m intervals (for both sides of the road)	Environmental	Categorical
Fence type	Four fence types identified in the study area (electric, game, cattle and cattle/electric combined)	Physical	Categorical
Fence distance to verge (m)	Visual estimate of five fence distance categories (<5 m, between 5 & 9 m, between 10 & 14 m, between 15 & 19 m, and 20 & >20 m)	Physical	Categorical
Traffic volume (number of cars per day)	Sensor traffic counter tube (PicoCount 2500)	Physical	Categorical
Vehicle axle (traffic class)	Sensor traffic counter tube (PicoCount 2500)	Physical	Categorical
Traffic speed ($km.h^{-1}$)	Sensor traffic counter tube (PicoCount 2500)	Physical	Categorical
Day of week	Weekdays and weekends	Physical	Categorical

2.2 Determinants of roadkill

2.2.1 Biophysical characteristics

Humidity, cloud cover, wind speed, temperature and rainfall were recorded daily at 12:00. Temperature, humidity and wind speed, were recorded using Skywatch ® atmos, (JDC Electronic SA 2012; an anemometer, thermometer and hygrometer). Nine cloud cover categories were identified (0-8, with '0' being when no cloud was present, and '8' being overcast; modified from Stubenrauch *et al*. 1996). Rainfall data were recorded at 21 separate rain gauges within the study area (Venetia Limpopo Nature Reserve and Mopane Bush Lodge; see chapter 2) and the mean taken for each day. Moon phases were taken from the United States Naval Observatory (USNO) and divided into eight phases; new moon, waxing crescent, first quarter, waxing gibbous, full moon, waning gibbous, last quarter and waning crescent (USNO 2011).

2.2.2 Environmental characteristics

Since it was not always possible to determine which direction an animal was travelling or the habitat being used by an animal prior to a vehicle collision (Caro *et al.* 2000), land cover types on both sides of the paved and unpaved road were recorded for each roadkill observed. The predominant habitat category was recorded within a 10 m radius of where the roadkill was detected.

The method used by Conard & Gipson (2006) was adopted to measure vegetation type and vegetation was assumed to remain constant during the study (i.e. vegetation types were unlikely to change over a 120 day period). However, grass height, grass density and the presence/absence of seeds were variable and were therefore quantified separately.

Using Mucina & Rutherford's (2006) classification of Mopaneveld (chapter 2), nine vegetation communities were subjectively identified along the paved and unpaved roads (Figure 4.4; Table 4.4).

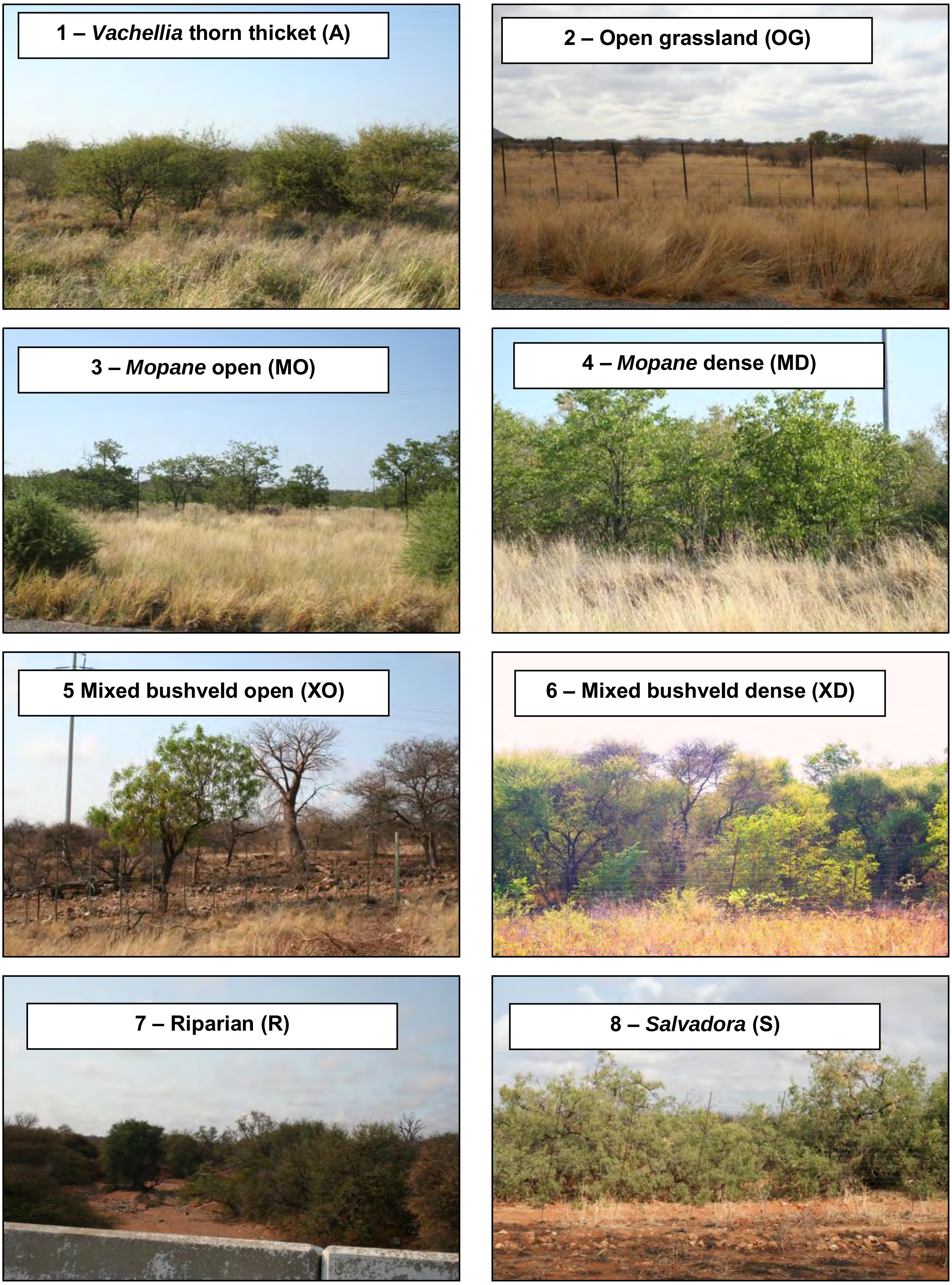

Figure 4.4: Photographs representing the nine vegetation communities identified on the transect roads in the GMTFCA, South Africa.

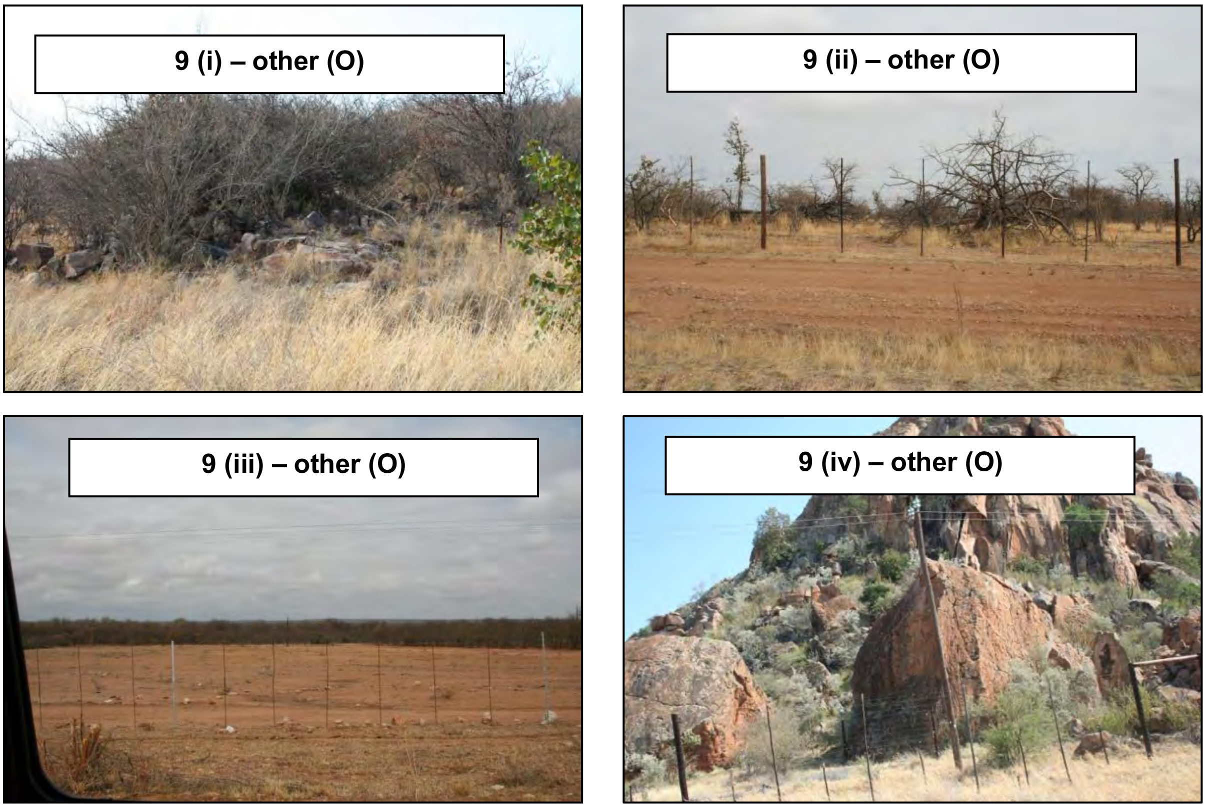

Figure 4.4 (continued): Photographs representing the nine vegetation communities identified on the transect roads in the GMTFCA, South Africa.

Table 4.4: The proportions of each of the nine vegetation communities on both sides of the 100 km paved road and the 20 km unpaved road in the GMTFCA, South Africa.

		Paved road (100 km)		Unpaved road (20 km)	
Habitat type	**Code**	**Total (km)**	**%**	**Total (km)**	**%**
Mopane dense	MD	72.2	36.1	4.2	10.5
Mixed bushveld open	XO	40.7	20.4	13.1	32.8
Mixed bushveld dense	XD	36.0	18.0	6.4	16.0
Mopane open	MO	23.6	11.8	9.2	23.0
Riparian	R	14.0	7.0	0.0	0.0
Vachellia	A	9.1	4.6	2.1	5.3
Salvadora	S	1.9	1.0	0.0	0.0
Open grassland	OG	1.5	0.8	4.0	10.0
Other	O	1.0	0.5	1.0	2.5
Total		**200**	**100**	**40**	**100**

Mopane open (MO) and *Mopane* dense (MD) were estimated according to overall height and the distance between individual trees (O'Connor 1992). When the distance between trees was visually estimated to be less than 2 m the vegetation was considered to be dense (Pitt & Schwab 1988). *Mopane* dense vegetation also had taller trees present (~10 m; O'Connor 1992). Mixed bushveld was defined as the vegetation type which had more than two tree species present within a 10 m radius on either side of the road where a roadkill was detected. The same categories used for the *Mopane* was used for mixed bushveld open (XO) and mixed bushveld dense (XD), with tree height and distance between trees determining the degree of openness. In areas where *Vachellia nigrescens* (Knobthorn), *Vachellia tortilis* (Umbrella Thorn) and *Vachellia senegal* (Slender Three-hook Thorn), dominated, the vegetation was categorised as *Vachellia* (A) (O' Connor 1992, Mucina & Rutherford 2006). Similarly, when *Salvadora angustiflora* was prevalent, the vegetation was classed as *Salvadora* (S).

Where livestock ranching took place, the vegetation was categorised as open grassland (OG). The dominant grass species in these areas are Nine-awned Grass (*Enneapogon cenchroides),* Blue Buffalo Grass *(Cenchrus ciliaris*), Silky Bushman Grass (*Stipagrostis uniplumis*), Tassel Three-awn (*Aristida congesta*) and Sand Quick (*Schmidtia pappophoroides*; van Oudtshoorn 1999).

Riparian (R) areas were defined as areas within 50 m of a stream, running either perpendicular or parallel to the roadway (Conard & Gipson 2006) with Apple Leaf (*Phylonoptera violacea*), Leadwood (*Combretum Imberbe) and* Ana Tree (*Faidherbia albida) as* the most common species *(*Mucina & Rutherford 2006). Category O was used when the vegetation could not be conclusively classified as one of the eight categories; for example, when the area was dominated by rocks, bare earth, or less common tree species.

The extent of each vegetation/habitat type was recorded during the hot/wet season of 2012 by slowly driving the transect route and recording the distance (km) of each habitat on both sides of the road, based on odometer readings. The distance recorded for each vegetation type on both sides of the road was converted into a proportion of the total linear kilometres along the transect (100 km for the paved road and 20 km for the unpaved road) to determine overall availability (%) of each vegetation type.

The presence and extent of grass on the right and left hand verges of the paved and unpaved roads was measured in three ways; grass height (cm), grass density (scale of 1-9) and the presence or absence of grass seed.

Three grass heights (cm) were recorded on one side of the road, adjacent to a roadkill on the road (Figure 4.5a) with a one-metre L-shaped chequered rule, divided into 10 cm lengths (Figure 4.5b). The first height was taken at the road edge, the second, one metre from the verge, and the third, two metres from the verge (Figure 4.5b). The L-shaped rule enabled easier location of the second and third points. This was then repeated for the other side of the road and the data used to generate the standard error (as an estimate of the population mean) of grass height for the two sides.

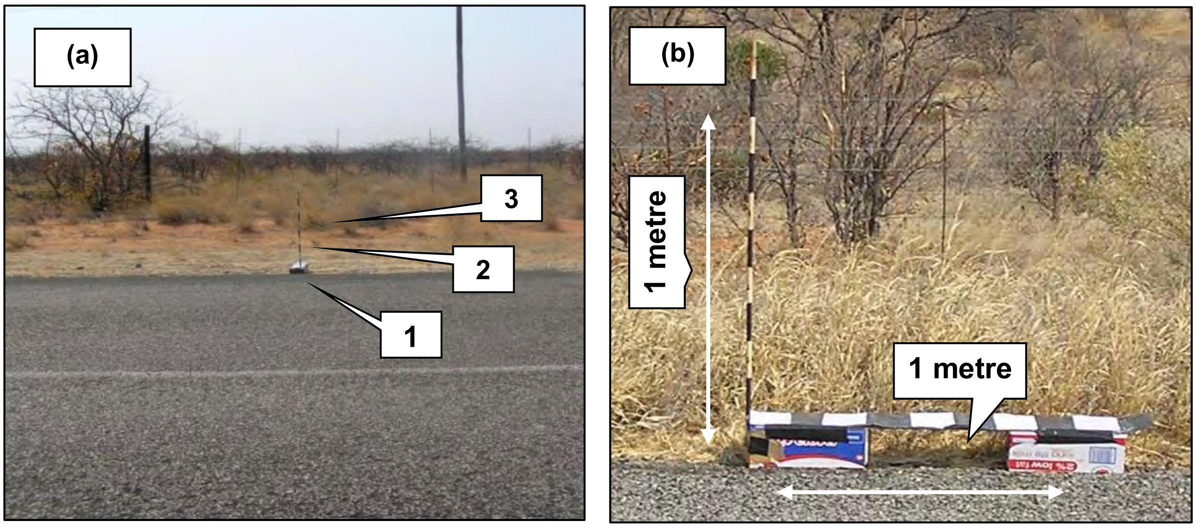

Figure 4.5: Two photographs demonstrating grass height measurement using a one-metre L-shaped chequered rule divided into 10 cm lengths, where (a) the rule is displayed at point one of three, (b) with points two and three also marked as a reference.

A photographic index for grass density was generated using calibrated photographs (modified from Haydock & Shaw 1975; Friedel & Bastin 1988). A scale of 1-9 (using visual estimates of density) was used, with no grass being level 1, and the densest grass being level 9 (Figure 4.6). This was recorded for both sides of the road where a roadkill was detected. The presence or absence of grass seeds was noted.

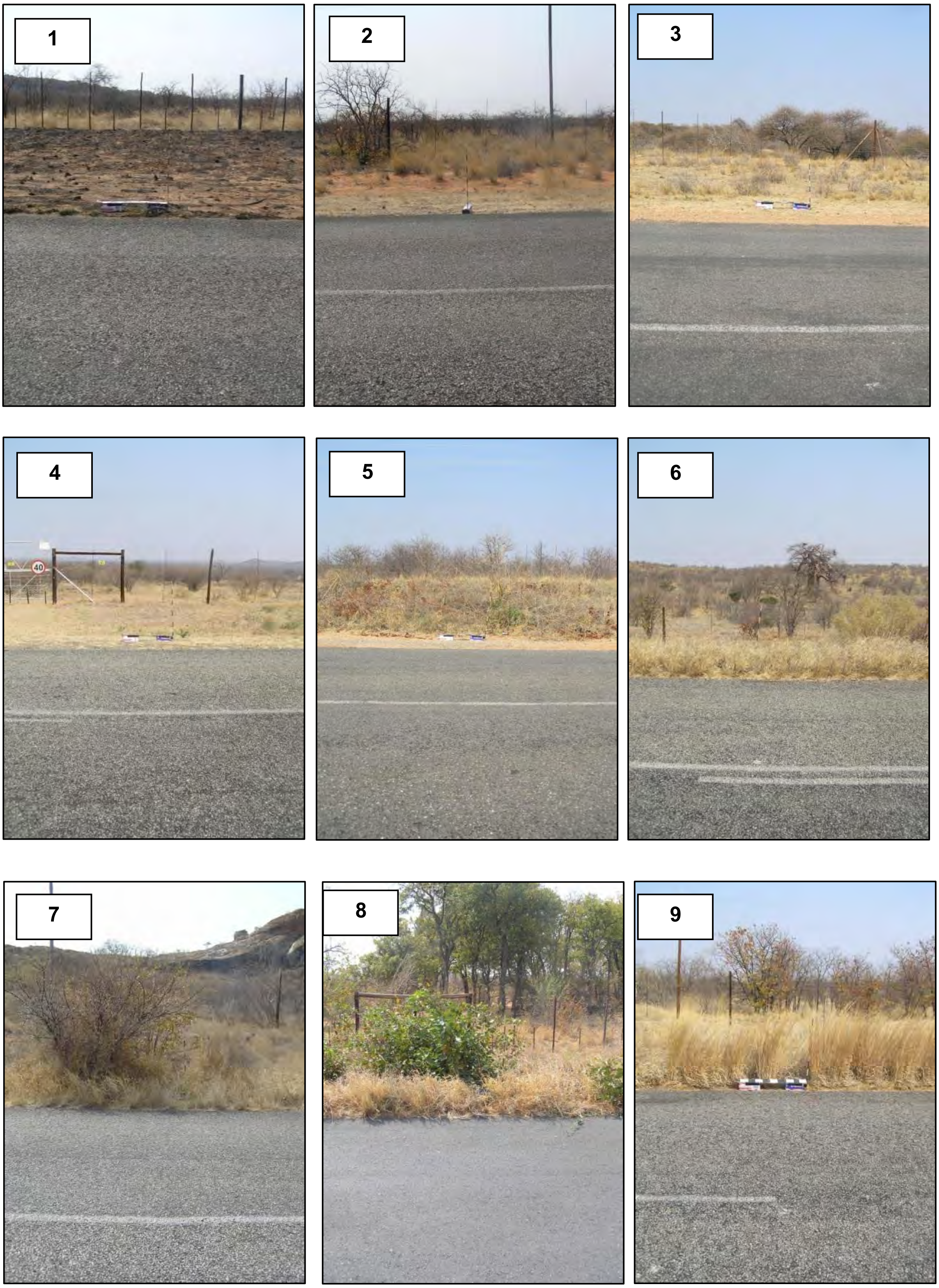

Figure 4.6: Photographs depicting the nine grass density levels used in the study, with a value of one being the least dense, and nine being the densest.

2.2.3 Physical road characteristics

For each roadkill (or random point), all physical characteristics within 50 m (including hills, road bends, culverts, bridges and gates, for both right and left hand sides of the paved and unpaved transects), were recorded (Figure 4.7; Table 4.5).

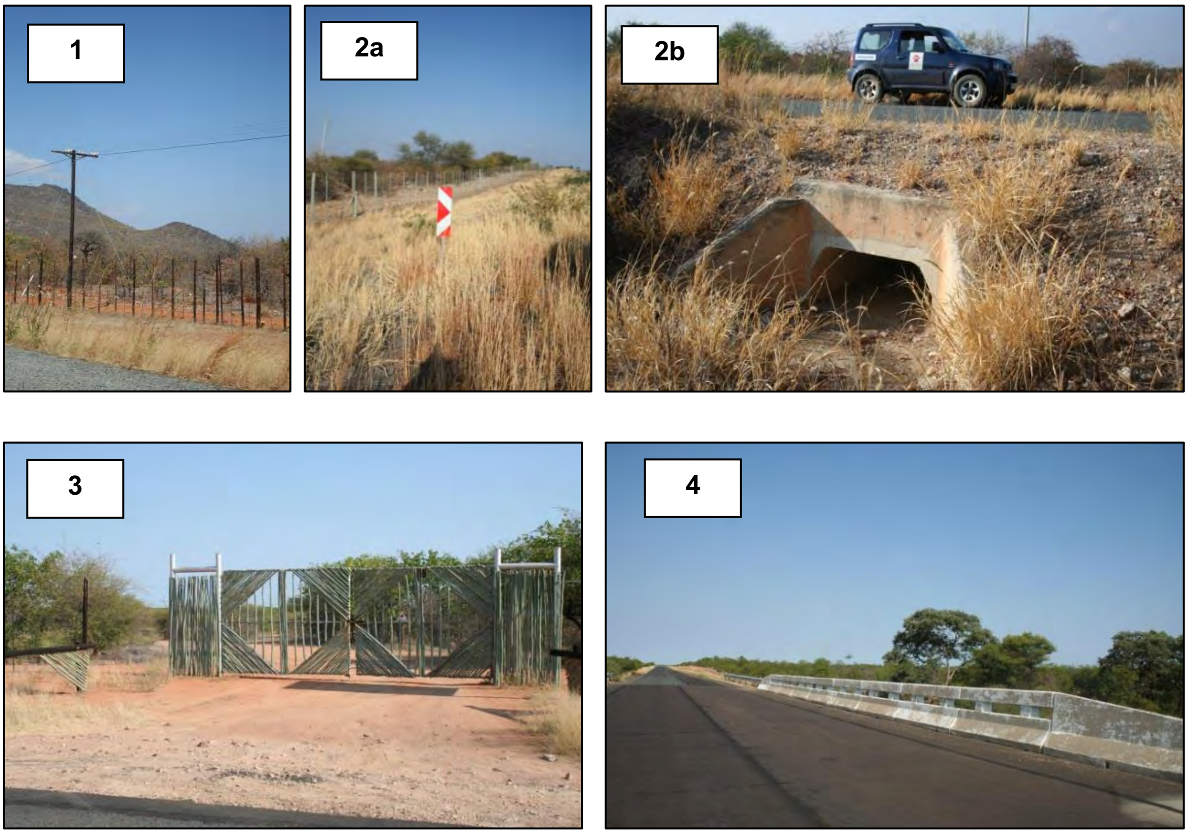

Figure 4.7: Photographs of the four different physical road characteristics (1) telephone pole, (2a/b) culvert, (3) gate, (4) bridge, observed on the transect roads in the GMTFCA, South Africa.

Table 4.5: The major characteristics of the paved and unpaved transects, showing the number of occurrences of each feature on both sides of the road.

Road characteristic	Number of occurrences	
	100 km (paved road)	20 km (unpaved road)
Culvert	202	0
Bridge	10	0
Gate	49	15
Junction	11	2
River crossing	11	0

The method used by Conard and Gipson (2006) was adapted to measure fence type and the distance of a fence from the road verge. As fences were permanent structures, fence type and the distance from the verge to the fence were assumed to remain constant during the study. By measuring the extent (km) of each fence type in the same way as for vegetation coverage (described earlier), both sides of the paved and unpaved roadways were classified as either cattle (C), game (G), electric (E), cattle/electric combined (CE), gate (G) or bridge/barrier (B); (Figure 4.8; Table 4.6). The cattle/electric combined fence consisted of cattle fencing nearest the road verge with the electric fence ~20 m further away.

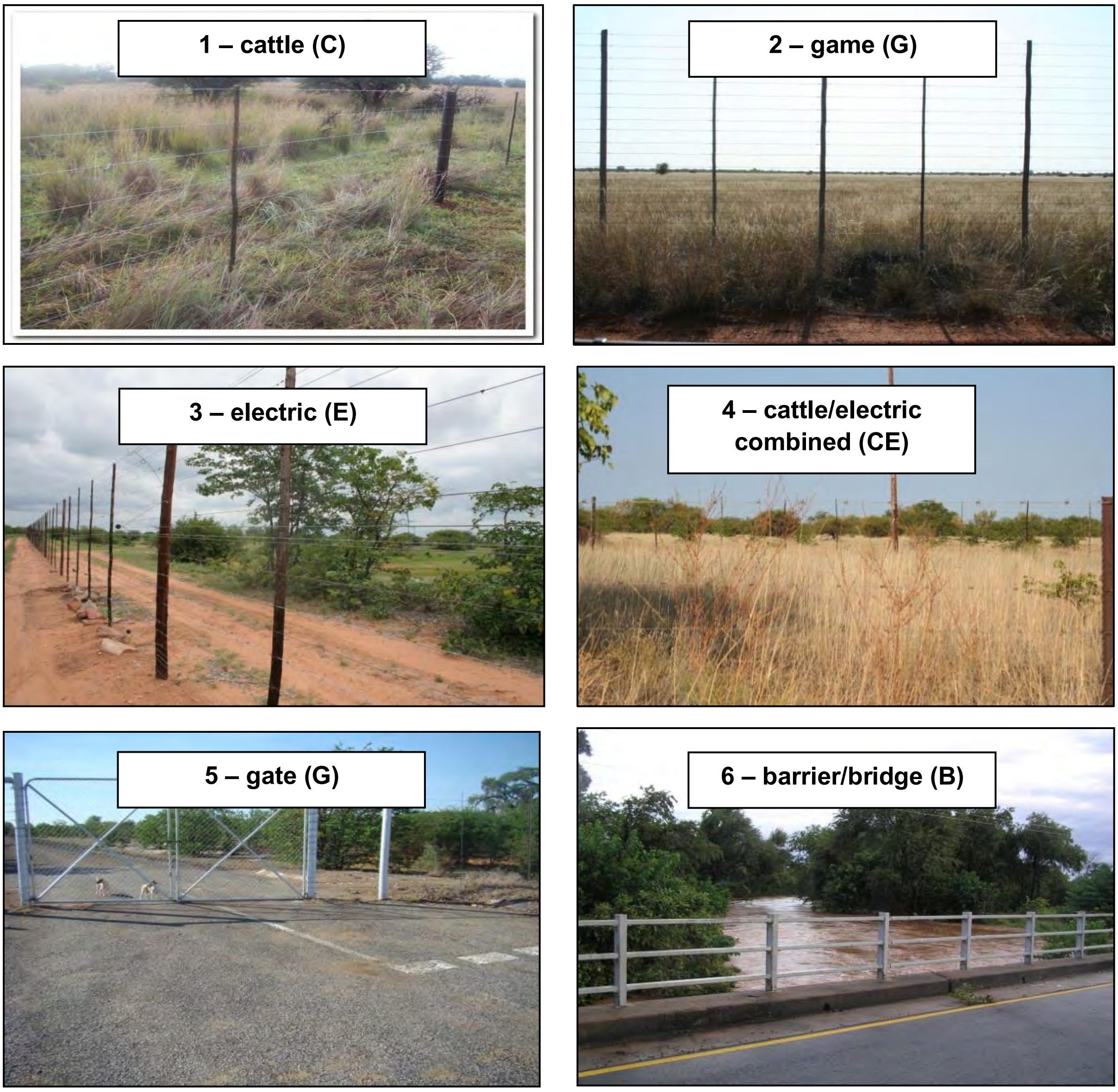

Figure 4.8: Photographs representing the six different fence types on the transect roads in the GMTFCA, South Africa.

Table 4.6: The proportions (in descending order) of each of the four fence types (cattle (C), game (G), electric (E), cattle/electric combined (CE)), along (a) the 100 km paved road and (b) the 20 km unpaved road in the GMTFCA, South Africa.

(a) Paved road		
Fence type	**Total (km)**	**%**
G	100.4	50.2
E	59.1	29.6
C	39.3	19.6
C/E	1.2	0.6
Total	200	100

(b) Unpaved road		
Fence type	**Total (km)**	**%**
G	18.7	46.8
C/E	10.1	25.2
C	8.8	22.0
E	2.4	6.0
Total	40	100

The distance of the fence from the verge (m) was visually estimated and placed into one of five categories (Table 4.7).

Table 4.7: The proportions of each of the five categories of fence distance from road verge (m) along (a) the 100 km paved road and (b) the 20 km unpaved road (b) in the GMTFCA, South Africa.

Fence distance from verge (m)	**(a) Paved Road**		**(b) Unpaved Road**	
	Total (km)	**%**	**Total (km)**	**%**
< 5	10.6	5.3	16.9	42.2
Between 5 & 9	102.3	51.2	18.0	45.0
Between 10 & 14	77.4	38.6	2.7	6.8
Between 15 & 19	7.2	3.6	1.8	4.5
20 & > 20	2.5	1.3	0.6	1.5
Total	200	100	40	100

Both fence type and fence distance were then recorded for paved and unpaved roads and for both sides of the road each time a roadkill was detected.

2.2.4 Human road usage characteristics

Traffic volume, traffic speed and vehicle classification

Traffic volume is a count of the number of vehicles that use a road each day (Transportation Research Board 1998). Two methods of counting traffic were employed: observational and sensor techniques. Observational traffic counts were conducted on the unpaved and paved road during the cold/dry season between 06h00 and 18h00 on four randomly selected days (two weekdays and two weekends) and recorded vehicle type and traffic volume. Sensor techniques were conducted during the three seasons of data collection and used a PicoCount 2500 Traffic Counter (PicoCount 2500 Traffic Counter Manual 2009; VehicleCounts.com 2012) as a vehicle counter in combination with TrafficViewer Pro software (version 1.3.1.79, VehicleCounts.com © 2008-2011) which calculated traffic volume, speed and vehicle classification.

Speed was measured in $km.h^{-1}$ divided among 15 equal categories, starting at 5 $km.h^{-1}$ and finishing at 159 $km.h^{-1}$.

Vehicle classification schemes use vehicular axle spacings to separate vehicles into a number of classes of vehicles (Table 4.8). The United States Federal Highway Administration (FHWA 2001) scheme administers 13 classes of vehicles whilst South Africa only uses four (AA South Africa 2012). The FHWA scheme was the model used in my study as it allowed a more detailed description of traffic classes.

Table 4.8: Classification scheme of the 13 categories for vehicles as used by the Federal Highway Administration (FHWA/USA).

Classification scheme (FHWA)		
Class	Vehicle description	Number of axles
1	Motorcycles	2
2	Passenger	2
3	Pickup trucks, vans	2
4	Buses	No data
5	Single unit	2 (6 tyres)
6	Single unit truck	3
7	Single unit	4
8	Single unit	4 or less
9	Double unit	5
10	Double unit	6 or more
11	Multi-unit	5 or more
12	Multi-unit	6
13	Multi-unit	7 or more

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Setting up the traffic counter and road tube

For studies of volume, a single traffic tube is needed. However, in order to measure speed, volume and vehicle classification, a two-tube set up is required (PicoCount 2500 Traffic Counter Manual 2009; VehicleCounts.com 2012). This requires two traffic tubes cut to the same length, mounted parallel to each other with a spacing of between 30 to 500 cm. The accuracy of the speed calculation (and hence the classifications) depends on the parallel tubes being maintained at a precise spacing. For example, if the default traffic tube spacing is 100 cm, a 1 cm error in traffic tube spacing would result in a 1% error in the calculations (PicoCount 2500 Traffic Counter Manual 2009).

To measure volume, speed and classification, two traffic tubes were placed parallel across the lane with a spacing of 150 cm, since the wider the spacing the smaller the error (~10%; PicoCount 2500 Traffic Counter Manual 2009). Once the traffic tubes were set, they were connected to the PicoCount 2500 (Figure 4.9).

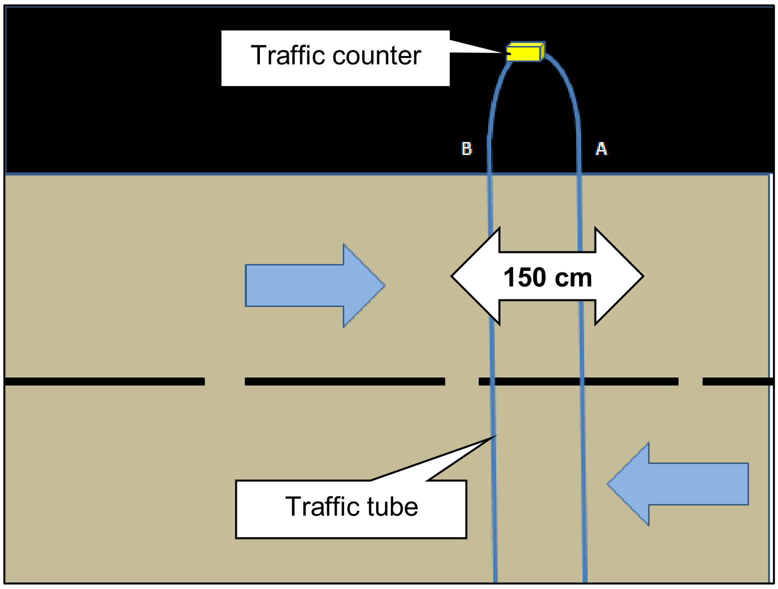


Figure 4.9: A diagrammatic representation of the dual traffic tube set up on the R572 paved road used to measure traffic volume, speed and vehicle class in the study. The arrows indicate the direction of traffic.

Round traffic tubes were selected for use in this study as they are considered to be the most popular and easiest to use since it has good resistance to wear and generates healthy air pulses (PicoCount 2500 Traffic Counter Manual 2009). To attach the traffic tube, an anchor and a grip were used. An anchor is the device attached to the roadway or shoulder that the traffic tube will be attached to and a grip is the device used to attach the traffic tube to an anchor. The traffic tube was anchored with a “figure-8” grip to the tarmac in the centre of the road using 150 mm masonry nails (Figure 4.10a). Figure-8 grips are made from a thick gauge of stainless steel formed into a loop that is pinched near one end and are attached to the tube (Figure 4.10b). Black duct-tape was also used to prevent the traffic tube from bouncing after being driven over (Figure 4.10c).

Figure 4.10: Photographs demonstrating the attachment of the road traffic tube to the paved road showing (a) the detail of the figure-8 grip (PicoCount 2500 Traffic Counter Manual 2009), (b) the attachment of the traffic tube to the paved road surface using a 150 mm masonry nail to secure the figure-8 grip and, (c) the detail of the attached traffic tube showing duct tape and 150 mm masonry nail to secure it in place.

A “Chinese finger” grip (Figure 4.11a) was attached to either end of the traffic tube (Figure 4.11b) at the roadway shoulder and then secured to the tarmac using 150 mm masonry nails. Chinese fingers are made from stainless steel wire formed into a patented web pattern that grips the traffic tube in such a way that it will not pinch shut, or slip (PicoCount 2500 Traffic Counter Manual 2009).

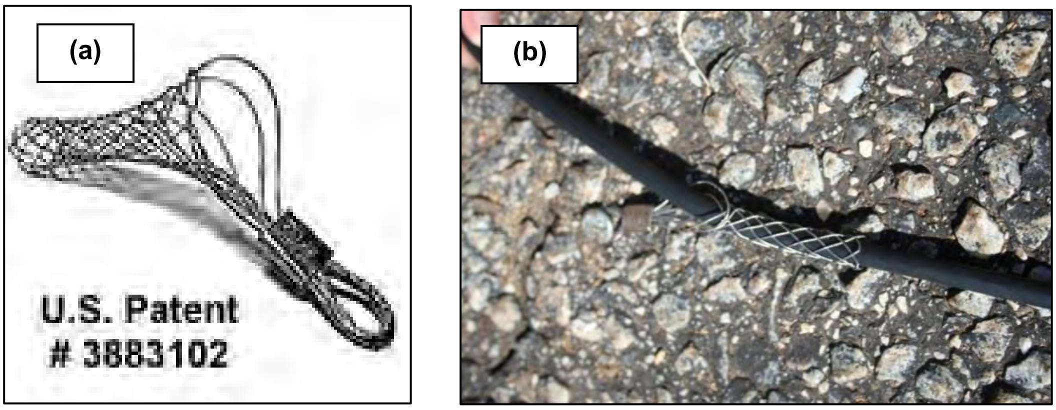


Figure 4.11: Photographs demonstrating the attachment of the road traffic tube to the paved road showing (a) the detail of the Chinese finger grip (Vehiclecounts.com 2009), and (b) the attachment of the Chinese finger grip to the traffic tube with the grip secured to the road surface by a 150 mm masonry nail.

One end of the traffic tube was then attached to the PicoCount 2500 traffic counter (Figure 4.12a) and the other was plugged to prevent moisture, dirt, and grit from entering the tube (Figure 4.12b). This was done to prevent the air switches from becoming become clogged and non-functional. The PicoCount 2500 traffic counter was padlocked and chained to a sign post to prevent possible theft.

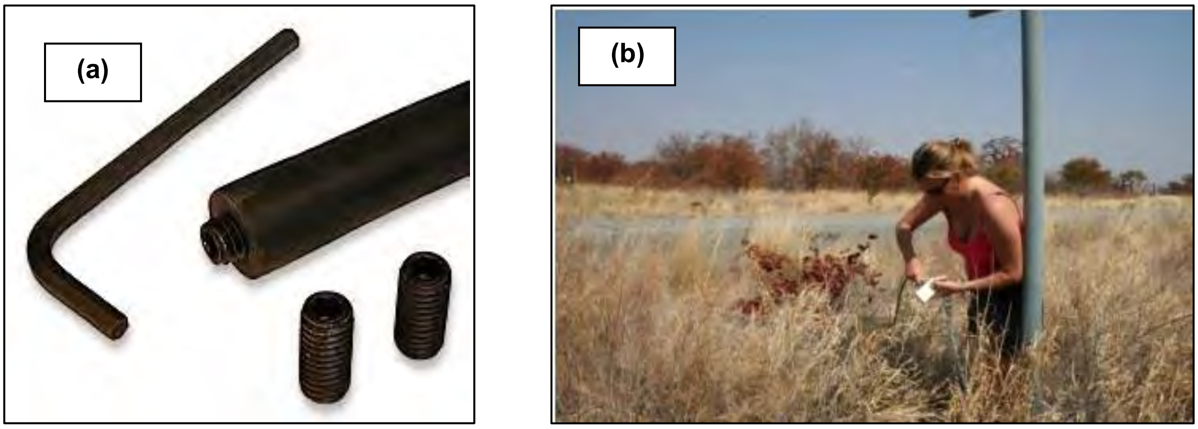


Figure 4.12: Photographs demonstrating the attachment of the traffic tube to the traffic counter showing (a) the detail of the traffic tube plug with the tools needed to plug the end of the tube (PicoCount 2500 Traffic Counter Manual 2009), and (b) the attachment of the PicoCount 2500 traffic counter to the traffic tube and chained to a sign post.

A 100 m straight, smooth and flat section of paved road was selected so that both tyres of the vehicle passed over the traffic tube simultaneously, and vehicle speed was consistent and not impeded by a hill or any other obstacles on the road, such as potholes (PicoCount 2500 Traffic Counter Manual 2009).

The distance between the two traffic tubes was measured at three different points on the road (both right and left road verges and the centre) to ensure that the traffic tubes were set up accurately and were not angled (Figure 4.10). Once the traffic tube was set and anchored, it was put under tension so that it lay flat across the road. This was done by pulling the traffic tube tight and stretching it to a recommended 110% of the original traffic tube length (PicoCount 2500 Traffic Counter Manual 2009).

Figure 4.10: A photograph demonstrating the placement of the two traffic tubes (150 cm apart) on the paved road with a tape measure at the centre point to ensure accurate placing of the figure-8 grip.

The PicoCount 2500 was removed at the end of each season so that the data could be downloaded and analysed using the TrafficViewer Pro software.

During the hot/dry season, two multi-traffic tubes were set up on the northern paved road, R572, and the southern paved road (paved by Venetia Mine; Figure 4.3b).

The traffic tube on the southern paved road was damaged on day 18 of the field transects during the hot/dry season and as a result, speed and class were not recorded for the final 22 days. Traffic volume was still recorded for the duration of the study, since only one traffic tube was damaged. However, the traffic tube, PicoCount 2500 traffic counter and security chain were stolen on day 26.

A multi-traffic tube was set up on the northern paved road, R572, but only 20 days were recorded during the hot/wet season and 39 days during the cold/dry season (Figure 4.3b). This was due to it being stolen on day 38, although the PicoCount 2500 traffic counter was not taken.

The traffic tube was not set up on the unpaved road, since the substrate was mainly sand and there were no points available to anchor the tubes. Manual observational traffic counts were conducted on the unpaved road instead and compared to traffic count data collected on the paved road.

2.2.5 Animal behaviour

The activity period of each roadkill species was recorded as either diurnal, nocturnal or crepuscular by reference to literature (Branch 1998; Hockey *et al*. 2005; Skinner & Chimimba 2005; Carruthers & du Preez 2011). The presence of ‘live’ animals present on the road verge, perched on fence posts or feeding on roadkill carcasses, was also noted. The same was done for both paved and unpaved roads (Appendix D). Roadkill carcasses were only counted as data if they were detected on the road. Any carcasses discovered off-road were not considered as part of the data but were recorded in the ‘additional comments’ on the data sheet. Off-road carcasses were not recorded due to bias in detection, for example, a roadkill carcass is easily visible where there is no grass on the road verge, but less easy to detect when the grass is high or dense (Noss 2002).

2.2.6 The characteristics of roadkill (observed) and control sites (expected)

To assess whether the characteristics of roadkill sites differed significantly from sites where no roadkill were recorded, a series of control points was generated on the paved and unpaved roads using a Random Number Generator (RNG; Microsoft Office Excel 2010). Based on the average roadkill rate detected during preliminary transects conducted in March 2011 (see Chapter 3), 10 random points per day were generated for the paved road and 1 random point was generated for the unpaved road. Each point was generated from a number range (1-1000) that corresponded to an actual distance along the transect and each position was separated by 100 m. Thus, the number one represented 0.0 km along the transect and the number 1000 represented 100 km along the transect. Different random points were generated for each day. If an actual roadkill was detected within 100 m of the randomly generated point, then another 100 m was driven to record the next non-roadkill point. This was to ensure that the randomly generated points did not reflect actual roadkill sites on the day the roadkill occurred, and so an arbitrary distance of 100 m was set to separate these characteristics. At each random point, the characteristics were recorded for both sides of the road.

A photograph, the position on the road, and a GPS reading (using a Garmin eTrex) was taken of each carcass to avoid recounts on consecutive days.

2.3 A summary of the statistical procedures

Roadkill data were divided into the four vertebrate classes, Amphibia, Reptilia, Aves and Mammalia for each season (hot/dry, hot/wet and cold/dry). A fifth class was added to include roadkill that could not be identified beyond Phylum, Vertebrata, and was classed as ‘unknown’. Each class was then further divided into orders and families, and arranged according to genus and species (Branch 1998; Hockey *et al*. 2005; Skinner & Chimimba 2005; Carruthers & du Preez 2011). Each species was categorised as either nocturnal, diurnal, crepuscular, or both diurnal and nocturnal (Branch 1998; Hockey *et al*. 2005; Skinner & Chimimba 2005; Carruthers & du Preez 2011). Roadkill rate per day and rate per km was also examined for each class. All statistical analyses were conducted using Statistica (v10, StatSoft, Inc. Tulsa, OK

2011). Tests are deemed significant at $p < 0.05$ (Fowler *et al.* 2009). All ANOVAs were preceded by tests for homogeneity of variance. Scheffé's post-hoc range tests were used to examine differences among means when the p-value was significant.

Data from the 20 km sub-transect of the paved road that was driven pre-dawn, post-dawn and post-dusk was used to test the effect of animal pattern and season, and the effect of season and time of day on the occurrence of roadkill. The 100 km transect data was used to analyse the effects of the seventeen variables on roadkill.

Categorical and continuous variables were split into three broad categories: biophysical, environmental and physical (Table 4.3). Roadkill data were then analysed within each of these three categories for both the paved and unpaved roads to assess the effect of each variable on the occurrence of roadkill. These procedures were then repeated for the randomly selected sites (control sites) on both the paved and unpaved roads and comparisons of the characterics of roadkill and control sites made.

3 RESULTS

3.1 Overall results

During the 120 days of the study (40 days per season), a total of 18,000 km were driven. A total of 522 hours were driven with a daily average of 180 minutes (range 132 – 278 minutes) on the 100 km paved road and 33 minutes (range 22 – 66 minutes) on the 20 km unpaved road.

A total of 991 roadkill were observed on the 100 km paved road transect and 36 roadkill on the unpaved road. These comprised 162 species from 24 orders and 65 families and 93 individual roadkill that could not be identified to species level. These roadkill were classified to genus (25), family (12), order (19) or class (29) depending on the state of the remains. Only eight roadkill were completely unidentifiable and could not be classified further than Vertebrata (Appendix B).

3.1.1 Roadkill rates

With all the data pooled for each road type, the number of roadkill differed significantly between road type and season (χ^2 = 11.40; df = 2; p <0.05). On both road types the proportion of roadkill was greatest in the hot/wet season and lowest in the cold/dry season (Table 4.9). On the paved road, numbers of roadkill in the two hot seasons were similar (Table 4.9).

Table 4.9: Number of roadkill detected per season on the 100 km paved road and the 20 km unpaved road in the GMTFCA, South Africa.

Season	Number of roadkill detected (100 km paved road)	Number of roadkill detected (20 km unpaved road)	Season totals
Hot/dry	376	9	385
Hot/wet	416	25	441
Cold/dry	199	2	201
Total	**991**	**36**	**1027**

When these data were further stratified by vertebrate class, the highest roadkill rates on both road types in the hot/dry and hot/wet seasons were for birds, while in the cold/dry season, it was for mammals (Table 4.10). Roadkill rates were highest for all classes except mammals in the hot/wet season, lower in the hot/dry season and very low in the cold/dry season (Table 4.10). Across all three seasons, roadkill rates were highest for birds, lower but similar for reptiles and mammals and lowest for amphibians (Table 4.10).

3.1.2 The effect of animal activity pattern and season on roadkill

All of the amphibian species and 62% of all mammalian species were nocturnal (Appendix B). The reptiles were more evenly balanced, with 47% of roadkill species being diurnal and 41% nocturnal (Appendix B). By contrast, the majority of the birds (80%) were diurnal (Appendix B).

In this analysis, data from the 20 km sub-transect of the paved road that was driven pre-dawn (n=26 roadkill), post-dawn (n=61 roadkill) and post-dusk (n= 27 roadkill) was used to analyse the effect of animal activity pattern and season on roadkill. In a two way ANOVA with activity pattern and season as predictor variables and roadkill rate per km as the dependent variable, there was a significant effect of activity pattern ($F_{4,15}$ = 9.29; p <0.05: Figure 4.11) with significantly more nocturnal species killed than species in any other animal activity category. This trend was similar in each of the three seasons and there was no effect of season ($F_{2,15}$ = 0.18; p = 0.83). There was no significant interaction between animal activity and season ($F_{4,15}$ = 1.06, p = 0.44).

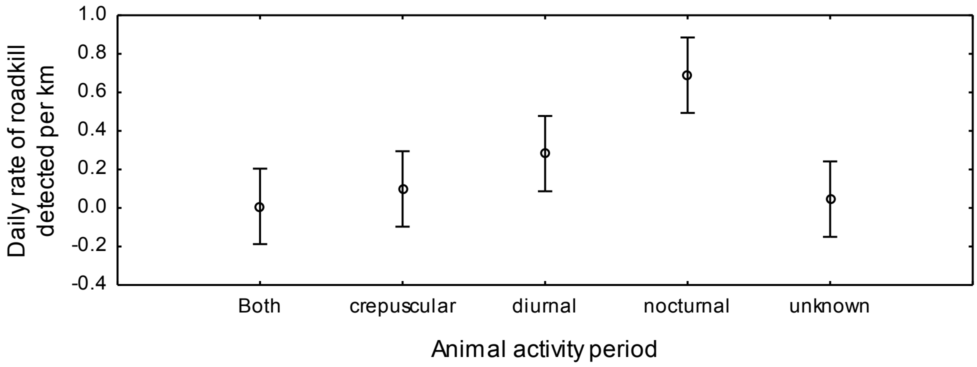


Figure 4.11: The rate of roadkill (all species combined) detected per km for diurnal and nocturnal species (data are means ± 95% CI) along a 100 km section of paved road and 20 km section of unpaved road in the GMTFCA, South Africa during the three ecological seasons.

Table 4.10: Roadkill rates for each class detected across three ecological seasons on the GMTFCA, South Africa (a) paved road, (b) unpaved road. (For identified species only.) The highest rate per season is highlighted in bold.

(a) Paved	**Hot/dry**			**Hot/wet**			**Cold/dry**			**All 3 seasons**		
Taxa	Rate per km	Rate per day	Number of species	Rate per km	Rate per day	Number of species	Rate per km	Rate per day	Number of species	Rate per km	Rate per day	Number of species
Amphibia	0.4	1.0	2	0.1	0.2	2	0.0	0.0	0	0.2	0.4	3
Reptilia	0.9	2.3	22	1.3	3.6	27	0.1	0.2	7	0.8	2.0	34
Aves	**1.4**	**3.4**	**49**	**2.2**	**5.6**	**52**	0.8	2.0	**21**	**1.5**	**3.7**	**81**
Mammalia	1.0	2.6	28	0.7	1.8	24	**1.0**	**2.8**	19	1.0	2.4	44
Total	3.7	9.3	101	4.3	11.2	105	2	5	47	3.4	8.5	162

(b) Unpaved	**Hot/dry**			**Hot/wet**			**Cold/dry**			**All 3 seasons**		
Taxa	Rate per km	Rate per day	Number of species	Rate per km	Rate per day	Number of species	Rate per km	Rate per day	Number of species	Rate per km	Rate per day	Number of species
Amphibia	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0
Reptilia	0.0	0.0	0	0.1	0.1	2	0.0	0.0	0	0.1	0.0	2
Aves	**0.3**	**0.1**	**4**	**0.9**	**0.4**	**11**	0.0	0.0	0	**0.2**	**0.2**	**16**
Mammalia	0.2	0.1	2	0.3	0.2	2	**0.1**	**0.1**	2	0.2	0.1	3
Total	0.5	0.2	9	1.3	0.7	25	0.1	0.1	2	0.5	0.3	36

Five hundred and eighty eight live animals (Appendix D) were observed either crossing the road or feeding on the road verge on the 100 km paved road transect over a period of 120 days. Of these, 13% occurred during the hot/dry season, 35% during the hot/wet, and 52% during the cold/dry. This was despite there being less roadkill during the cold/dry season. Mammals were the most visible class accounting for 67% of the sightings during the hot/dry season, and 70% during the cold/dry season with the two most common species being Warthog (*Phacochoerus africanus)* and Chacma baboon (*Papio hamadryas)*. Reptiles were most visible during the hot/wet season (48%) with the Flap-neck Chameleon (*Chamaeleo dilepsis)* being the most sighted. Individual bird species were not counted unless it was a bird of prey or they were in flocks (such as Helmeted Guineafowl *Numida meleagris*).

3.1.3 The effects of time of day and season on the occurrence of roadkill

The 20 km sub-transects of the paved road (pre-dawn, post-dawn and post-dusk) was used to test if time of day and season affected the occurrence of roadkill. In a two way ANOVA with roadkill/km as the dependent variable and time of day and season as predictor variables, there was a significant effect of time of the day ($F_{2,291}$ = 18.67, p <0.05; Figure 4.12) and significantly more roadkill was detected 1.5 hours after sunrise than in the pre-dawn (1.5 hours before sunrise) and post-dusk (1.5 hours after sunset) periods (Figure 4.12). There was a significant effect of season ($F_{2,291}$ = 3.84 p = 0.02; Figure 4.12) with more roadkill/km in the hot/dry season than any other season. There was no significant interaction between season and the time of day when roadkill was detected ($F_{4.291}$ = 1.5, p = 0.2; Figure 4.12).

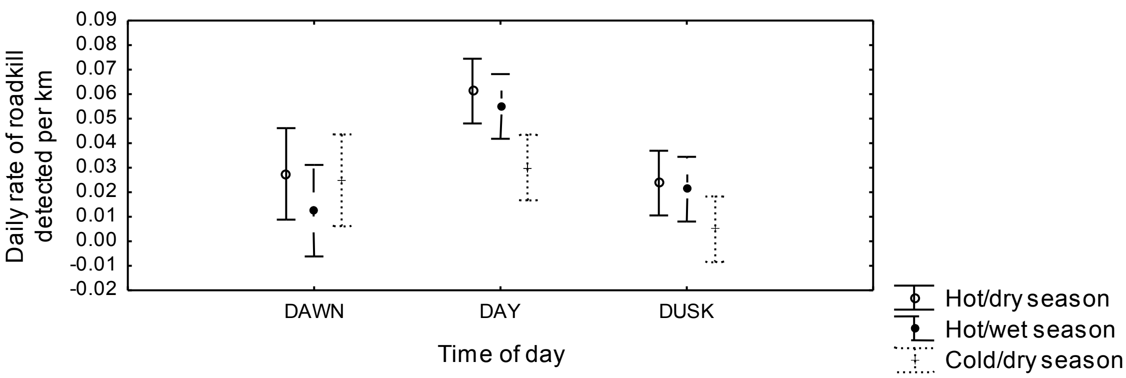


Figure 4.12: The rate of roadkill detected per km at three different times of day within a 24 hour period and the three ecological seasons along a 20 km section of paved road in the GMTFCA, South Africa species (data are means ± 95% CI).

3.2 The effects of biophysical factors on the occurrence of roadkill on paved and unpaved roads

3.2.1 Season

Season had a significant effect on roadkill numbers on the paved road (one way ANOVA; $F_{2,117} = 19.037$, $p < 0.05$; Figure 4.14a) with significantly more roadkill per day occurring during the hot/wet and hot/dry seasons than during the cold/dry season (Figure 4.13a). Season had no significant effect on the number of roadkill detected per day on the unpaved road (one way ANOVA; $F_{2,20} = 0.49$, $p = 0.62$; Figure 4.13b).

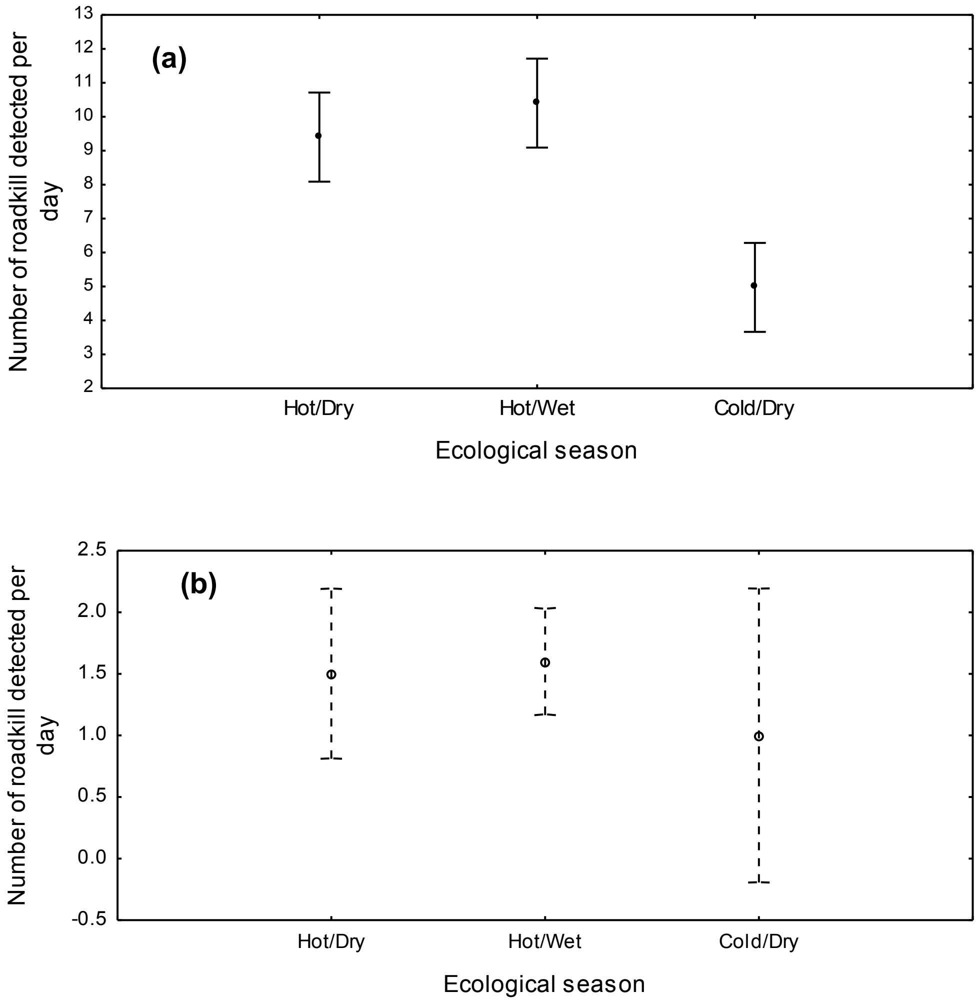


Figure 4.13: The difference between the three ecological seasons and the number of roadkill detected per day (data are means ± 95% CI) along (a) a 100 km section of paved road and (b) a 20 km section of unpaved road in the GMTFCA, South Africa.

3.2.2 Rainfall

Rainfall is ordinarily a continuous variable but in this analysis, it was categorised into days in which rain had fallen in the preceding 24 hours and days when no rain had fallen in the preceding 24 hours. A t-test was used to assess the difference between the number of roadkill detected per day on days when no rainfall had fallen and when it had rained in the preceding 24 hours. Rainfall was selected as a categorical variable due to the poor rains experienced in the region during the study, and was therefore erratic. The highest rainfall occurred during the hot/dry season (28.6 mm), with 18.5 mm during the hot/wet season. No rain fell during the cold/dry season.

Rain in the preceding 24 hours had a significant effect on roadkill on the paved roads, with more roadkill observed per day when rain had fallen 24 hours prior to the assessment than when it had not (t_{118} = -3.4, p <0.05; Figure 4.14a). There was no significant effect of rain in the preceding 24 hours on the unpaved road (t_4 = -0.32_{118}, p = -0.75; Figure 4.14b).

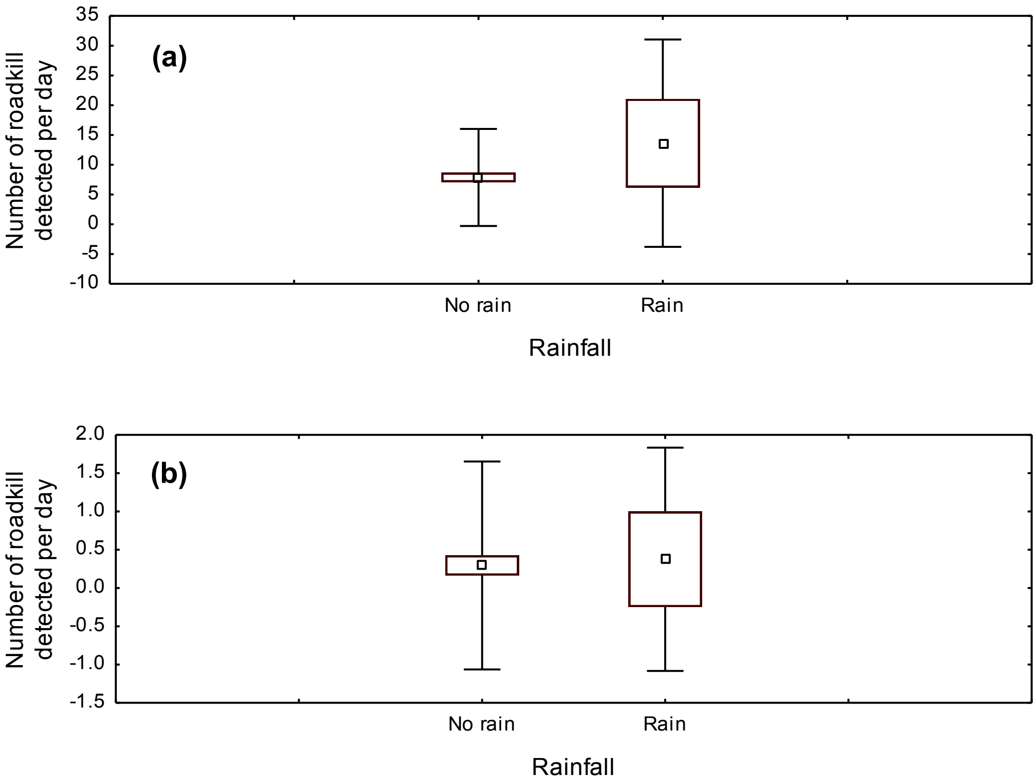
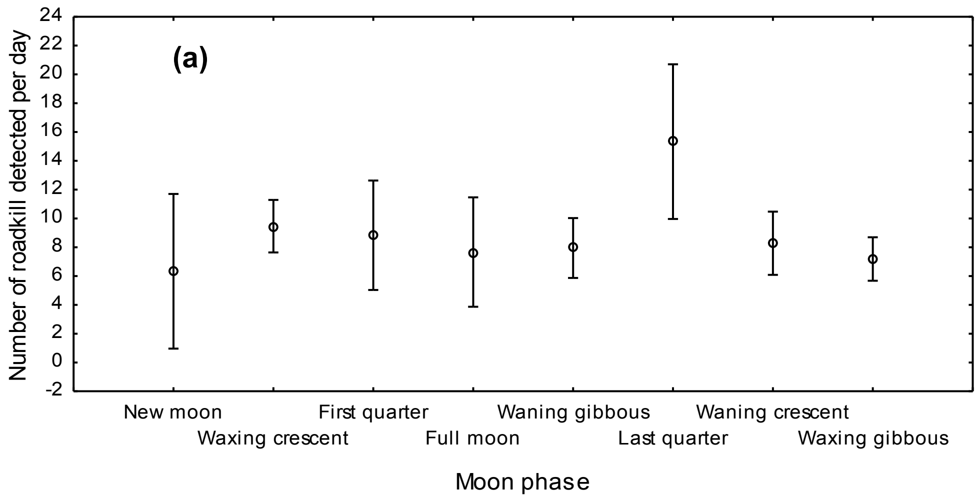


Figure 4.14: The difference between the number of roadkill detected per day on days when no rainfall had fallen in the preceding 24 hours, and days when rainfall had not fallen (± 95% CI) along (a) a 100 km section of paved road and (b) a 20 km section of unpaved road in the GMTFCA, South Africa.

3.2.3 Moon phase

Moon phase had no significant effect on the number of roadkill detected per day on the paved road (one way ANOVA; $F_{7,112}$ = 1.6, p = 0.98 ; Figure 4.15a) or on the unpaved road (one way ANOVA; $F_{7,15}$ = 0.3, p = 0.96; Figure 4.15b).



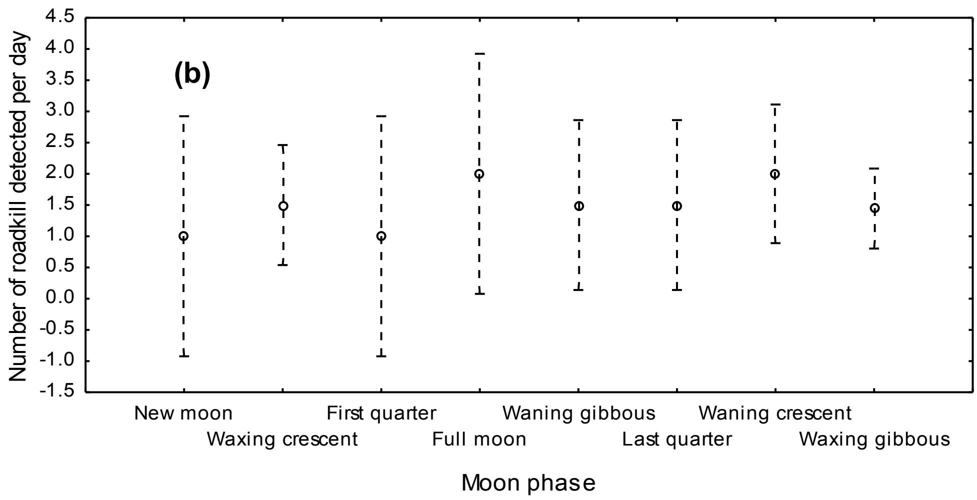
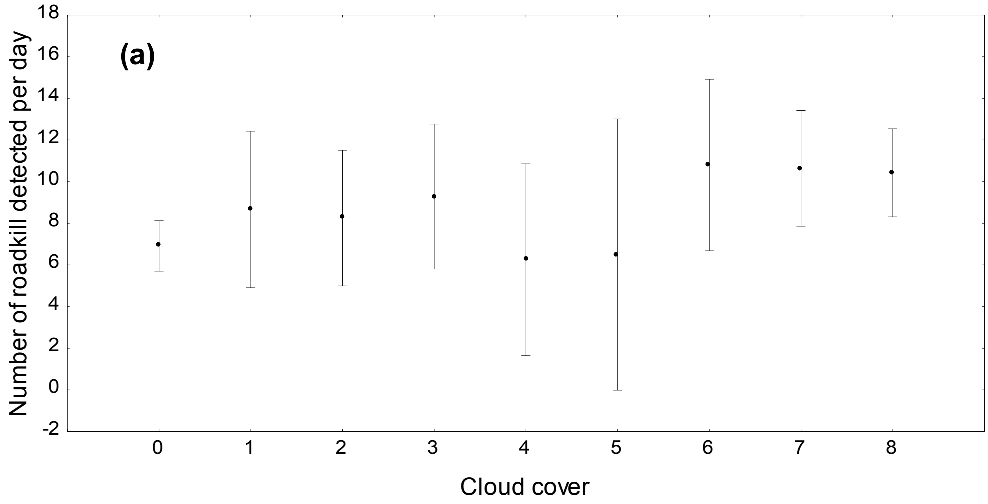


Figure 4.15: The difference between the number of roadkill detected per day and moon phase (data are means ± 95% CI) along (a) a 100 km section of paved road and (b) a 20 km section of unpaved road in the GMTFCA, South Africa.

3.2.4 Cloud cover

There was no significant effect of cloud cover on the number of roadkill detected per day on either the paved (one way ANOVA; $F_{8,111} = 1.84$; p = 0.8; Figure 4.16a) or unpaved roads (one way ANOVA; $F_{8,14} = 0.67$; p = 0.7; Figure 4.16b).



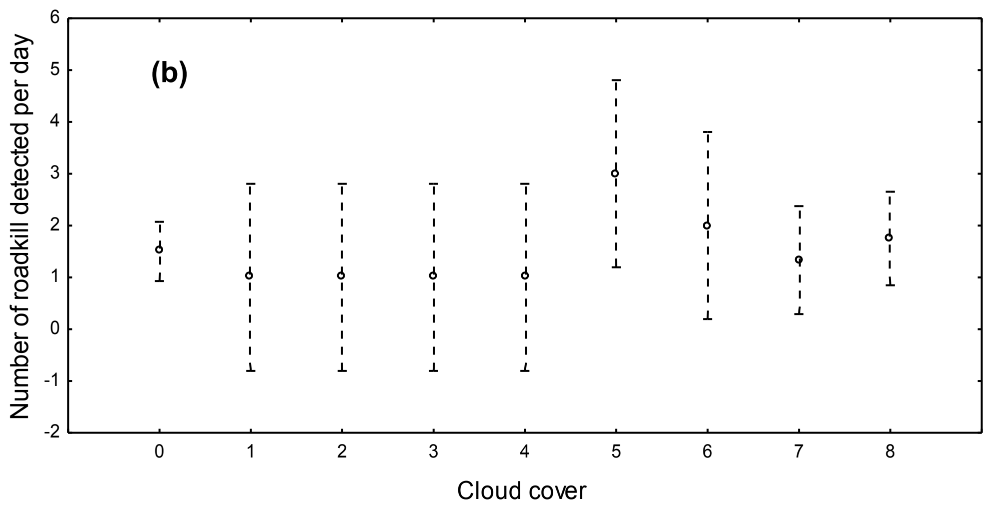


Figure 4.16: The difference between the number of roadkill detected per day and cloud cover (data are means ± 95% CI) along (a) a 100 km section of paved road and (b) a 20 km section of unpaved road in the GMTFCA, South Africa.

3.2.5 Humidity

A simple regression was used to examine the relationship between humidity and the number of daily roadkill. There was no significant relationship between humidity and roadkill detected per day on the paved road (adjusted R^2 = -0.007; $F_{1,118}$ = 0.86; p = 0.77; Figure 4.17a) or on the unpaved road (adjusted R^2 = -0.0077; $F_{1,21}$ = 0.09; p = 0.77; Figure 4.17b). While the linear relationships between the variables were significant, the low r^2 indicates that the data points are scattered away from the best-fit line and that the independent variable was a poor predictor of the dependent variable.

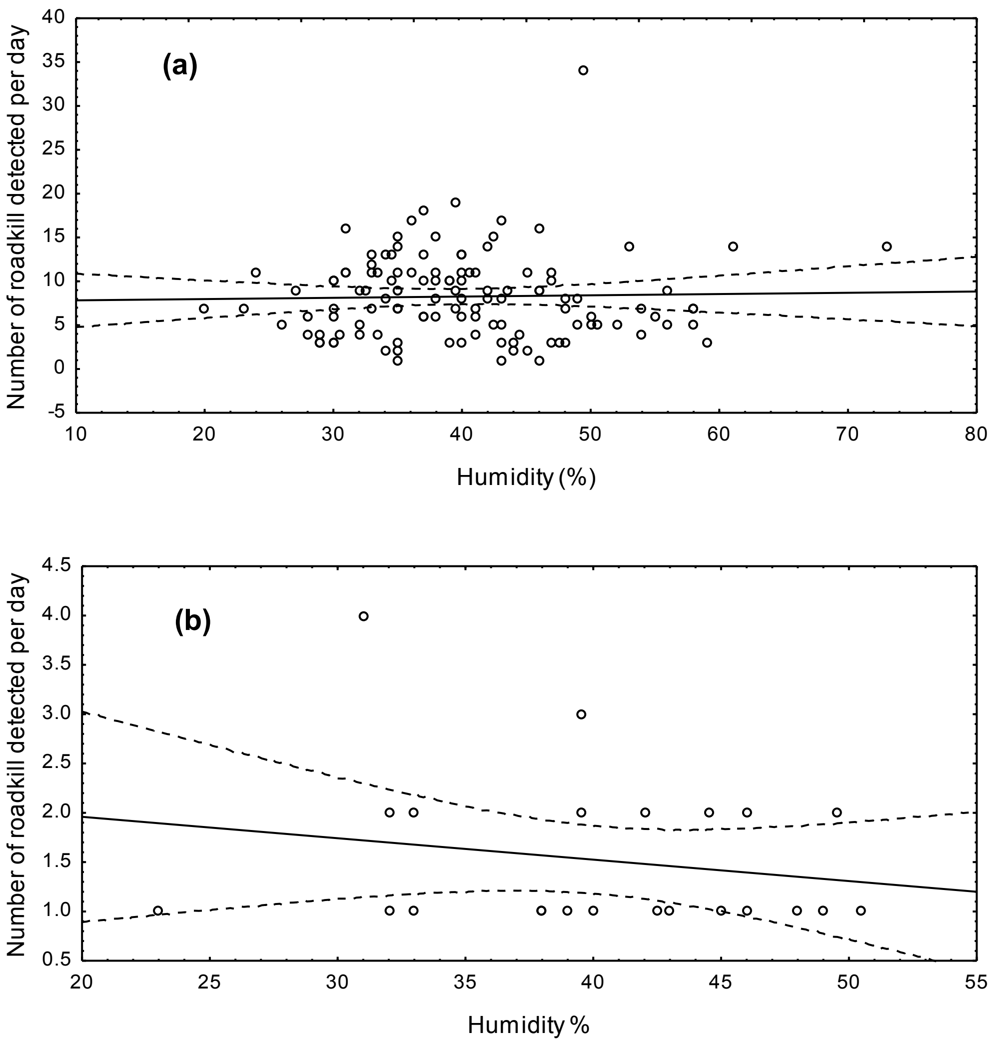


Figure 4.17: The relationship between the number of roadkill detected per day and humidity along (a) a 100 km section of paved road and (b) a 20 km section of unpaved road in the GMTFCA, South Africa, (dashed line = 95% CI).

3.2.6 Minimum temperature

A simple regression was used to examine the relationship between minimum temperature and the number of daily roadkill. There was a significant relationship between minimum temperature and roadkill on the paved road (adjusted $R^2 = 0.16$; $F_{1,118} = 23.79$; $p < 0.05$; Figure 4.18a) with more roadkill detected per day as the temperature increased. There was no significant relationship between minimum temperature and roadkill on the unpaved road (adjusted $R^2 = -0.03$; $F_{1,21} = 0.59$; $p = 0.29$; Figure 4.18b).

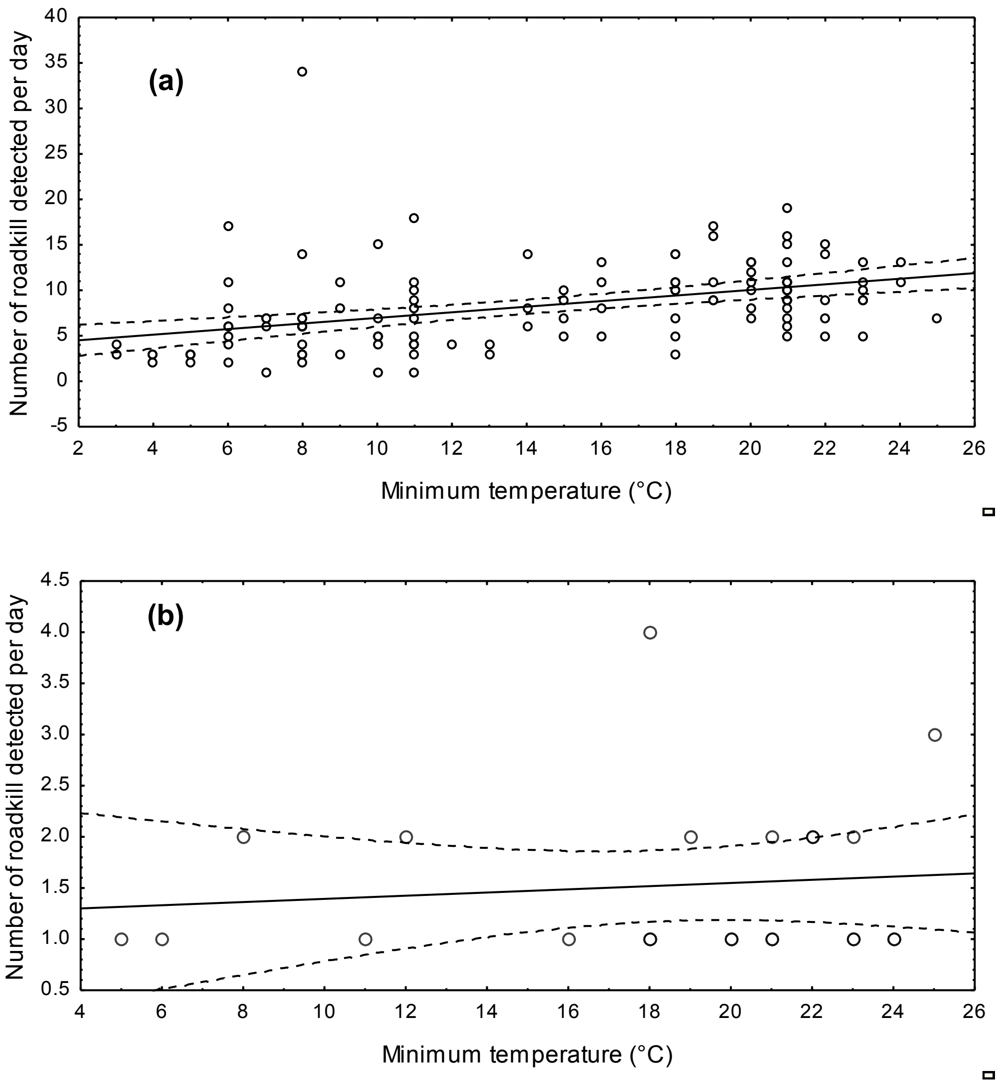


Figure 4.18: The relationship between the number of roadkill detected per day and minimum temperature (data are means ± 95% CI) along a (a) 100 km section of paved road and (b) 20 km section of unpaved road in the GMTFCA, South Africa, (dashed line = 95% CI).

3.2.7 Maximum temperature

A simple regression was used to examine the relationship between maximum temperature and the number of daily roadkill. There was also a significant relationship between maximum temperature and roadkill on the paved road (adjusted R^2 = 0.09; $F_{1,118}$ = 12.89; p <0.05; Figure 4.19a) with more roadkill detected per day when temperature increased (Figure 4.19a). There was no significant relationship between maximum temperature and roadkill on the unpaved road (adjusted R^2 = -0.02; $F_{1,21}$ = 0.47; p = 0.49; Figure 4.19b).

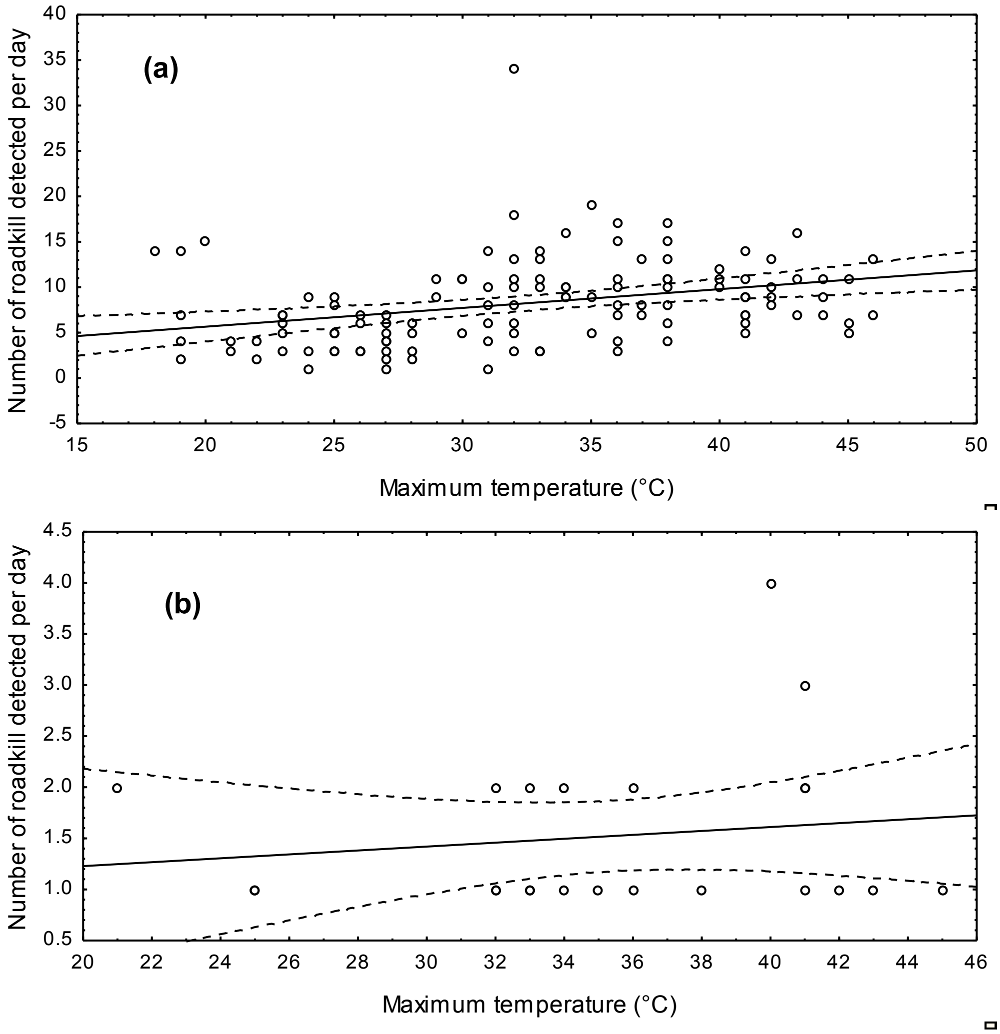


Figure 4.19: The relationship between the number of roadkill detected per day and maximum temperature (data are means ± 95% CI) along a (a) 100 km section of paved road and (b) 20 km section of unpaved road in the GMTFCA, South Africa, (dashed line = 95% CI).

3.3 The effect of environmental factors on the occurrence of roadkill on paved and unpaved roads

In these analyses, roadkill rate is expressed by km of the feature to control for the differences in the relative sizes (length or proportion of the full transect) of the various habitat features.

3.3.1 Vegetation type

There was a significant difference in the number of roadkill detected per km in each of the nine vegetation types on the paved road (one way ANOVA; $F_{8,1071} = 8.09$, $p < 0.05$; Figure 4.20a) with significantly more roadkill in open *Mopane* (MO) than in dense *Mopane* (MD), open mixed bushveld (XO), dense mixed bushveld (XD), *Vachellia* (A), Riparian (R), and other (O). Significantly more roadkill was also detected in *Salvadora* (S) than in dense *Mopane* (MD), Riparian (R) and other (O). There was a significant difference in the number of roadkill detected per km in each of the seven vegetation types on the unpaved road (one way ANOVA; $F_{8,1071} = 8.09$, $p < 0.05$; Figure 4.20b) with significantly more roadkill in open grassland (OG) than in open mixed bushveld (XO), *Vachellia* (A), and other (O).

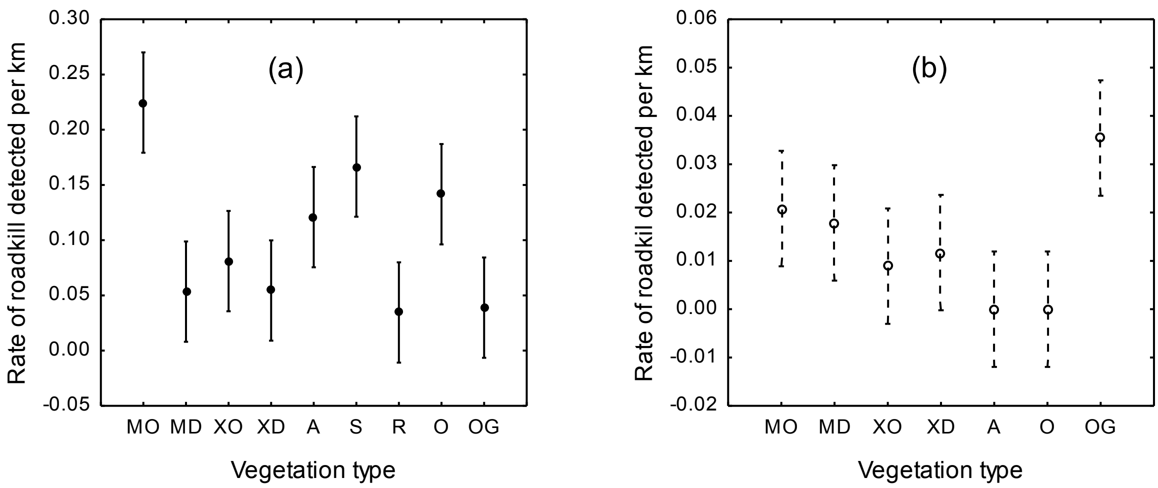


Figure 4.20: The rate of roadkill detected per km in each vegetation type (data are means ± 95% CI) along (a) a 100 km section of paved road (nine vegetation types), and (b) a 20 km section of unpaved road (seven vegetation types), in the GMTFCA, South Africa. (*Mopane* dense (MD), mixed bushveld open (XO), mixed bushveld dense (XD), *Mopane* open (MO), Riparian R), *Vachellia* thicket (A), *Salvadora* (S), open grasslands (OG), and other (O)).

In a two way ANOVA with seven habitat types (Salvadora (S) and Riparian (R) could not be tested because these two habitats were not present on the unpaved road), there was a significant effect of vegetation type ($F_{6,1666} = 8.13$, $p < 0.05$; Figure 4.21) and road type on roadkill/km ($F_{1,1666} = 111.14$, $p < 0.05$; Figure 4.21). Furthermore, road type and vegetation type interacted significantly in some cases ($F_{6,1666} = 9.87$; $p < 0.05$; Figure 4.21); for open *Mopane* (MO), *Vachellia* (A) and other (O) habitats, significantly more roadkill per km was observed on the paved road than on the unpaved road (Figure 4.21). No other pairs were significantly different ($p > 0.05$).

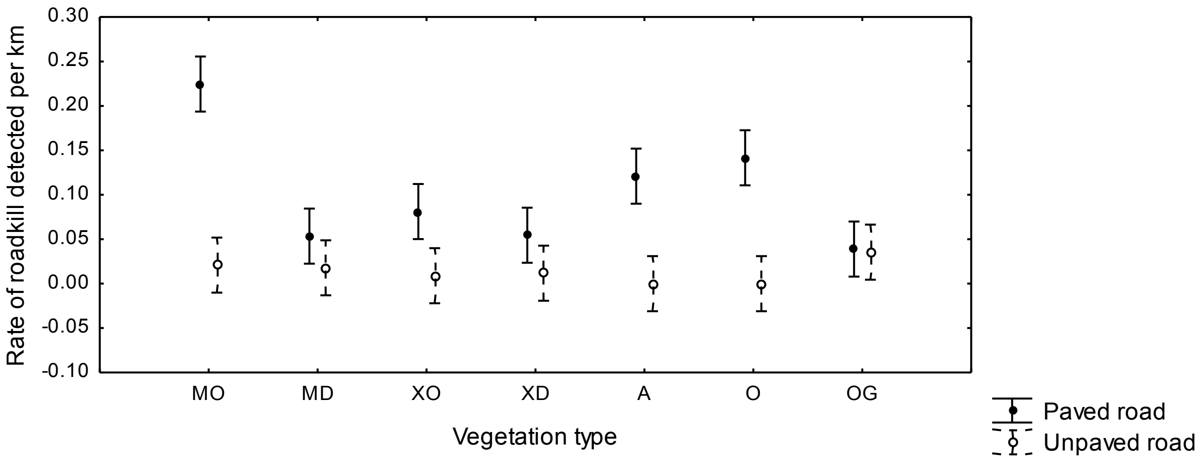


Figure 4.21: The rate of roadkill detected per km in each of nine vegetation types (data are means ± 95% CI) along a 100 km section of paved road and 20 km section of unpaved road in the GMTFCA, South Africa. (*Mopane* dense (MD), mixed bushveld open (XO), mixed bushveld dense (XD), *Mopane* open (MO), Riparian R), *Vachellia* thicket (A), *Salvadora* (S), open grasslands (OG), and other (O).

3.3.2 Grass height, grass density and grass seed

The number of times a roadkill occurred in each of the grass density and grass height categories was recorded per day for both sides of the road and these data used for the statistical analyses.

In a two way ANOVA with grass height and road type as predictor variables, there was a significant effect of grass height on roadkill ($F_{10,44} = 2.99$, $p < 0.05$; Figure 4.22). Road type and grass height interacted significantly ($F_{10,44} = 2.85$; $p < 0.05$; Figure 4.22) and at intermediary heights (between 30 and 60 cm), more roadkill was detected per category on the paved road than on the unpaved road (Figure 4.22).

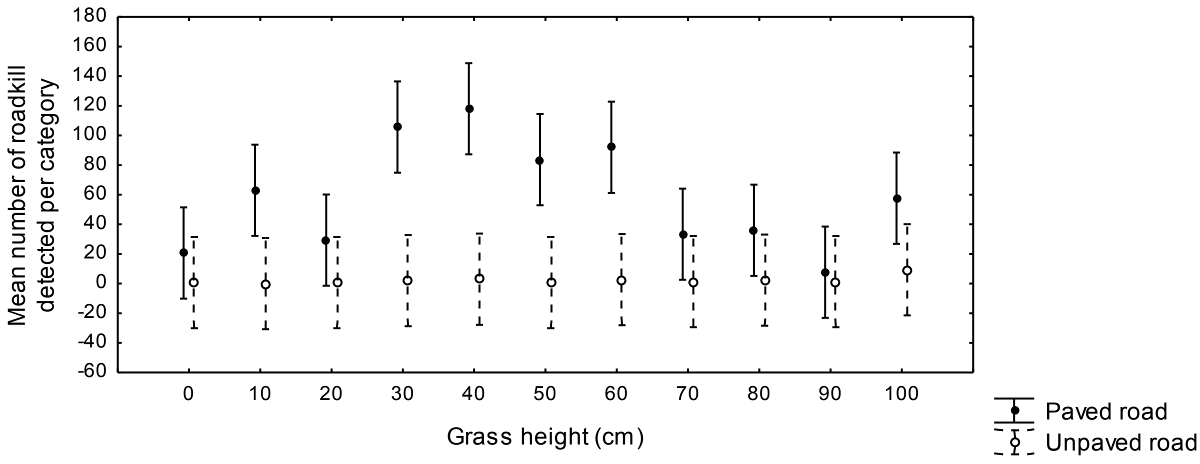


Figure 4.22: The difference between eleven grass heights and the mean number of roadkill detected per category (data are means ± 95% CI) along a 100 km section of paved road and 20 km section of unpaved road in the GMTFCA, South Africa.

There was no significant effect of grass density on the occurrence of roadkill (two way ANOVA; $F_{8,\ 36}$ = 1.3, p = 0.27) and there was no significant interaction between road type and grass density (two way ANOVA; $F_{8,36}$ = 1.04; p = 0.42).

A Mann-Whitney *U* test showed there was no significant difference between roadkill numbers when grass seed was present and when it was absent (U (10) = 14.5, Z = -0.48, p = 0.59).

3.4 The effect of physical factors on the occurrence of roadkill on paved and unpaved roads

A two-way ANOVA was used to analyse the effect of mean daily traffic volume and mean daily traffic speed on daily roadkill numbers detected on the paved road. Traffic volume and speed are ordinarily continuous variables but in this analysis, they were categorised into six equal categories commencing at 75 $km.h^{-1}$ and 75 vehicles per day to 249 $km.h^{-1}$ and 249 vehicles per day.

The relationship between vehicle type (traffic axle) and daily roadkill detected on the paved road was analysed using a Pearson r correlation, with roadkill per day as the dependent variable and traffic axle as the categorical variable.

Manual observational traffic counts were conducted for traffic volume on the unpaved road (as the traffic tube could not be set up) and was a mean based on four 12-hour observations. No statistical comparision was made between roadkill rates and traffic volume on the unpaved road, due to low roadkill numbers (n=36) and limited traffic data collection (n= 4 days).

3.4.1 Traffic volume and traffic speed

There was no significant effect of traffic volume on roadkill detected per day on the paved road (two way ANOVA; $F_{5,84}$ = 1.09, p = 0.37), and no effect of traffic speed on roadkill detected per day ($F_{1,84}$ = 0.05, p = 0.81). There was no significant interaction between traffic speed and traffic volume and roadkill detected per day on the paved road (two way ANOVA; $F_{5,84}$ = 1.2, p = 0.32).

Mean traffic volume for the paved road was 90 vehicles per day (*s* = 9.34) and 25 vehicles per day (*s* = 7.02) for the unpaved road.

3.4.2 Vehicle class

Roadkill numbers and the volume of vehicles in four classes (axle) were significantly correlated (Table 4.11). The numbers of roadkill increased when there were more passenger cars (class 2; Figure 4.23a) and large trucks (classes 9 and 10; Figure 4.23b, 4.23c) (Table 4.11). However, roadkill numbers declined when there were more very large (class 12; Figure 4.23d) trucks on the paved road (Table 4.11). While the linear relationships between the variables were significant, the low r^2 indicates that the data points are scattered away from the best-fit line and that the independent variable was a poor predictor of the dependent variable.

Table 4.11: Thirteen traffic axle classes and number of roadkill detected per day on the R572 paved road using a Pearson r correlation. Significant correlations are highlighted in bold.

Paved roads: roadkill sites (n=100)				
Physical Factor	**Type of data**	correlations are significant at $p < 0.05$		
Vehicle axle/class	**Categorical**	**r value**	**r^2 value**	**p value**
1 (motorcycles = 2 axles)		0.17	0.03	0.1
2 (passenger cars = 2 axles)		**0.29**	**0.08**	**0.003**
3 (pickup trucks, vans = 2 axles)		-0.06	0.001	0.73
4 (buses)		-0.71	0.005	0.48
5 (single unit = 2 axles, 6 tyres)		0.09	0.008	0.36
6 (single unit truck = 3 axles)		0.18	0.03	0.07
7 (single unit = 4 axles)		0.02	0.00	0.82
8 (single unit = 4 axles or less)		-0.08	0.007	0.4
9 (double unit = 5 axles)		**0.2**	**0.04**	**0.03**
10 (double unit = 6 axles of more)		**0.36**	**0.13**	**0.002**
11 (multi-unit = 5 axles or more)		-0.15	0.02	0.14
12 (multi-unit = 6 axles)		**-0.23**	**0.05**	**0.02**
13 (multi-unit = 7 axles or more)		0.04	0.001	0.69

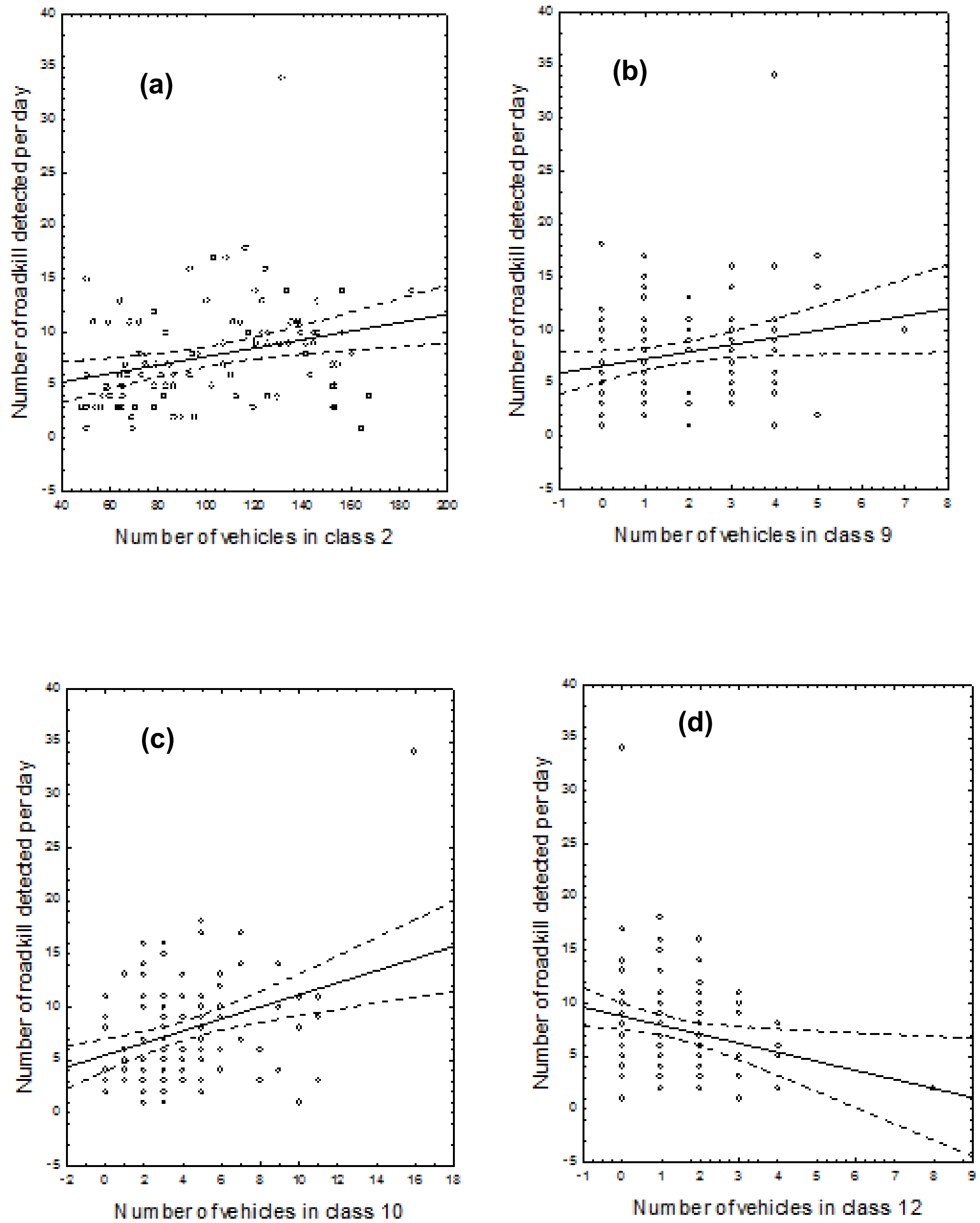


Figure 4.23: The correlations between daily number of vehicles in a) class 2 (passenger cars = 2 axles), b) class 9 (double unit = 5 axles), c) class 10 (double unit = 6 axles or more), and d) class 12 (multi-unit =6 axles) and the number of roadkill per day (± 95% CI) along the R572 paved road in the GMTFCA, South Africa.

3.4.3 Day of the week

There was no significant effect of the day of week on roadkill detected per day on either the paved (one way ANOVA; $F_{6,113} = 2.17$, $p = 0.97$; Figure 4.24a) or unpaved roads (one way ANOVA; $F_{6,16} = 0.91$, $p = 0.51$; Figure 4.24b).

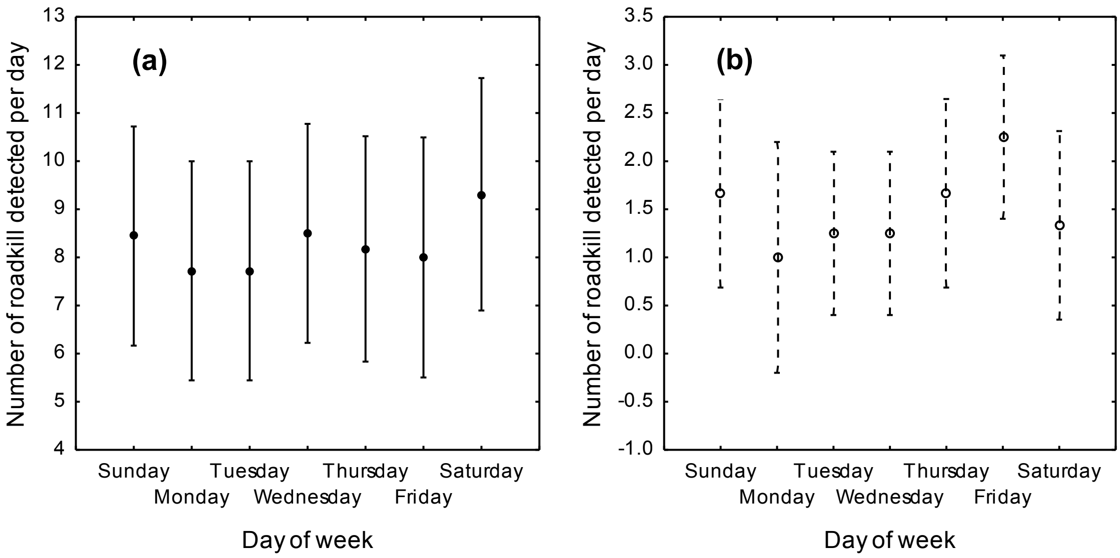


Figure 4.24: The difference between days of the week and number of roadkill detected per day (± 95% CI) along a (a) 100 km section of paved road and (b) along a 20 km section of unpaved road in the GMTFCA, South Africa.

3.4.4 Fence type and fence distance from verge

Six fence types were present on the paved transect but only five on the unpaved transect and in the initial analyses, two one way ANOVAs have been used.

On the paved transect, there was a significant effect of fence type ($F_{5, 714} = 30.18$, $p < 0.05$; Figure 4.25) with significantly more roadkill when there was a gate (Ga) than when there was a game (G), electric (E) or cattle (C) fence present. Significantly more roadkill were also detected per km when there was a barrier (B) or a combined cattle/electric (C/E) fence than if there were a game (G), electric (E) or cattle (C) fence present. There was no significant difference in the number of roadkill detected per km in each of the five fence types on the unpaved road ($F_{4,115} = 0.85$, $p = 0.49$).

Using the five common fence types on the paved and unpaved road a two way ANOVA showed a significant effect of fence type ($F_{4, 710}$ = 8.57, p <0.05; Figure 4.25) a significant effect of road type ($F_{1,710}$ = 14.7 p <0.05; Figure 4.25) and a significant interaction ($F_{4, 710}$ = 6.86; p <0.05; Figure 4.25). Significantly more roadkill per km occurred on the paved road when there was a gate (Ga) within 10 m of roadkill and a cattle/electric combined (C/E) fence than for the other three fence types.

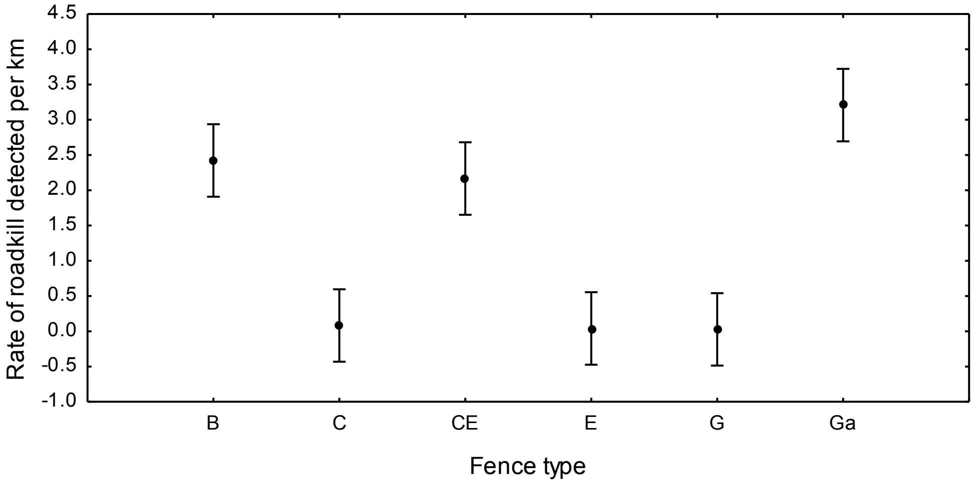


Figure 4.25: The difference between six fence types and rate of roadkill detected per km (data are means ± 95% CI) along a 100 km section of paved road in the GMTFCA, South Africa. (Barrier (B), cattle (C), cattle/electric combined (CE), electric (E), game (G), and gate (Ga).

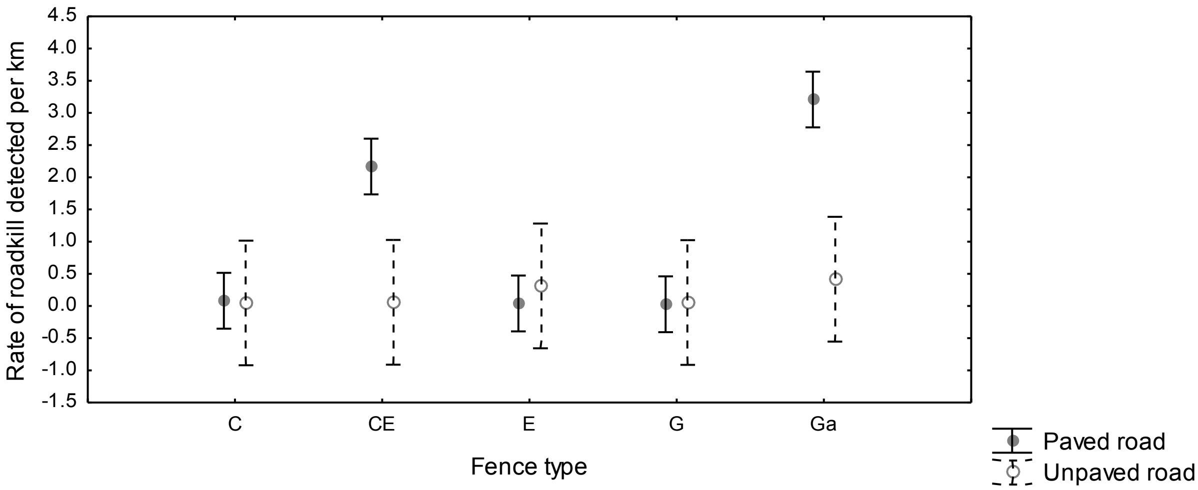


Figure 4.26: The difference between five fence types and rate of roadkill detected per km (data are means ± 95% CI) along a 100 km section of paved road and 20 km section of unpaved road in the GMTFCA, South Africa. (cattle (C), cattle/electric combined (CE), electric (E), game (G), and gate (Ga).

In a two way ANOVA with distance of the fence to the road and road type as predictor variables, there was no significant effect of either variable on roadkill/km (distance; $F_{4,\ 710}$ = 1.29, p = 0.27; road type; $F_{1,710}$ = 0.48 p = 0.49; Figure 4.27). However, road type and fence distance interacted significantly ($F_{4,710}$ = 3.82; p <0.05; Figure 4.27) with more roadkill detected per km on the paved road when the fence was between 10-14 m and >20 m from the road verge than when the fence was <5 m from the road verge.

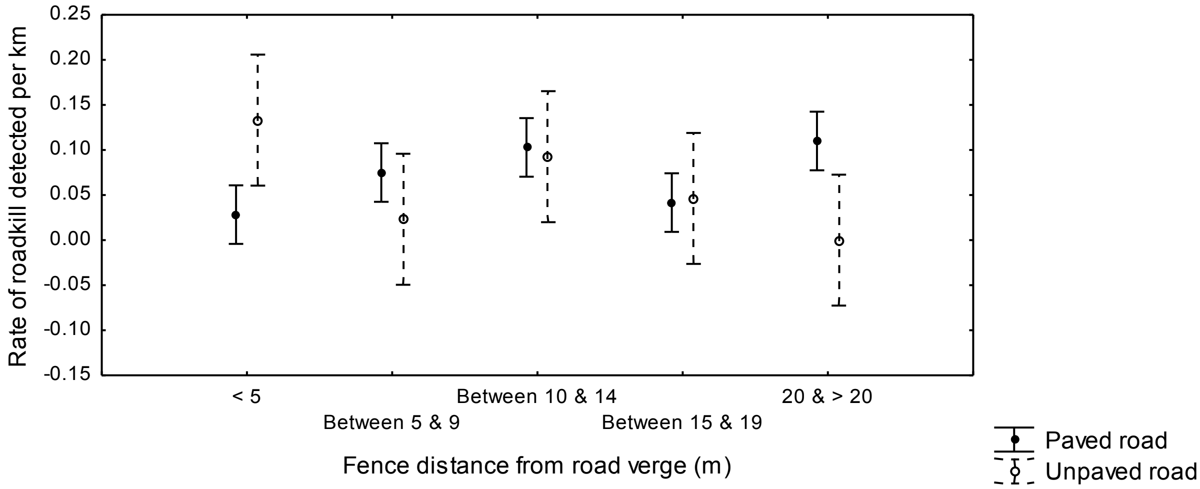


Figure 4.27: The difference between five fence distances from the road verge and roadkill detected per km (± 95% CI) along a 100 km section of paved road and 20 km section of unpaved road in the GMTFCA, South Africa.

3.5 A comparison of the characteristics associated with roadkill sites (observed) and control sites (expected)

The differences between the environmental characteristics of roadkill and control sites (where no roadkill was detected) on the paved and unpaved road were tested using a Chi-square test of association. This was to determine whether roadkill were distributed according to the amount of available vegetation type and grass density/height/seed, or if they occurred more or less often than expected within certain vegetation types and grass density/height/seed. Only seven of the nine vegetation types were measured on the unpaved road with *Salvadora* (S) and Riparian (R) being absent.

Observed values for a Chi-square test for vegetation types were determined by recording the environmental factors on both sides of the roadway adjacent to each roadkill carcass and adding up the total number of times each factor was recorded for each species. The same was done for expected values (control points). Observed and expected values for vegetation type were then divided by the proportion of each vegetation type (km) found along both sides of the transect to provide an overall rate. The same was applied to the two physical variables, using the six fence types and the five fence distances form the road verge.

Observed and expected values for grass density, grass height and presence/absence of grass seed were analysed using daily units. In addition, the differences between the physical characteristics of roadkill (observed value) and control sites (expected value) on the paved and unpaved road were also tested using a Chi-square test. The total number of times each factor was recorded for each species was summed and then divided by the proportion of the factor (km) found along both sides of the transect to provide an overall rate.

The data for paved and unpaved roads were combined due to the low sample numbers of roadkill on the unpaved road.

3.5.1 Vegetation type

Significantly more roadkill were observed than expected based on the random sample points across the nine vegetation types (X^2 = 27.28, df = 8, p <0.05; Figure 4.28). Twice as many roadkill were detected in *Salvadora* (S) and other habitat (O) than expected (Figure 4.28). More roadkill than expected were also observed in the *Vachellia* (A), open grassland (OG) and riverine (R) habitats (Figure 4.28). However, fewer roadkill than expected were found in the *Mopane* (MO and MD) and mixed bushveld (XO and XD) vegetation (Figure 4.28).

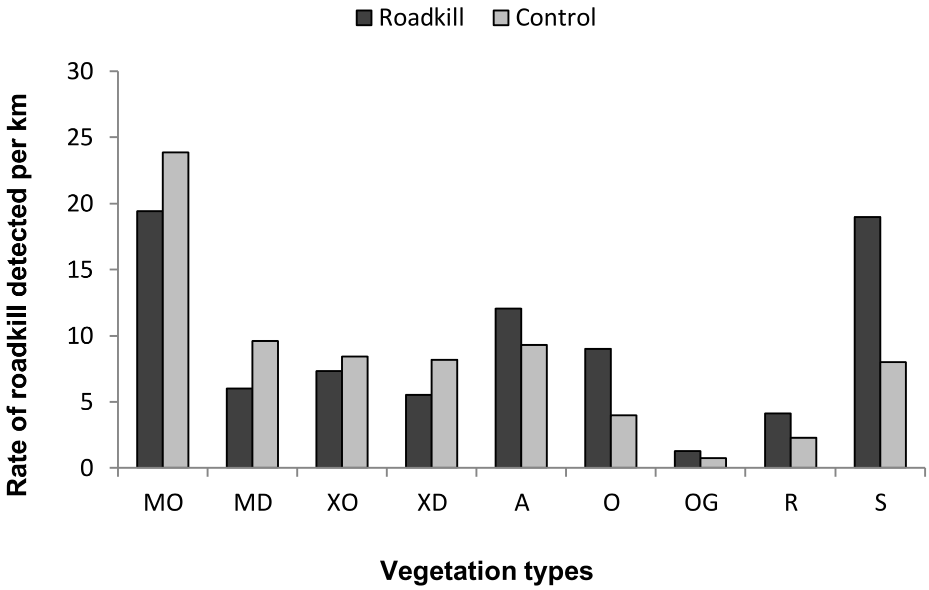


Figure 4.28: The rate per km of roadkill (observed) and control (expected) detected per km in each of nine vegetation types along a combined 100 km section of paved road and 20 km section of unpaved road in the GMTFCA, South Africa. (*Mopane* open (MO), *Mopane* dense (MD), mixed bushveld open (XO), mixed bushveld dense (XD), *Vachellia* thicket (A), other (O), open grasslands (OG), Riparian (R), and *Salvadora* (S).

3.5.2 Grass height, density and seed

Less roadkill were observed than expected based on the random points in four of the 11 intermediary grass height categories (X^2 = 0.62, df = 10, p = 1; Figure 4.29a). More roadkill were observed than expected when grass was shortest (<10 cm) and when it was highest (60, 70, 80 and 100 cm), although this was not significant (Figure 4.29a).

Less roadkill were observed than expected based on the random points when grass was denser (categories 6, 8 and 9; X^2 = 0.44, df = 8, p = 1; Figure 4.29b) with more roadkill observed than expected when grass was less dense (category 5 and less; Figure 4.29b).

Less roadkill were observed than expected when there was no grass seed (X^2 = 0.01, df = 1, p = 0.9; Figure 4.29c), and slightly more roadkill were observed than expected when grass seed was present, although this was not significant (Figure 4.29c).

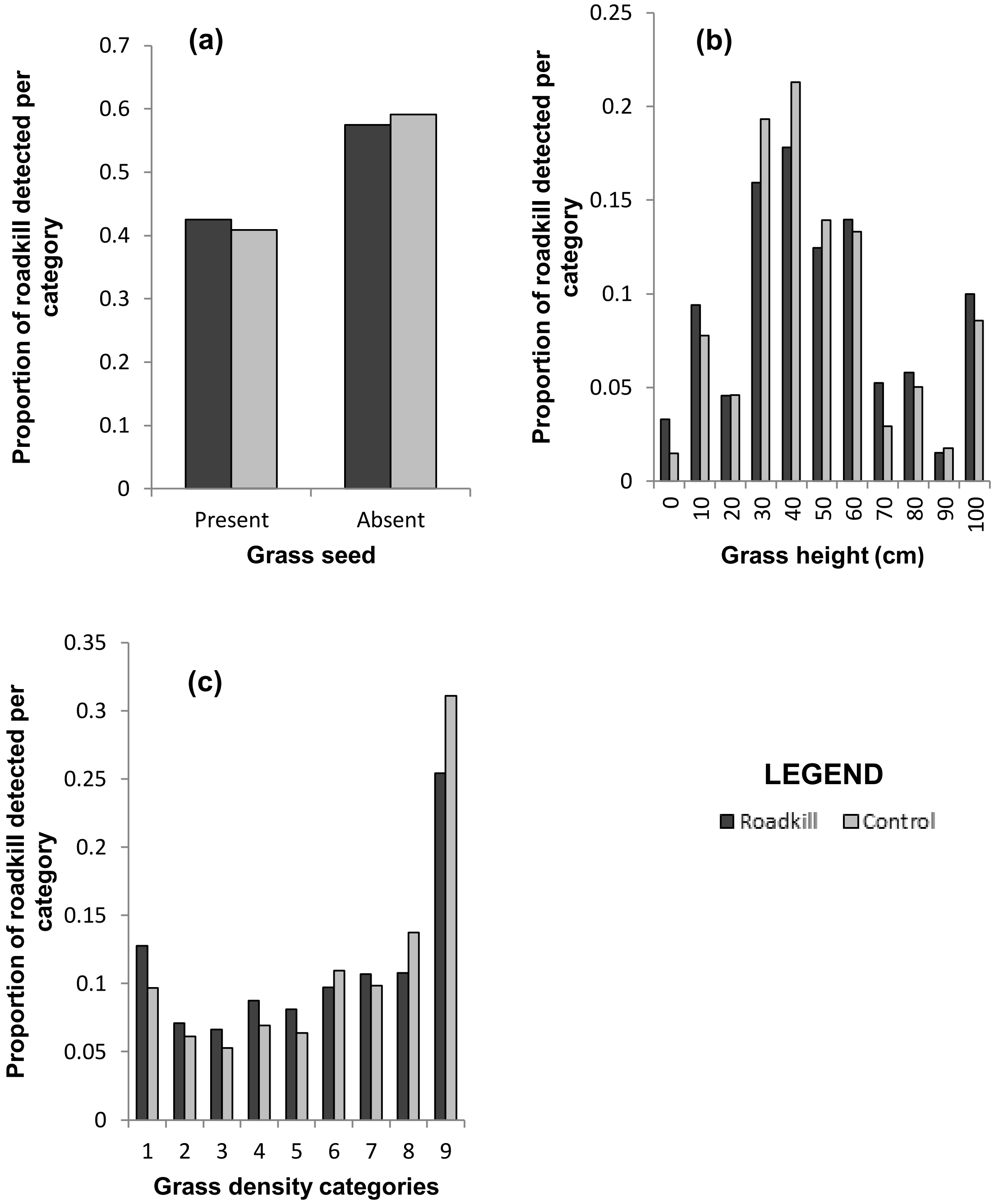


Figure 4.29: The proportion of roadkill (observed) and control (expected) detected in (a) each of the eleven grass heights categories, (b) each of the nine grass density categories and (c) the presence/absence of grass seed (for both sides of the road) along a combined 100 km section of paved road and 20 km section of unpaved road in the GMTFCA, South Africa.

3.5.3 Fence type and fence distance from road verge

Significantly less roadkill were observed than expected based on the random points for each of the six fence categories (X^2 = 55.83, df = 5, p <0.05; Figure 4.30a).

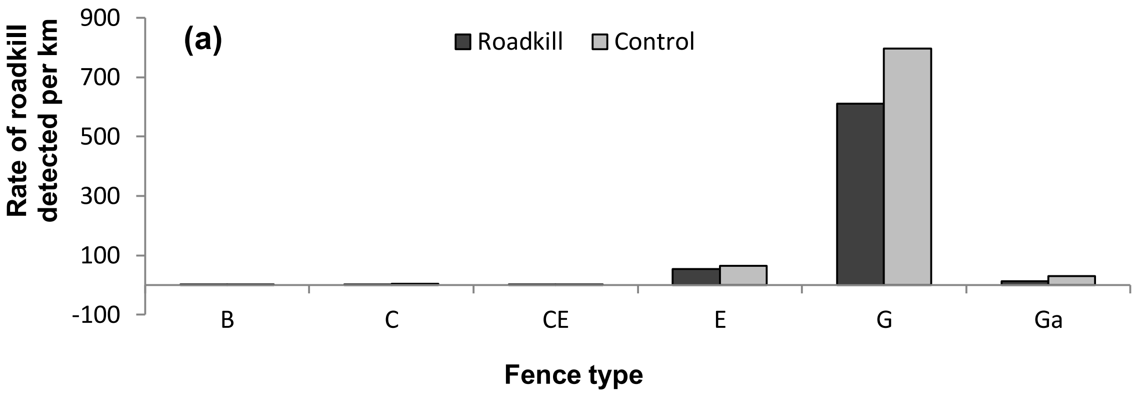


Figure 4.30a: The rate per km of roadkill (observed) and control (expected) detected per km in each of the six fence types along a combined 100 km section of paved road and 20 km section of unpaved road in the GMTFCA, South Africa. Bridge/barrier (B), cattle (C), cattle/electric (CE), electric (E), game (G) and gate (Ga).

There was a significant difference between the observed and expected number of roadkill when categorised according to the distance of the fence from the road verge (X^2 = 408.64, df = 4, p = <0.05; Figure 4.30b). There were almost twelve times as many control sites than roadkill observed per km when the fence was between 5 and 9 m from the road verge (Figure 4.30b) and eight times as many when the fence was between 10 and 14 m from the road verge (Figure 4.30b). However, more roadkill were observed than expected in all fence distance categories that were >15 m (Figure 4.30b).

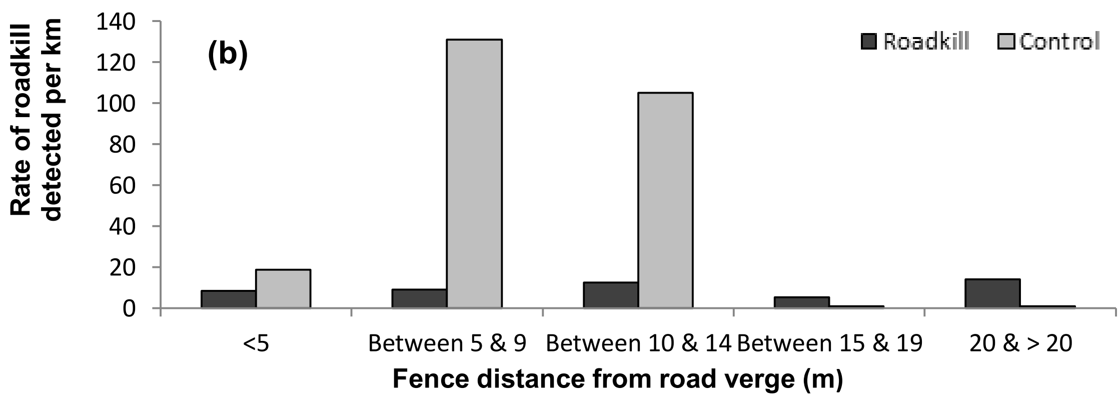


Figure 4.30b: The rate per km of roadkill (observed) and control (expected) detected per km in each of the five fence distances from the verge categories along a combined 100 km section of paved road and 20 km section of unpaved road in the GMTFCA, South Africa.

3.6 Results summary

More vertebrate roadkill were detected during the hot/wet season than during the hot/dry and cold/dry seasons. However, amphibian roadkill was highest during the hot/dry (Appendix B) and mammals highest during the cold/dry seasons (Appendix B). The majority of roadkill species were nocturnal (43%; Appendix B). However, more roadkill were detected 1.5 hours after dawn than 1.5 hours before dawn and 1.5 hours after dusk (five times and three times more, respectively). Fifty per cent of live animal sightings were recorded during the cold/dry season, although roadkill numbers were ~50% lower during this season (Appendix D).

Four of the seven biophysical factors had a significant effect on the occurrence of roadkill on the paved road (season, rainfall and minimum and maximum temperatures; Table 4.12). No biophysical factors significantly influenced the occurrence of roadkill on the unpaved road. Three of the environmental factors influenced the occurrence of roadkill on the paved road (habitat, grass density and grass height; Table 4.12), but only habitat influenced the occurrence of roadkill on the unpaved road (Table 4.12).

Table 4.12: A statistical summary of the results for the number of roadkill detected and the variables tested on the paved and unpaved roads over 120 days across the three ecological seasons in the GMTFCA, South Africa. (Significant variables are highlighted in bold).

Number	**Factor**	**Variable**	**Road type**	
			Paved	**Unpaved**
1	Biophysical	Season	**p <0.05**	p >0.05
2	Biophysical	Rainfall	**p <0.05**	p >0.05
3	Biophysical	Moon phase	p >0.05	p >0.05
4	Biophysical	Cloud cover	p >0.05	p >0.05
5	Biophysical	Humidity	p >0.05	p >0.05
6	Biophysical	Minimum temperature	**p <0.05**	p >0.05
7	Biophysical	Maximum temperature	**p <0.05**	p >0.05
8	Environmental	Habitat	**p <0.05**	**p <0.05**
9	Environmental	Grass height	**p <0.05**	p >0.05
10	Environmental	Grass density	**p <0.05**	p >0.05
11	Environmental	Grass seed	p >0.05	p >0.05
12	Physical	Traffic volume	p >0.05	No data
13	Physical	Traffic speed	p >0.05	No data
14	Physical	Vehicle class	**p <0.05**	No data
15	Physical	Fence type	**p <0.05**	p >0.05
16	Physical	Fence distance from verge	p >0.05	p >0.05
17	Physical	Day of week	p >0.05	p >0.05

4 DISCUSSION

4.1 Roadkill rates and comparisons with existing studies

Roadkill rate/km and roadkill rate/day were compared with existing studies for each taxa (Table 4.13). Roadkill rate data from my study show that rate/km was up to nine times higher for mammals and up to 10 times higher for birds than other studies (Table 4.13). This suggests that my study area has high species richness and density hence biological diversity for these two taxa. Data for amphibians and reptiles were more difficult to compare due to a paucity of studies on these groups (Table 4.13). However, comparing traffic volumes and the number of amphibian and reptile roadkill recorded, suggests that roadkill numbers in the GMTFCA are still higher than other studies (Table 4.13).

Table 4.13: A comparison of roadkill rates per 100 km (paved roads) for each of the four taxa (Amphibia, Reptilia, Aves, Mammalia) for 15 peer-reviewed roadkill studies conducted across the world. Average daily rate of traffic is given where data was available. All studies are ranked from lowest rate per km to highest, with data from my study highlighted in bold.

Amphibians	Study area	Rate per 100 km	Number of species	Average number of vehicles per day
Clevenger *et al.* (2003)	Canada (Rocky Mountains)	0.003	2	5,000-10,000
Collinson 2012	**RSA (GMTFCA)**	**1.6**	**2**	**149**
Sutherland *et al.* (2010)	USA (North Carolina)	2	15	20/48
Sutherland *et al.* (2010)	USA (North Carolina)	35	15	535

Reptiles	Study area	Rate per 100 km	Number of species	Average number of vehicles per day
Collinson 2012	**RSA (GMTFCA)**	**7.8**	**35**	**149**
MacKinnon *et al.* (2005)	Canada (Ontario)	22.04	10	3,000
Coelho *et al*. (2008)	Brazil (Atlantic Forest Biosphere Reserve)	23.85	20	6,884

Table 4.13 (continued): A comparison of roadkill rates per 100 km (paved roads) for each of the four taxa (Amphibia, Reptilia, Aves, Mammalia) for 15 peer-reviewed roadkill studies conducted across the world. Average daily rate of traffic is given where data was available. All studies are ranked from lowest rate per km to highest, with data from my study highlighted in bold.

Birds	**Study area**	**Rate per 100 km**	**Number of species**	**Average number of vehicles per day**
Hell *et al.* (2005)	Europe (Slovenia)	0.0072	37	7,400
Dean & Milton (2003)	RSA (Succulent & Nama-Karoo)	0.12	-	-
Siegfried (1965)	RSA (Northern Cape)	0.22	14	-
Lodé (2000)	Europe (France)	0.27	-	-
Clevenger *et al.* (2003)	Canada (Rocky Mountains)	0.48	36	5,000-10,000
Bullock *et al.* (2011)	RSA (Southern Kalahari)	1.14	6	-
Collinson 2012	**RSA (GMTFCA)**	**10.46**	**86**	**149**
Coelho *et al.* (2008)	Brazil (Atlantic Forest Biosphere Reserve)	17.95	52	6,884

Table 4.13 (continued): A comparison of roadkill rates per 100 km (paved roads) for each of the four taxa (Amphibia, Reptilia, Aves, Mammalia) for 15 peer-reviewed roadkill studies conducted across the world. Average daily rate of traffic is given where data was available. All studies are ranked from lowest rate per km to highest, with data from my study highlighted in bold.

Mammals	**Study area**	**Rate per 100 km**	**Number of species**	**Average number of vehicles per day**
Hell *et al.* (2005)	Europe (Slovenia)	0.06	15	7,400
Lodé (2000)	Europe (France)	0.44	-	-
Clevenger *et al.* (2003)	Canada (Rocky Mountains)	0.48	18	5,000-10,000
Siegfried (1965)	RSA (Northern Cape)	0.48	-	-
Dean & Milton (2003)	RSA (Succulent & Nama-Karoo)	0.53	-	-
Glista & DeVault (2008)	USA (Indiana)	0.93	14	-
Caro *et al*. (2000)	USA (California)	1.2	10	-
Ford & Fahrig (2007)	North America	1.38	38	-
Oxley *et al.* (1974)	Canada (Ontario/Quebec)	2.2	9	-
Barthelmess & Brooks (2010)	USA (New York State)	3.8	21	-
Bullock *et al.* (2011)	RSA (Southern Kalahari)	5.44	17	-
Smith-Patten & Patten (2008)	USA (Kansas)	8.6	18	-
Collinson 2012	**RSA (GMTFCA)**	**9.6**	**44**	**149**
Coelho *et al*. (2008)	Brazil (Atlantic Forest Biosphere Reserve)	26.67	22	6,884

4.2 Biophysical variables

4.2.1 Season

Seasons influence cycles of animal behaviour, with most activity occurring during the reproductive and dispersal periods (Branch 1998; Hockey *et al*. 2005; Skinner & Chimimba 2005; Carruthers & du Preez 2011). Consequently, this is when animals are most likely to be active near roads and road mortality rates increase (Clevenger *et al.* 2001).

Both meteorological and ecological seasons have been applied in existing Southern African studies (e.g. Mkanda & Chansa 2010; Bullock *et al*. 2011). The hot/wet season in Southern Africa falls between February to May (modified from Viljoen 1989; Viljoen *et al.* 2008) and this is when animals are most active (Branch 1998; Hockey *et al*. 2005; Skinner & Chimimba 2005; Carruthers & du Preez, 2011). Data from my study supports the existing literature that shows season effects road mortality although only one of the peer-reviewed roadkill surveys (Mkanda & Chansa 2010) was conducted using the three ecological seasons (hot/dry, hot/wet and cold/dry).

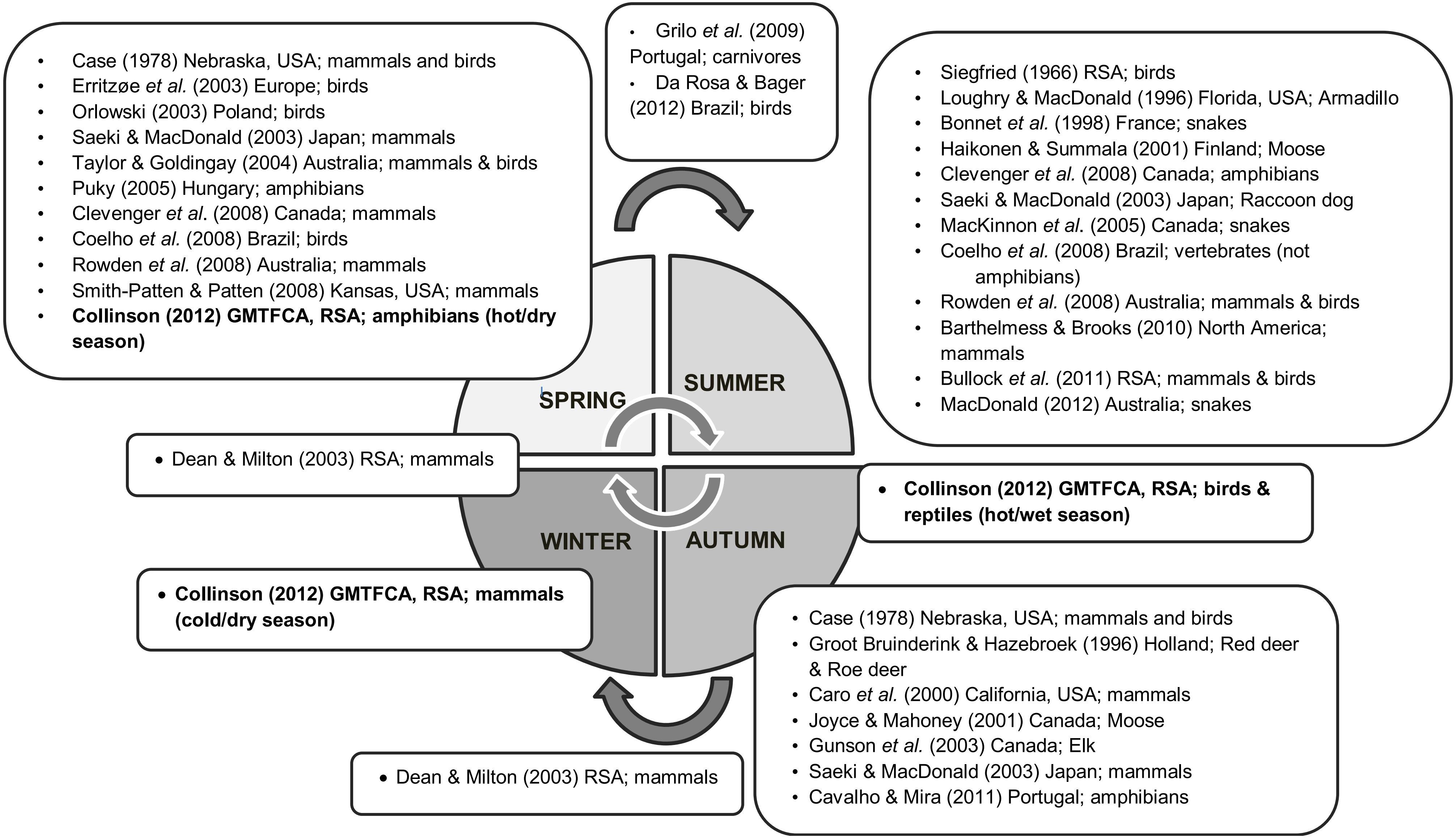


Figure 4.31: A diagram showing the seasonal variation and the seasonal peak among the four taxa for roadkill surveys conducted across the world. Data are for surveys conducted during the four meteorological seasons (spring, summer, autumn and winter). Although not directly comparable, the results of this study are shown in bold, indicating approximately where the three ecological seasons (hot/dry, hot/wet and cold/dry) coincide with the four meteorological seasons.

To allow comparison of the data from my study with other studies, a seasonal calendar showing approximate meteorological and ecological overlaps is shown (modified from Viljoen 1989; Viljoen *et al.* 2008; South African Weather Service 2011; Figure 4.31, Figure 4.32). For example, studies conducted during the summer in the northern hemisphere will be the approximate equivalent time of year to winter in the southern hemisphere. Therefore, when making seasonal comparisons between hemispheres, summer is taken as the hottest period of the year, with winter being the coldest.

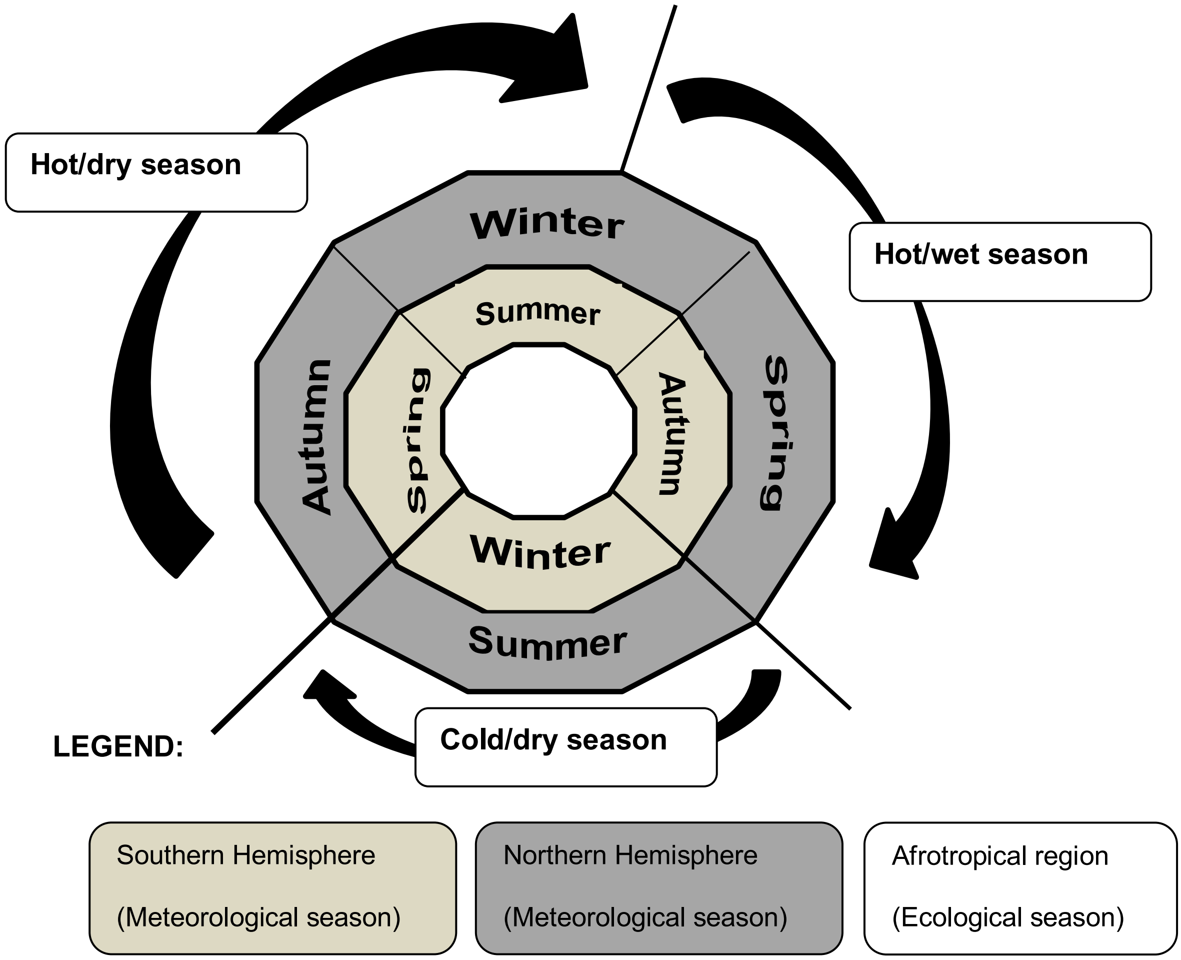


Figure 4.32: A diagram comparing the four meteorological seasons for the northern and southern hemispheres with the three ecological seasons for the Afrotropical region (Schulze & McGee 1978).

Of 27 studies that examined the impacts of roadkill during the four meteorological seasons, 45% detected more vertebrate roadkill during the summer months than during the other three meteorological seasons (e.g. Siegfried 1966; Coelho *et al.* 2008; Rowden *et al*. 2008; Figure 4.31). Summer forms part of the hot/dry and hot/wet seasons (Figure 4.32) and vertebrate roadkill numbers were also shown to be higher during these two seasons in my study. However, Case (1978) found peaks for vertebrate roadkill (in the Northern Hemisphere) in spring (May) and autumn (October). These peaks were associated with animal breeding activities and dispersal (Case 1978).

Mammals and birds are the most studied roadkill taxa (Taylor & Goldingay 2010; Figure 4.31. From 20 existing studies, slightly more roadkilled mammals were detected during the summer (34%) with 29% during the spring, 29% during the autumn, and 8% during the winter (Figure 4.31). Of the 10 avian roadkill studies, equal percentages of birds were detected during spring and summer (45.5%) with 9% detected during the autumn and none in the winter (Figure 4.31).

All four reptile studies detected more roadkill during the summer. Of the two amphibian studies, one detected more roadkill during the spring and the other during the summer. No roadkill were detected for reptiles or amphibians during the winter (Figure 4.31).

More bird and reptile roadkill were detected in the GMTFCA during the hot/wet season (Appendix B). Mammal roadkill numbers in existing studies were similar across three of the four meteorological seasons (spring, summer and autumn) with less mammal roadkill occurring in the winter (Figure 4.31). Similarly, there was little difference among the percentage of mammal roadkill detected during the three ecological seasons in my study (Appendix B). More amphibian roadkill was detected during the hot/dry season in the GMTFCA (Appendix B; Figure 4.31).

Four published studies from South Africa, that examined the determinants of roadkill (Siegfried 1966; Dean & Milton 2003; Eloff & van Niekerk 2008; Bullock *et al.* 2011; Figure 4.33), conducted their studies across the four meteorological seasons. This is possibly because two of the study areas (Siegfried 1966; Eloff & van Niekerk 2008) fall into the more temperate zones of South Africa (Schulze & McGee 1978), whilst the other two (Dean & Milton 2003; Bullock *et al.* 2011) border the temperate and subtropical zones of South Africa (Schulze & McGee 1978). Therefore, ecological seasons would not have been appropriate for these studies. Nevertheless, the data for these four studies are consistent with this GMTFCA study for mammalian and avian roadkill in South Africa (Figure 4.33).

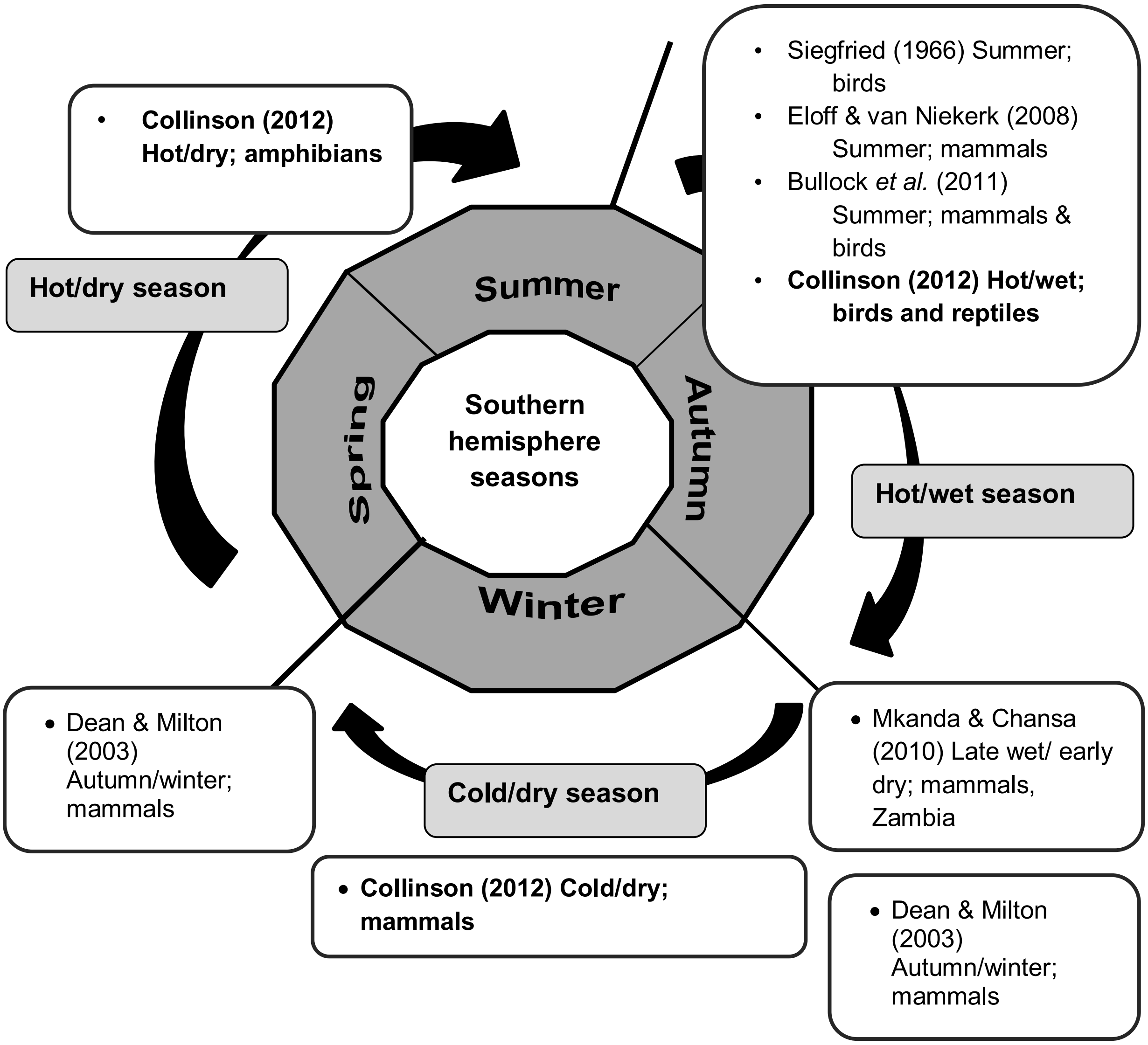


Figure 4.33: A diagram comparing four meteorological seasons for the southern Hemisphere for four published studies in South Africa with the three ecological seasons for one published study in Zambia and data collected in the GMTFCA, Limpopo, South Africa.

More bird mortalities were detected during the summer in the southern Kalahari (November to February; Bullock *et al.* 2011) with similar data recorded in the Northern Cape (Siegfried 1966; Figure 4.33). This was considered to be due to an increase in food supply during the summer and lack of breeding opportunities in the winter. Similarly, more mammals were killed during the summer in the southern Kalahari (Bullock *et al*. 2011) and the Eastern Cape (Eloff & van Niekerk 2008; Figure 4.33). However, more mammals were killed on roads in late winter/spring (August/September) and autumn/winter (April-June) than at other times of year in the

Nama-Karoo although no explanation was supplied (Dean & Milton 2003; Figure 4.33).

One study, which was conducted during the ecological seasons in Zambia (Mkanda & Chansa 2010; Figure 4.33) found more mammal roadkill in the late wet and early dry seasons (March/April). A number of artificial water sources were close to the roads which may explain why more animals were present near or on the roads during the dry season (Mkanda & Chansa 2010).

4.2.2 The other biophysical variables

Of 152 peer-reviewed studies, only Oxley *et al.* (1974) found that light intensity (i.e. cloud cover) had no significant influence on roadkill numbers of small mammals and is similar to what was found in my study. Whilst moon phase was not a significant predictor of roadkill during my study, there was a peak in roadkill when there was a new moon (i.e. when there was less light). A study conducted in Zimbabwe also found that moon phase did not affect the number of nightjars (Caprimulgidae) killed on the road, despite the species being nocturnal (Jackson 2003). No satisfactory explanation was provided for the number of nightjars present, other than that they tend to sit on roads at night as it provides them with a clear view for catching food (insects) regardless of moonlight (Jackson 2003). By contrast, more kudu were hit by vehicles at night in the Eastern Cape, South Africa when the moon was brightest (Eloff & van Niekerk 2005). Kudu feed both during the day and at night (Skinner & Chimimba 2005), but have been shown to reduce the amount of time spent feeding during periods of bright moonlight to reduce the risk of predation (Kie 1999).

Dickerson (1939) detected less roadkill across 14 states in the USA when temperatures were low and on mornings when there had been rain. Significantly more roadkill were detected in Poland when it was hotter, although rainfall was not significant (Ciesiolkiewicz *et al.* 2006). In contrast, amphibian roadkill peaked during months when there was rain in Portugal and Canada (Cavalho & Mira 2011; Clevenger *et al*. 2003) with a dip in roadkill numbers when it was drier. Increased rainfall precipitated more snake activity in an arid area of Australia, resulting in more snake road mortalities (McDonald 2012).

Increases in temperature and rainfall significantly influenced roadkill numbers in the GMTFCA, despite the poor rains experienced in the region during my study. The highest rainfall occurred during the hot/dry season (28.6 mm), with 18.5 mm during the hot/wet season. No rain fell during the cold/dry season. In the case of Amphibia, more roadkill were detected during the hot/dry season than during the hot/wet (n = 40; n = 7 respectively), with none recorded during the cold/dry season. Amphibia are usually most active during times of high rainfall (Carruthers & du Preez 2011) and are therefore expected to be more mobile during the hot/wet season. This was not the case during my study since the hot/dry season was wetter than the hot/wet season.

Poor rainfall experienced during the hot/wet season may have also impacted the activity patterns of other species during my study and resulted in a decrease in roadkill numbers. For example, invertebrates are often more prevalent after rains (Shyama Prasad Rao & Saptha Girish 2007), and therefore species that feed on them are more likely to become roadkill (Shyama Prasad Rao & Saptha Girish 2007). Less rain during the hot/wet season may have seen a reduction in invertebrate numbers, and therefore a decrease in insectivore presence.

4.3 Environmental variables

4.3.1 Vegetation type and roadside vegetation

There are a shortage of studies examining the effects of habitat on roadkill (Bright *et al.* 2005; Orlowski 2008; Barrientos & Bolonio 2009) although habitat type is known to influence wildlife mortality (Clevenger *et al.* 2003). Animals cross roads and this will either be in open or dense vegetation (Carvalho & Mira 2011). Some studies have identified ‘danger zones’ where there were gaps and openings in between habitats for animals to cross (Dunthorn & Errington 1964; Erritzøe *et al.* 2003). For example, mortality of raccoon dogs (*Nyctereutes procyonoides*) peaked where roads were in an open cutting (Saeki & MacDonald 2003). Similarly, mule deer (*Odocoileus hemionus)* were hit more often by vehicles in open habitat in the USA (Craighead *et al.* 2001). However, whilst some animals may risk crossing roads in more open habitat (Caro *et al.* 2000), others more frequently become roadkill when the roadside vegetation is denser (Newmark e*t al.* 1996; Caro *et al*. 2000; Mkanda & Chansa 2010). This is because increased cover provides greater protection and security for animals approaching roads (Clevenger *et al.* 2003). In addition to the habitat surrounding the road playing an important role in the frequency of roadkill (Litvaitis & Tash 2008), the proximity of the habitat itself to the road is also important. For example, moose collisions increased in coniferous and deciduous forest when the forest edge was closest to the road (Seiler 2005).

Habitat significantly influenced roadkill numbers found in the GMTFCA, with more roadkill detected in *Salvadora* and open *Mopane*. The latter vegetation type correlates directly with other studies which show that animals will attempt crossing when the roadside habitat is more open (Craighead *et al.* 2001; Erritzøe *et al.* 2003). Roadkill in the GMTFCA was not found to increase when the vegetation was denser or higher.

4.4 Physical

4.4.1 Roadside fencing

Fencing is recommended as an effective mitigation measure for reducing wildlife road mortality in many studies (e.g. Patterson 1977; Clevenger *et al*. 2001; Lyren & Crooks 2002; Caltrans 2003). Fencing either prevents animals from crossing roads, or directs animals to cross at specific locations (i.e. over-or underpasses; Ludwig & Bremicker 1983). However, fences that are too short (in length) may exacerbate the problem of roadkill (Seiler 2005) by causing wildlife to follow the fence until the end is reached and there is a gap at which to cross, thus creating a 'fence-end hotspot' (Seiler 2005).

A study conducted on the presence and absence of game fencing in the Eastern Cape, South Africa showed that fewer roadkill were detected where there was full fencing on both sides of the road (Eloff & van Niekerk 2005). More roadkill were detected when there was partial fencing or when only one side of the fence had a game fence, with 80% of roadkill detected when there was no fencing. In addition, where there was no fencing, there was often dense bush, on which ungulates could feed, increasing the likelihood of them becoming roadkill (Eloff & van Niekerk 2005).

Furthermore, almost 40% of roadkill were detected near fence-ends (Eloff & van Niekerk 2005).

Most roadkill in the GMTFCA occurred where there was either a gate, barrier/bridge or a combined cattle/electric fence. Gates and barriers in the GMTFCA were often found in between fences and could therefore be considered to be 'fence-ends' (Clevenger *et al*. 2003). The cattle/electric fence comprised a cattle fence, which was nearest to the road, whilst the electric fence was ~20 m further away and bordering a property. This 'no-man's land' area, between the cattle and electric fence, consisted mostly of grass as opposed to woody vegetation (i.e. shrubs and trees) and therefore provided favourable habitat for rodent species, seed-eating birds and ungulates.

Cattle fencing alone did not significantly influence roadkill numbers in the GMTFCA. However, the combination with an electric fence, which effectively creates an almost impenetrable barrier for many species by forcing species in one direction (i.e. towards the road), may explain why this combined fencing significantly impacted road mortality more than other fence types.

Significantly more roadkill were detected near to habitat, in South Africa, Spain and Sweden, that extended to the road edge than habitat that was further away (Dickerson 1939; Ansara 2004; Malo *et al.* 2004; Seiler 2005). This is in contrast to my study that detected more roadkill when the fence was >15 m from the road verge rather than by the road edge. This is possibly due to the roadside verge acting as a buffer between the fence and the road.

4.4.2 Road characteristics

Smith-Patten & Patten (2008) detected more mammal roadkill on paved roads than unpaved roads with 8.6/100 km and 3.65/100 km mammal roadkill, respectively. This compares favourably with data from my study (9.6/100 km and 2/100 km mammal roadkill on the paved and unpaved roads respectively). Road type did not appear to be a critical factor affecting roadkill numbers as animals will cross paved and unpaved roads (Oxley *et al*. 1974). However, road type (paved or unpaved) does affect speed and traffic volume and therefore influences road mortality (Oxley *et al*.

1974), with vehicles on unpaved roads more likely to travel slower than on paved roads due to the substrate of the road surface (Oxley *et al.* 1974).

Existing data suggest that birds often prefer unpaved roads as there is grit on the roads which birds seek to aid digestion (Jackson 2003). However, when examining the impact of roads on nightjars in Zimbabwe Jackson (2003), did not find this to be the case. The stomach contents of 282 nightjars found more insects than grit, which suggests they did not 'feed' on the gravel (Jackson 2003). Nightjars were less likely to be hit by cars on unpaved roads than on paved, since, whilst nightjars favour unpaved roads to doze on, the slightest sound of gravel shifting (i.e. from cars) will wake them up (Jackson 2003). The GMTFCA study detected slightly more nightjar roadkill per km on the paved road (0.2), compared with 0.13 nightjar roadkill on the unpaved road (Appendix C).

There was little variation in roadkill numbers between straight sections, road bends and elevation on the roads sampled in the GMTFCA study area. In addition, little difference was observed between roadkill numbers detected at road junctions where vehicles slow down, and other sections of the transect (Appendix F).

4.4.3 Traffic

Traffic volume and speed are generally considered to be two of the most important determinants of the rate of roadkill on roads (Clevenger *et al.* 2003; Seiler 2005). However, many studies conflict with one another in defining the levels that influence this impact (e.g. Gunson *et al.* 2003; Barrientos & Bolonio 2009). Some studies define traffic volume as either low, intermediate or high (e.g. Fahrig *et al.* 1995) but there are no standardised figures for such quantities. For example, some authors define intermediate traffic volume as ~3000 vehicles per day (Seiler 2005), whilst Conard & Gipson (2006) refer to this as a low traffic volume. There is thus a need to define traffic volume levels more clearly in order for future studies to be comparable.

Nevertheless, some studies found traffic volume not to be significant (Clark *et al.* 1998; Clevenger *et al*. 2003; Conard & Gipson 2006). Foxes (*Urocyon littoralis clementae*) on San Clemente Island were not influenced by traffic volumes and still crossed the road, although the daily rate was 60-366 vehicles per day (Snow *et al.*

2011). By contrast, red foxes (*Vulpes vulpes*) in Portugal avoided roads where traffic volumes were 2,161 vehicles per day (Grilo *et al.* 2009).

Seiler (2005) and Brockie *et al*. (2009) both found that when traffic volumes peaked (~5,000 vehicles per day), then roadkill numbers decreased either side of this figure. Data collected in the GMTFCA found that traffic volume had no significant influence on roadkill numbers and this is likely to be due to the low mean daily traffic volume (n = 149) in the study area.

The mean daily speed for roadkill detected in the GMTFCA was 90 km.h^{-1} which is considered to be an intermediate speed that can increase roadkill numbers (Seiler 2005). However, traffic speed had no significant effect on roadkill numbers found in the GMTFCA.

Gunson *et al.* (2003) detected more roadkill when the road was utilised by larger vehicles (trucks) than by passenger vehicles (cars). A weak correlation was found between vehicle type and roadkill in the GMTFCA, with more roadkill detected when there were passenger vehicles on the road, and trucks of between 5 and 6 axles.

4.4.4 Animal behaviour and traffic

Traffic volumes vary by hour and generally have peak/rush hour periods in the morning and evenings (van Langevelde & Jaarsma 2004). Based on data collated from 13 surveys, the daily traffic volume pattern in Holland on a two-lane urban road (over a 24-hour period) is characterised as 7% in the morning, 5% during the evening, and 2% at night (with the remaining 86% during the day; van Langevelde & Jaarsma 2004). Nocturnal and crepuscular species encounter considerably lower hourly volumes of traffic than diurnal species (van Langevelde & Jaarsma 2004) and yet significantly more nocturnal species were found as roadkill in my study and five others (Clevenger *et al.* 2003; Puky 2005; Ramp *et al.* 2005; Rowden *et al.* 2008; Bullock *et al.* 2011).

Whilst traffic volume is lower at night, animals are still killed (Brockie *et al.* 2009) and this is likely due to their behaviour. For example, many animals such as rabbits (Leporidae) ‘freeze’ in the headlights, and even if they are not killed by the first vehicle, a stationary animal will then be at risk from other vehicles (Brockie *et al.* 2009). Scrub hare (*Lepus saxatilis*; Appendices B & G) was the most prevalent mammal species detected as roadkill during the GMTFCA study, followed by bushveld gerbils (*Tatara leucogaster*) and the African civet (*Civettictis civetta*; Appendices B & G). African civets characteristically move slowly and when disturbed lie still or stand motionless (Skinner & Chimimba 2005). They also frequent roads, preferring to use established pathways, and are also nocturnal (Skinner & Chimimba 2005), which would possibly explain why road morality is so high for this species.

Similarly, Timber Rattlesnakes (*Crotalus horridus)* cross roads slowly (~1 cm/s;) and individuals that stop moving can remain immobile for up to a minute or more in response to traffic noise (Andrews & Gibbons 2005). Consequently, Timber Rattlesnakes crossing roads suffer ~80% mortality rate with traffic volumes of 3,000 cars per day (Andrews & Gibbons 2005). Fast moving animals are generally less vulnerable to traffic mortality (van Langevelde & Jaarsma 2004). It was therefore unsurprising that more snakes than lizards were detected as roadkill during the GMTFCA study (143:28; Appendix B). Lizards are generally faster moving than snakes and therefore able to react faster to vehicles (Branch 1998).

Many animals modify their behaviour near roads. For example, hedgehogs (*Erinaceus europaeus)* in England were found to move faster when crossing roads than they did in grassland areas (Bright *et al.* 2005). In the GMTFCA, only three chacma baboon (*Papio hamadryas*) road fatalities were detected (Appendix B), despite 169 baboon sightings along the transects (Appendix D). This would suggest that baboons are more ‘streetwise’ and may better understand the relevant clues that could save them on roads (Woodside 2011). This is most likely to be learnt behaviour (Jackson & Griffin 2000).

By contrast, raccoons (*Procyon lotor*) and bobcats (*Lynx rufus*) tend to avoid roads (Lovallo & Anderson 1996; Gerht 2003). Road avoidance has more impact on wildlife than roadkill since it forces many populations to become fragmented (Forman & Alexander 1998). For example, genetic differences have been noticed in the common frog (*Rana temporaria)* where roads have become barriers because of road avoidance behaviour (Reh & Seitz 1990). It is likely that many species in the GMTFCA avoid roads, and therefore were not encountered as roadkill during the study. However, whilst data are available for species that are likely to occur in the GMTFCA (Branch 1998; Hockey *et al*. 2005; Skinner & Chimimba 2005; Carruthers & du Preez 2011), little data are available for population densities, and the true impact of the roadkill figures from my study (Appendix B) has yet to be quantified.

As well as having a direct effect on wildlife, traffic indirectly effects wildlife with traffic noise (Jaarsma *et al.* 2006). An increase in traffic will equate to an increase in traffic noise (van der Ree 2011) and anthropogenic noise has the potential to severely disrupt the communication between species by acoustic interference and masking. Parris & Schneider (2009) found that the Grey Shrike-thrush *(Colluricincla harmonica)* sang at a higher frequency in areas with high traffic noise. Traffic noise has also been found to alter frog calls (Byrnes *et al.* 2012). A similar effect has been recorded in marine animals (Koper & Plön 2012), with sounds generated by large shipping vessels having substantial negative impacts on marine organisms. Further indirect effects from traffic can be caused by vehicle emissions, such as carbon and nitrogen and other pollutants (i.e. oil and tyre parts; Evink 2002). Little data are available on the indirect effects of traffic (van der Ree *et al*. 2011) and more research is needed.

5 CONCLUSION

Seabloom *et al*. (2002), suggest that humans are the cause of numerous species extinctions primarily through the conversion of natural habitat into land dominated by agricultural and other anthropogenic activities. Research on wildlife casualties and ecology is largely focussed on vertebrates (Shyama Prasad Rao & Spatha Girish, 2007), and mostly large mammals (Taylor & Goldingay 2012). Benitez-Lopez *et al*. (2010) highlights the importance of broadening analyses to include other taxonomical groups such as plants and invertebrates. Insects too are prone to a very high rate of roadkill incidence (Munguira & Thomas 1992; Shyama Prasad Rao & Spatha Girish 2007; Yamada *et al*. 2010; Soluk *et al*. 2011) and insect roadkill may affect the population dynamics of plants since many of them are insect-pollinated (Shyama Prasad Rao & Spatha Girish 2007).

Despite much work conducted on the determinants of roadkill, more intensive study is recommended to examine how and to what extent all of these variables interact (Ansara 2004). Simply counting the number of dead animals on the road will not inform whether roads and vehicles are endangering the existence of populations or species (van der Ree *et al.* 2011). Short term projects (i.e. MSc and PhD projects) need to extend to larger spatial and temporal scales (van der Ree *et al.* 2011) that combine with multiple road projects in different countries and are studied as part of integrated and well-replicated research projects. Roadkill is not random (Clevenger *et al.* 2003) but appears in clusters related to habitat, fence type, traffic volume and road size (Jaeger *et al.* 2005). These variables in isolation will not significantly affect road mortality, but rather in combination (Jaeger *et al.* 2005). Consequently, there is a pressing need to understand the factors influencing the location of roadkill for a wide variety of species (Kolowski & Nielson 2008) and the determinants of roadkill need to be better understood to enable decisions to be made in the future design of roads (Taylor & Goldingay 2010; van der Ree 2011).

Nine of the seventeen variables tested significantly influenced roadkill numbers in the GMTFCA. Of these, the four biophysical variables (season, rainfall, and minimum and maximum temperature), which determine animal activity, cannot be physically altered. However, the five environmental and physical variables (habitat, grass height and density, vehicle type and fence type) can be altered to lessen the effect of roads on wildlife. To address these alterations, mitigation measures need to be applied and the determinants of roadkill need to be more fully understood. Therefore, it is recommended that further testing of the protocol is conducted in other areas of South Africa to provide a greater understanding of the causes of roadkill.

CHAPTER 5

THE ROAD AHEAD: strategies for roadkill mitigation in South Africa

"… Two roads diverged in a wood, and I -
I took the one less travelled by,
And that has made all the difference."

Robert Frost: *The Road Not Taken*, 1920

1 THE ROAD AHEAD

Roads are integral to the financial development and prosperity of the local and national economy in South Africa and there is a potential conflict between development and conservation (van der Ree *et al.* 2007). South Africa needs infrastructure and road building cannot be prevented. With tourism being an important revenue earner for the country, there needs to be a compromise between conserving the country's wildlife from the impacts of roads, and providing networks that enable South Africa's main industry to function effectively. People do not want to spend hours travelling to a destination due to an inefficient route, but at the same time, the environment should not be compromised entirely for the sake of roads. To achieve a balance between these two, a national strategy to mitigate the impacts of roads on wildlife populations is long overdue. Caltrans (2003) state there should be three steps to facilitate a successful reduction of roadkill; mitigate, monitor and maintain with adequate funding for each. It is unrealistic to aim for the complete removal of the problem and the goal should be to reduce collision rates to socially acceptable levels at the same time as implementing public awareness (Malo *et al.* 2004).

An extreme measure would involve not building a road (Forman *et al.* 2002; Bennett 1991), however, this is often impractical, and therefore other options need to be considered. These could include changing the proposed route to avoid wildlife corridors (Forman *et al.* 2002) or building the road underground (tunnel; Clevenger & Waltho 2001; Forman *et al*. 2002). Other proposals include closing the road to motor vehicles (permanently or seasonally; Groot Bruinderink & Hazebroek 1995), installing wildlife fences (Lyren & Crooks 2002), building underpasses and overpasses (Forman *et al.* 2002), or restricting or screening human activities in wildlife corridors and crossings (Forman *et al.* 2002). More effective measures might be to reduce the width of the verge (Meunier *et al*. 2000) or the verges could be fenced off (Dodd *et al.* 2004).

Roadkill mitigation strategies can be implemented during the planning process for new roads. However, for existing roads, the connectivity between habitats which has already been bisected by roads should be restored, so that animals can approach roads and cross safely. Wildlife crossing structures not only provide connectivity of habitats and populations but also aim to reduce roadkill numbers (Ruediger 2001).

Mitigation measures have been prompted mainly by the human-safety issue posed by animal-vehicle-collisions rather than the effects on wildlife (van der Ree *et al.* 2007). Many mitigation monitoring studies have examined before and after figures for roadkill rates, but little data are available to examine any improvement of wildlife crossing structures on the other impacts of roads, such as, animal road avoidance and the impacts of road noise (Ng *et al*. 2004). Nor is there much follow up work that monitors the implementation and maintenance of mitigation structures (Spellerberg 1998).

2 FACTORS AFFECTING ROADKILL RATES IN THE GMTFCA AND STRATEGIES FOR SOUTH AFRICA

South Africa is fundamentally different to Europe and North America. There are major differences existing between the species of wildlife, landscapes and geography, the density of roads and humans, and funding and support for road ecology research and mitigation measures. However, the information and lessons learned in these developed countries can be implemented and adapted to the South African situation.

A variety of mitigation measures have been proposed globally to reduce roadkill occurrence. However, none are actively practised in South Africa and many successful global mitigation measures are taxon specific (Patterson 1977; Bertwistle 1999; Clevenger *et al*. 2001; Mount Kenya Trust 2011). Studies suggest that the most effective methods, for mammals in particular, are fencing and reduced speed limits (Clevenger 2002, Bullock *et al.* 2011). Whilst this may be a favoured method for roadkill mitigation, the disadvantages of fencing are that it can increase the isolation of wildlife populations and constrain the movement of animals, usually by preventing access to adjacent habitats and impeding dispersal. Mitigating the barrier effects of roads may also be compounded by fencing and creates a challenge that is unique to South Africa, since many thousands of kilometres divide properties in South Africa.

Nine of seventeen predictor variables assessed in my study significantly impacted wildlife road mortality numbers in the GMTFCA. These were season, rainfall, temperature (minimum and maximum), habitat, grass height and density, fence type and traffic class. The following mitigation measures (derived from existing literature) are therefore proposed as options to roadkill numbers in the GMTFCA and, by extension, similar habitats across South Africa.

2.1 Habitat and roadside verges (grass height)

More roadkill was detected in the GMTFCA in open grasslands and open *Mopane* than dense *Mopane*, and when grass was at intermediary heights on the roadside verge (30-60 cm).

The edge effects of roads might be partially mitigated with vegetation management (Smit & Meijer 1999; Kociolek *et al.* 2010) such as the removal of grass verges (Oxley *et al*. 1974; Orlowski 2008) although this is controversial since it alters the habitat available for small rodents, and the destruction of plants along roadsides (Noss 2002). Alternatively, rather than the complete removal of roadside vegetation, Groot Bruinderink & Hazebroek (1995) suggest planting thorny, unpalatable, cover plants for grass verges, and to refrain from planting fruit-bearing vegetation along the roadside (Kociolek *et al.* 2010).

Studies that have identified ‘danger zones’ where habitat was more open (Dunthorn & Errington 1964; Erritzøe *et al.* 2003) propose a combination of mitigation practices. This involves erecting fences to prevent animals from crossing the road, combined with signage, warning drivers that wildlife may be crossing (Bullock *et al*. 2011). However, my study area already had fencing surrounding the habitats, which may suggest that more effective fencing is required in addition to signage.

2.2 Fencing

More roadkill were detected in the GMTFCA when there was a gate, barrier or cattle/electric combined fence, and less when there was an electric or game fence. This suggests that the higher and more permanent the structure, the more effective it is at preventing wildlife from crossing roads. Literature suggests that the most effective method of reducing roadkill rates is fencing (Lyren & Crooks 2002; Caltrans 2003; Seiler 2005). However, fencing does not stop all animals from crawling through or jumping over them. Many South African antelope can easily jump over 2.4 m fences (Ludwig & Bremicker 1983; Eloff & van Niekerk 2005) and other species will often dig under a fence and provide an opening for other animals (Ballon 1995, Davies-Mostert 2012). Therefore, modifications to improve existing fencing in the GMTFCA could include; combining fencing with finer mesh to stop smaller animals getting through (FHWA 2000; FHWA 2003), or a lip bent at right angles at the top of the fence (with a one metre extension) to prevent animals from climbing over (FHWA 2003). This has proved effective in Canada for preventing black bears *(Ursus americanus;* Lewis *et al.* 2011) and cougars (*Puma concolor*) from climbing over fences (Clevenger *et al*. 2001). One-way gates have also shown some success (Ludwig & Bremicker 1983) in providing an escape route for those animals that manage to bypass a fence and then find themselves trapped next to the road.

However, additional fencing can be expensive, and landowners may be reluctant to make these modifications due to the trade-off between spending money to prevent wildlife that they own from crossing roads (i.e. game animals) and animals that naturally occur in the area (i.e. African Civet; *Civettictis civetta*). The loss of an African Civet will not impact a game farmer's livelihood, whereas a kudu *(Tragelaphus strepsiceros)* that can be sold to a trophy hunter is more likely to negatively impact upon the farmer's annual income. Therefore, if additional fencing is required, this may need to become part of the South African National Roads Agency's (SANRAL) future budget.

A long-term study which may be applicable to South Africa is the use of predator urine on roadside verges (Rowden *et al*. 2008; Ward & Williams 2010). This has been found to repel many animals, such as ungulates, from roads, particularly when used in conjunction with fencing (Curtis *et al.* 1994; Groot Bruinderink & Hazebroek 1995). However, it was not effective in Australia for Kangaroos (Rowden *et al*. 2008). Electric fencing, combined with repellents, was effective in deterring deer (Cervidae) from feeding on apples and therefore may be an effective deterrent for preventing deer from crossing roads (Jordan & Richmond 1991). However, the research is in need of further implementation in other countries and with other species.

2.3 Traffic and roads

Whilst traffic volume and traffic speed did not significantly impact roadkill numbers in the GMTFCA, the type of vehicle using the road did, with more roadkill detected when there were heavy trucks (5-6 axles) using the road. This would suggest there needs to be traffic control measures in place which limit the axle load of vehicles using the road. Signage specifying the vehicle types allowed access to the road will need to be erected with enforcement from SANRAL (South African National Roads Agency) and the Municipal Police (who are responsible for traffic policing in South Africa) to ensure that road users comply.

2.4 Public awareness and signage

Passive signage is used globally to warn drivers of animal presence but it has been largely ineffective (Hedlund *et al*. 2004) as the signs are usually fixed in one spot, with a standard picture of an animal (Figure 5.1a; Manual of Uniform Traffic Devices; Hedlund *et al*. 2004) and drivers usually ignore them (Sullivan & Messmer 2003). Whilst I recommend the use of signage (in combination) with better fencing and roadside verge maintenance, signage needs to be clearer, and, if possible, species specific. Many countries, other than South Africa, have more flexibility with the species displayed on the sign. For example, water birds and kangaroos (*Macropus* sp.) in Australia (Figures 5.1 b and c) tree kangaroos (*Dendrolagus* sp.) in Tasmania (Figure 5.1d), and (e) the African wild dog (*Lycaon pictus*) in Zimbabwe (WCN 2012; Figure 5.1e).

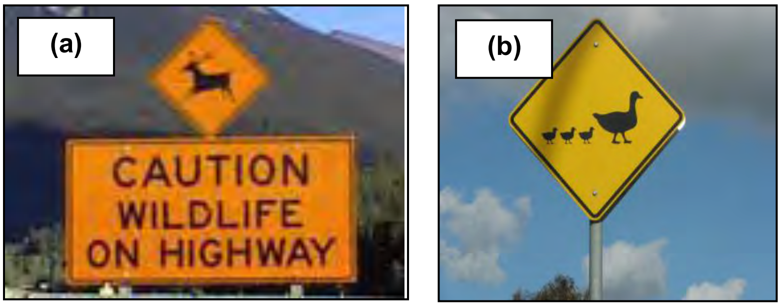


Figure 5.1: Photographs showing road signage from across the world warning drivers of wildlife on the roads in (a) Canada, (b) Australia, (c) Australia, and (d) Tasmania, (e) Zimbabwe.

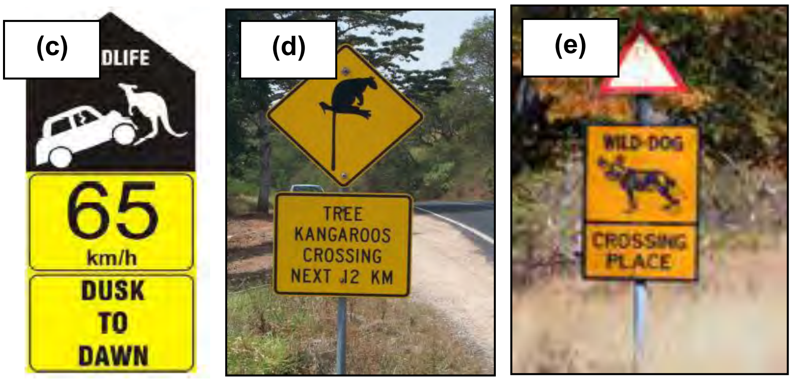


Figure 5.1 (continued): Photographs showing road signage from across the world warning drivers of wildlife on the roads in (a) Canada, (b) Australia, (c) Australia, and (d) Tasmania, (e) Zimbabwe.

South African road signage has strict guidelines (RTMC 1999) that limit signage to a few domestic and wildlife species which are all mammals (Figure 5.2) and this does not reflect the rich diversity of wildlife in the country. Therefore, the general public may only think that roadkill is a threat to certain mammals and not be aware of the threats to other species.

Figure 5.2: Eight road signs currently used in South Africa warning drivers to the presence of domestic and wildlife animals near the road (RTMC 1999).

Active signage has had more success. For example, signs implemented in Canada were placed in recognised 'hotspot' areas where elk *(Cervus canadensis)* and bighorn sheep (*Ovis canadensis*) occur (Figure 5.3a), and a 30% reduction in collisions was recorded (Bertwistle 1999). In addition, solar powered signage in Switzerland and Finland (Figure 5.3b) had motion sensors that flashed when an animal broke the infrared beam, therefore alerting drivers to their presence (Taskula 1997; Evink 2002).

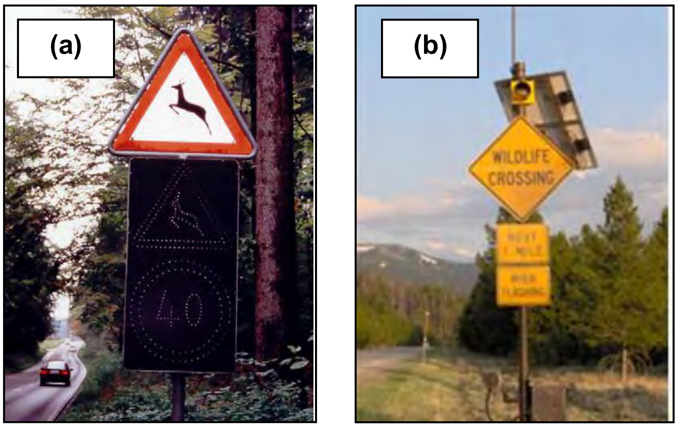


Figure 5.3: Two road signs employed in (a) Canada, and (b) Switzerland and Finland that respond to animal presence and alert drivers with flashing signage.

I recommend more active signage to be implemented in the GMTFCA that is more species-specific and deployed seasonally. For example, more roadkill was detected during the hot/wet season (February to May) than for the other two seasons, since wildlife were generally more active during this period due to breeding and dispersal cycles (Branch 1998; Hockey *et al*. 2005; Skinner & Chimimba 2005; Carruthers & du Preez 2011). Consequently, signage should be more prevalent during this period alerting drivers to increased animal activity near to the roads.

The most common amphibian roadkill species detected in the GMTFCA was the Eastern Olive Toad (*Amietophrynus garmani;* Appendices B & G*),* whilst the top three reptile species (Appendices B & G) were the Flap-neck Chameleon *(Chamaeleo dilepsis)* Mozambique Spitting Cobra *(Naja mossambica)* and the Brown House Snake *(Lamprophis fuliginosus*). Bird roadkill was the highest out of the four taxa (Appendix B), with the top three being Helmeted Guineafowl *(Numida meleagris;* Appendix G*),* Nightjars *(*Caprimulgidae; Appendix C*)* and Black-crowned Tchagras *(Tchagra senegala).* The top three mammal species (Appendix B) were scrub hare *(Lepus saxatilis:* Appendix G*),* bushveld gerbil *(Tatara leucogaster;* Appendix G*)* and African civet *(Civettictis civetta;* Appendix G*).* None of the species appear as signage as outlined by the Road Traffic Management Corporation (RTMC2005; Figure 5.3) and current signage would therefore be inappropriate for alerting drivers to roadkill in the GMTFCA.

2.5 Species-specific mitigation recommendations

The proposed mitigation measures recommended thus far in this chapter are generic and do not take into account differences amongst individual species. Therefore, further recommendations are outlined for the species that occurred as roadkill more often than others in the GMTFCA.

Many parts of South Africa are dependent on rain for growth of crops and providing food for livestock and game. The GMTFCA is in an area with a low annual rainfall (~278 mm per year; Nel & Nel 2009) and less than 50% of this amount fell during 2011 and 2012. This resulted in less food being available for ungulates on game farms (pers.obs.) and more herbivores were observed foraging on the roadside verges (pers.obs.), particularly during the cold/dry season (89%; Appendix D). A total of 20 antelope were killed on the road with the majority of these occurrences (65%) during the cold/dry season (Appendix B). Whilst grass density and height were not significant predictors of roadkill numbers detected in the GMTFCA, more grass was observed on the road verges than on adjacent farms during the cold/dry season (pers.obs.).

Road verges usually have higher plant species richness due to water run-off from roads (Forman & Alexander 1998; Dean & Milton 2003; Dean *et al.* 2006), taller plants and more seed production, and are therefore attractive foraging areas for animals (Gubbi *et al.* 2012). Deer (Cervidae) and other browsing herbivores are often attracted to the dense vegetation or so called 'green curtain' of roadside edges (Noss 2002).

Many measures have involved mitigating the impacts of deer-vehicle-collisions, most likely because they are the number one insurance claim in most countries (Craighead Institute 2000; Car accident statistics 2012), and therefore attract the greatest attention. A cheap and effective method adopted in the USA uses reflectors to deter deer from roadsides (Strieter-Lite ® 2002) and may be effective in South Africa. These reflectors have shown a 79 to 90% reduction in deer-vehicle collisions (Strieter-Lite ® 2002) and are mounted on posts along roadsides. They deter deer from attempting road-crossings by redirecting light from oncoming vehicle headlights across the road (Figure 5.4). This creates an optical warning fence to deer. Other reports though stated that the deer became habituated to the beam reflectors and were less successful in the long-term (Waring *et al.* 1991; D'Angelo *et al.* 2006). However, they may be effective when combined with other structures, such as fencing and the recommended lip bent at right angles at the top of the fence (Waring *et al*. 1991; FHWA 2003), roadside vegetation management (Smit & Meijer 1999; Kociolek *et al.* 2010) and increased active signage (Bertwistle 1999).

Figure 5.4: A photograph of a deer reflector (Strieter-Lite ® 2002).

A further recommendation is to make antelope species more visible, particularly those species prone to browsing at night. Two-thousand reindeer were fitted with antler tags over the festive period in December 2010 in Norway, in the hope that the reflective collars increased visibility and therefore protected against collisions. A test exercise with a snowmobile showed that the marked reindeer were much easier to spot in the dark (The Telegraph 2010), but no further data are available. This could be a relatively cheaper method to trial than upgrading fences.

Of the mammal roadkill, scrub hare had the highest levels of road mortality in the GMTFCA, with a total of 118 observed across all three seasons. Of these, 67 were sexed, and more males (69%) were detected as roadkill than females (Appendix B). Despite a peak during hot/wet summer months, scrub hares are aseasonal breeders (Skinner & Chimimba 2005). When a female is in oestrus, she is often accompanied by more than one male (Skinner & Chimimba 2005) which may explain the higher ratio of male to female roadkill. Additionally, scrub hares are nocturnal and my data showed that nocturnal species were more likely to become roadkill than diurnal species. Whilst population figures were not available for scrub hare, they appear to be an abundant and prolific species (Skinner & Chimimba 2005) and road mortality is unlikely to impact populations. However, dead carcasses often result in a cascade effect along the trophic hierarchy where scavenging animals seek out roadkill and often become roadkill themselves (Antworth *et al*. 2005; Dean & Milton 2009).

Mammal body size is often an excellent indicator of vulnerability to becoming roadkill (Fagan *et al*. 2001; Cardillo 2003; Ford & Fahrig 2007; Barthelmess & Brooks 2010). Over one third of rodent species (Rodentia) were found to have a high incidence of roadkill in total numbers in the GMTFCA (Appendices B & G), but the impact on the population may be less than for a large mammal species, such as the African civet (that had 16 road mortalities recorded; Appendices B & G) where reproductive rates are much slower and litter size is smaller (Feldhamer *et al*. 2007).

Whilst more effective fencing may assist with preventing these species from crossing the road, the barrier that is then created may actually impact the species more than the threat of roadkill as populations become more divided and fragmented (Dodd *et al*. 2004; Taylor & Goldingay 2010). A solution therefore, would be to not prevent species from crossing roads but to use fencing to direct them to wildlife crossing passages (Forman *et al*. 2002). Groot Bruinderink & Hazebroek (1995) suggest identifying locations at which wildlife may cross to create a wildlife crossing. Fencing can then be added to prevent animals from crossing everywhere, and instead funnel and guide the individuals towards the passages (Figure 5.5).

Figure 5.5: Two photographs showing how mesh fencing can be used to guide animals towards wildlife passages (a) small mammal wildlife passage leading to a culvert, Australia (van der Ree 2012), (b) Gopher Tortoise wildlife passage, Texas, USA (Lake Jackson Feasibility Study; Sewell 2004).

This may be effective not just for small mammal species but for all small terrestrial taxa. For example, Flap-neck Chameleon suffered the highest road mortalities for Reptilia with 45 roadkill detected (Appendices B & G) with a further 80 observed crossing the road (Appendix D). Flap-neck Chameleon are largely arboreal, but are found on the ground during the breeding season which occurs from March to May (during the hot/wet season; Branch 1998). Males will actively seek out females, often crossing roads to their detriment, whilst females seek damp soil to lay their eggs (Branch 1998). Due to its size (120-140 mm) and being one of the larger chameleon species, the Flap-neck Chameleon is feared by many tribal people and is the subject of much folklore (Branch 1998). This may result in purposeful killing of them on the roads (Bonnet *et al.* 1998).

Few amphibian species (n = 3) were detected during my roadkill surveys with a total of 48 road mortalities (Appendix A). Of these, 85% were attributed to the Eastern Olive Toad (*Amietophrynus garmani)*, with 90% occurring during the hot/dry season. This was over a three-day period when 60% of the rain for the hot/dry season occurred. Many amphibian species are therefore only active for a short and specific period of the year. For example, the endangered Western Leopard Toad (*Amietophrynus pantherinus)* in the Western Cape (South Africa) is active for ~one week per year in August, when it crosses a major road in search of a mate (Rebelo *et al.* 2004). Thousands are killed during this annual mating ritual, and consequently, volunteers are on stand-by to physically assist the toads crossing the road. The amphibians detected during my study were not only active at a specific period of the year, but were also found in one particular section of the transect. (Appendix G).

Combined with seasonal, species-specific signage, existing features (such as culverts) could be modified to create wildlife passageways to assist species such as the Flap-neck Chameleon and amphibians in crossing the road. A variety of animals are known to use wildlife crossings and movement patterns of many wildlife species are often associated with drainage lines (Sagastizabel 1999; Smith *et al.* 1999; Smith 2003; Caltrans 2003). Drainage culverts (Figure 5.6a) beneath roads can be modified with mesh fencing to encourage small vertebrate species and amphibians to cross (Figure 5.6b; Boarman & Sazaki 1996; Jackson 2000), whilst modified culverts with add-on shelves, slightly above the water surface, may be incorporated for small mammals and reptiles accessing the culvert (Figure 5.6c; Evink 2002). The additional cost is minimal in comparison to the overall cost of the structure (FHWA 2003).

Figure 5.6: Three photographs showing different types of underpass design for small mammals, reptiles and amphibians (a) amphibian underpass using existing road features (FHWA 2012b), (b) fine mesh fence and culvert for small mammals in Europe (Evink 2002), (c) small mammal wooden plank crossing in a drainage culvert (Cramer 2004).

Bridges can also be modified with the addition of a shelf pathway going under the bridge to create a wildlife passage (Figure 5.7a and b), whilst more permanent verge shelving can aid directing wildlife towards crossings (Figure 5.7c).

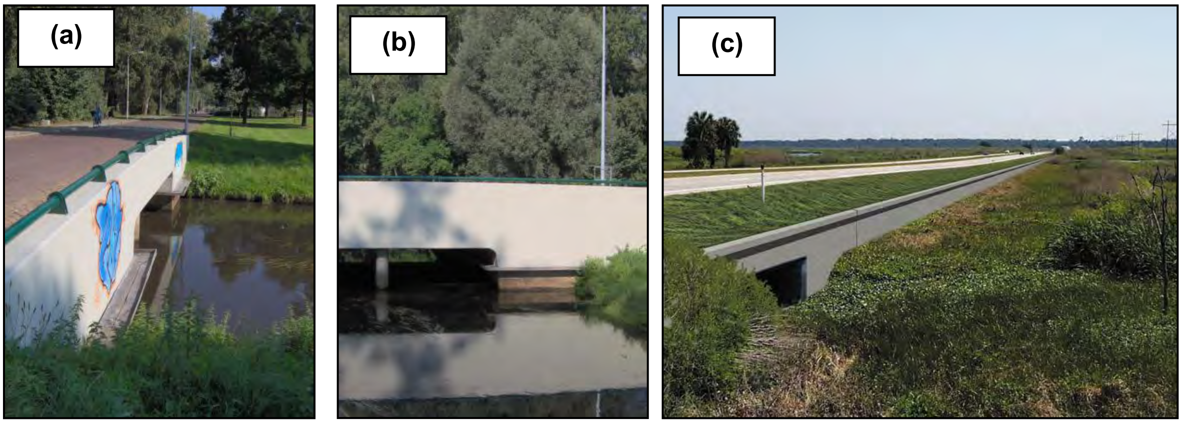


Figure 5.7: Photographs showing (a) and (b) a modified shelf pathway under a bridge for small mammals, The Netherlands (van der Ree 2012), and (c) a wall with a lip and culvert to prevent amphibians and small reptiles from crossing the road. The wall also directs them towards the culvert (bottom left of the photograph). (FHWA 2012a; Photograph © Forsyth, D).

These small underpasses are not appropriate for larger mammal species (i.e. antelope) and therefore larger underpass structures would need to be incorporated in the future planning of roads. However, this may be a challenge for South African road ecologists, as many landowners who own wild game do not want their property linked with adjacent properties, and prefer to keep their wildlife separated by fences. Any proposed wildlife passages such as overpasses and underpasses, as used in other countries (Figure 5.8), are likely to be met with resistance. Therefore, these larger wildlife crossing structures may be more applicable to protected areas and wildlife conservancies that are divided by roads, such as Hluhluwe-iMfolozi Game Reserve (KwaZulu-Natal, South Africa). However, these structures are expensive to build and also require monitoring and extensive maintenance.

Figure 5.8: A photograph showing the Mount Elephant Corridor in Kenya with elephants utilising the underpass beneath the Nanyuki-Meru Highway (Mount Kenya Trust 2012). The underpass cost US$1 million to build.

Avian roadkill was the most impacted taxa (43%) in my study. A total of 69 Helmeted Guineafowl roadkill were detected with the majority occurring during the hot/wet season (Appendix D). These birds were commonly seen feeding on roadside verges (pers.obs.). A total of 63 nightjar roadkill were recorded with the majority being during the hot/wet season. In addition, nightjar species are generally more prevalent in the GMTFCA from September to March (Hockey *et al*. 2005), which would explain why high roadkill numbers were observed for this bird family during this period (Appendix C). Signage erected during this time alerting drivers to nightjar on the roads may reduce mortality rates.

Global mitigation efforts for birds are limited due to the very nature of bird behaviour. Birds react to traffic by flying away, and this very act is often what results in their mortality as the down-draught from traffic 'sucks' them in and results in a collision (Dreyer 1935). Unlike terrestrial species, they are unable to use wildlife passageways, although Orlowski (2008) suggests constructing high embankments (Figure 5.9) on either side of the road to force birds to fly higher, and therefore avoid being pulled into the down-draught of vehicles. This may be an effective deterrent to implement in certain areas of the GMTFCA where large flocks of birds are likely to occur.

Figure 5.9: A photograph showing a dual-carriageway in Australia with raised roadside embankment either side of the road (van der Ree 2012).

Two snake species also suffered high roadkill numbers with a total of 22 Brown House Snake and 24 Mozambique Spitting Cobra accounting for 31% of snake (Squamata) roadkill. Snakes are often resented and misunderstood by people with the attitude of 'kill first', identify later'. Consequently, this may result in the deliberate killing on roads (Bonnet *et al.* 1998). Both the Mozambique Spitting Cobra and the Brown House Snake are nocturnal species with the former much feared due to its highly venomous bite (Branch 1998). If snakes are deliberately killed on roads, then it is easy to understand why the Mozambique Spitting Cobra was targeted. However, this does not explain why the Brown House Snake may be deliberately targeted above the other 22 snake species detected as roadkill. One possible suggestion may be due to the similarity in appearance of the Brown House Snake to the juvenile

Mozambique Spitting Cobra which are both brown in colour and may easily be mistaken for one another at night. Alternatively, it may just mean that both the spitting cobra and the house snake are the two most abundant snake species in the area.

Mitigation measures for snakes may involve modifying culverts for their use, but it is my opinion that understanding snake behaviour may motivate some motorists to alter their driving behaviour to avoid encounters with animals on roads. This may be done through the publishing of information in popular media channels, such as newspapers and magazines, thus portraying certain species more positively, providing information about their conservation status, and why it is important to protect them.

Of the 162 vertebrate species detected as roadkill, 88 were arboreal and 74 were terrestrial. The majority of the arboreal species were from the taxon group, Aves (81), with five from Mammalia and two from Reptilia. No cluster areas were identified for either of these two taxa nor did they occur in high roadkill numbers (apart from the Flap-neck Chameleon). Therefore, no mitigation measures are proposed for these seven species in the GMTFCA.

2.6 Public awareness campaigns

In addition to the above mentioned mitigation measures, raising public awareness to the broader threat that wildlife faces from roads should be a priority, not just in the GMTFCA, but across South Africa. This can include creating websites that are devoted to the effects of roads on wildlife. For example, a website in Tasmania (Roadkilltas 2012) displays annual roadkill statistics and encourages members of the public to report wildlife roadkill (Hobday & Minstrell 2008). Another website has launched a campaign to prevent the building of a highway through the Serengeti National Park in Tanzania (Stop the Serengeti Highway 2012). The public can further assist with monitoring roadkill through the use of Smartphones. Montana State University has developed a software tool called the Roadkill Observation Collection System (ROCS) which integrates a handheld computer with a global positioning system (GPS) that aids collection of wildlife-vehicle collision data. The eventual tool will be developed to Smartphones that will enable the general public to also report on roadkill (Ament 2008). Other awareness programmes could include posters displayed in national parks or other public places.

Public awareness should also include drivers taking more responsibility for their vehicles and consider modifications. For example, General Motors (Bendix 2002) and Volvo are piloting a new system specifically designed to sense animals that are on the road ahead and therefore avoid a collision. The technology is based on existing pedestrian detection systems and use both radar and infrared sensors to scan the road ahead. If a collision is thought likely, the system emits an audible warning and if no action is taken, the brakes of the vehicle are automatically applied (Daily News 2011).

Education of the public and politicians about the far-reaching effects of roads is critical (Groot Bruinderink & Hazebroek 1995) and will need strong arguments to convince the public of the trade-off between the benefits of fast transportation and easy access to recreational areas and the threat of roads on wildlife (Noss 2002). Through highlighting the threat of roadkill on biodiversity, the public should be encouraged to take the death of an animal killed on the road as seriously as one would a human being.

3 CONCLUDING REMARKS

Often road agencies design structures and only then consult road ecologists to assess their effectiveness (Lesbarrieres & Fahrig 2012). Therefore, wildlife researchers need to be involved in the planning of new roads from the outset with ongoing research that examines the impacts before and after construction. Funding of mitigation measures and their monitoring and maintenance needs to become a standard in road development budgets. Currently, little money is available in budgets for mitigation (van der Ree *et al.* 2007) and the amount of money spent on mitigation is relatively small compared with overall construction and maintenance budgets of state and national road agencies (van der Ree *et al.* 2007).

Existing literature has shown that data examining the impacts of roads on wildlife in South Africa is scarce and is trailing behind the rest of the world. South Africa has the opportunity to accelerate progress in road ecology and avoid making the mistakes that other countries have made. Continued research is required to ensure that roads are both ecologically sustainable and able to improve people's livelihoods with a need for the development and implementation of national policies that require national roads agencies to address highway impacts on wildlife.

It is also important that future research on roads becomes more standardised to enable the statistical comparison of different studies. The protocol outlined here is repeatable and can also be used to examine mitigation successes (before and after studies). A balance between the need for an effective transport network and a sustainable environment is a challenge facing any government and the financial resources made available to address this will be a true test of the Government's commitment to sustainability.

3.1 Recommendations

Data collected from this research highlights some immediate priorities for SANRAL, which should form outcomes of this study. These include, to:

3.1.1 Local priorities (GMTFCA):

1. Limit the number of large vehicles (5-6 axles) utilising the road in the GMTFCA;
2. Implement seasonal signage (i.e. during the hot/wet season) warning drivers that more animals are crossing the roads during this period;
3. Erect species-specific signage and reduced speed limits in the hotspot areas identified in appendices F and G.
4. Assess the type of fencing utilised in these hotspot sections, with a view to upgrading them from cattle to electric fencing, or to create wildlife crossing structures using the existing culverts beneath the road.
5. Budget for follow-up research (during the hot/wet season) to examine the effectiveness of the mitigation measures introduced.

3.1.2 Broader priorities for South Africa:

1 Identify strategic partners to assist with managing the broader impacts of roads on wildlife in South Africa;

2 Conduct further research (using the standardised protocol) identifying other potential areas of South Africa which may be roadkill ‘hotspots’. This will guide the area of operation of key stakeholders, namely SANRAL;

3 Promote knowledge of the concerns facing wildlife from roads, through media releases and public forums.

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APPENDIX

APPENDIX A: A summary of previous roadkill studies (from peer-reviewed published journals) comparing sample methods used to detect roadkill.

APPENDIX A: A summary of previous roadkill studies (from peer-reviewed published journals) comparing sample methods used to detect roadkill. (Sampling distance (km) includes either total transect length of length of repeated transects, as stated in the literature).

#	Author	Year	Where	Species	Speed (km h^{-1})	# of observers	Sampling frequency (when)	Sampling frequency (months)	Sampling distance (km)	Road type	# of transects (repeated)	Time of day (start)	Other	Traffic count
1	Adams & Geis	1983	USA	Small mammals	Walk	1	June	1	1.6	Highways & state roads	5	Any	On-foot surveys on road verges	No
2	Antworth *et al*.	2005	Florida, USA	Vertebrates	50-80	No data	36-hour period	3	34	Two-lane highway	2	No data	-	No
3	Bager & da Rosa	2011	Southern Brazil	Vertebrates	50	No data	Weekly	36	117	Federal highway	1	No data	-	No
4	Barrientos & Bolonio	2009	Central Spain	Polecat (*Mustela putorius* L.)	40-50	2	Bi-monthly	23	246	No data	2	No data	Additional random on- foot surveys (road verges)	No
5	Barthelmess & Brooks	2010	New York, USA	Mammals	72	2	Weekly	14	206.3	No data	3	06:30 and 07:00	-	No
6	Bright *et al*.	2005	UK	Mammals	No data	No data	Over 3 months	monthly	>32	All roads excluding motorways/dual carriageways	Numerous	No data	Data taken from volunteers across the UK	Yes
7	Brockie *et al*.	2009	North Island, New Zealand	Mammals & birds	50-100	2	February (over 3 years)	3	1660	No data	16	Daylight hours	-	No
8	Bullock *et al*.	2011	RSA	Mammals & birds	100	No data	12 surveys	9	261	National road & gravel	1	No data	-	No
9	Caro *et al*.	2000	California, USA	Medium-sized mammals	No data	No data	10 – 30 times a month	25	14.2, 12,9 12.8	Two-lane paved roads	3	Daylight	Some transects were driven twice a day in different directions	No
10	Case	1978	Nebraska, USA	Birds and mammals	No data	No data	No data	84	732	Highway	1	No data	Data reported by service crew	Yes
11	Carvalho & Mira	2011	Portugal	Vertebrates	20	No data	Bi-monthly	24	26	National road	1	No data	-	No
12	Ciesiolkiewicz *et al*.	2006	Poland	Snakes	N/A	1	Daily for 3 months & then twice a week for remaining	11	1.8	Tarmac road	1	Between 06:00 & 10:00	Walking survey (both sides of the road)	No

#	Author	Year	Where	Species	Speed (km h^{-1})	# of observers	Sampling frequency (when)	Sampling frequency (months)	Sampling distance (km)	Road type	# of transects (repeated)	Time of day (start)	Other	Traffic count
13	Clevenger *et al.*	2003	Alberta, Canada	Small vertebrates	10-20 below posted speed limit	2	Daily	36	105.6 & 142.5	No data	2 (alternated each day)	1 hour after sunrise	-	Yes
14	Coelho *et al.*	2008	Brazil	Vertebrates	40-60	2	Monthly	12	195	National highway	2	No data	No count for amphibians due to size	Yes
15	Conrad & Gibson	2006	Kansas, USA	Mammals	55-65	No data	Weekly (over 2 years)	7	40	State highway	2	No data	-	Yes
16	Da Rosa & Bager	2012	Brazil	Birds	50	2	95 monitorings	27	117	Highway	2	07:00	No weekends and no days when there was rain	No
17	Dean & Milton	2003	Nama-Karoo, RSA	Raptors	100	2	6 - 26 surveys per month	162	90, 012	No data	1	No data	Data recorded on a tape recorder	No
18	Dickerson	1939	USA (14 states)	Vertebrates	No data	1 & 2	62 days	36	>75, 000	National roads	Various	No data	-	No
19	Dreyer	1935	USA (3 states)	Vertebrates	No data	No data	9 days	N/A	1, 500	National road	2	No data	--	No
20	Gerht	2002	Illinois, USA	Raccoon (*Procyon lotor*)	16-24	1 & 2	Bi-weekly	24	41.8	No data	3	No data	-	Yes
21	Gomes *et al.*	2009	Portugal	Owls (Strigiformes)	30	1	Bi-monthly	24	622	No data	14	No data	-	No
22	Grilo *et al.*	2009	Portugal	Carnivores	30	1	Bi-monthly	24	574	Highway and national road	2	No data	Both directions driven	Yes
23	Guinard *et al.*	2012	France	Birds	40-50	2	2.5 days per season totaling 10 a year	24	166	Highway	1	2 counts per day (no count at night)	Random foot surveys conducted over 10 km	Yes
24	Gunson *et al.*	2003	Canada	Large animals	No data	No data	No data	12	Part of study area	Highway	Numerous	No data	Data taken from insurance company reports of animal/vehicle collisions	Yes
25	Haikonen & Summala	2001	Finland	Moose *(Alces alces)* & White-tailed deer (*Odocoileus virginianus*)	No data	No data	Over 9 years	No data	Part of study area	No data	Numerous	No data	Data taken from crash statistics	Yes
26	Hegel *et al.*	2012	Brazil	Mammals	60	No data	No data	24	3720	Highway	1	No data	-	No

#	Author	Year	Where	Species	Speed (km h^{-1})	# of observers	Sampling frequency (when)	Sampling frequency (months)	Sampling distance (km)	Road type	# of transects	Time of day (start)	Other	Traffic count
27	Hell *et al.*	2004	Slovak	Vertebrates	No data	No data	Weekly	28	32	Highway	4	No data	Monitored by bike / car / on foot	-
28	Hels & Buchwald	2000	Denmark	Amphibians	No data	No data	Over 3 years	7	0.6	No data	1	Dawn	During breeding seasons	-
29	Jackson	2003	Zimbabwe	Nightjars (Caprimulgidae)	15-25	No data	Weekly	12	32	No data	1	Night	Both directions driven	No
30	Joyce & Mahoney	2001	Canada	Moose *(Alces alces)*	No data	No data	Over 6 years	No data	Part of study area	All road types	Numerous	No data	Data taken from crash statistics	Yes
31	Kleist *et al.*	2007	North Carolina, USA	White-tailed deer (*Odocoileus virginianus*)	No data	No data	Weekly	17	1.8	Highway	1	No data	Video surveillance also used	No
32	Kolowski & Nielson	2008	Illinois, USA	Bobcat *(Lynx rufus)*	No data	No data	Over 12 years	No data	Part of study area	No data	No data	No data	Opportunistically collected	Yes
33	Langen *et al.*	2012	New York State, USA	Freshwater turtles	32-46	2	Weekly (over 2 years)	12	160	Highways	1	06:30-12:00	Direction alternated	Yes
34	Loughry & McDonough	1996	Florida, USA	Armadillo (*Darypus novemcinctus)*	No data	No data	Over 3 years	3 (August)	5	Highway	1	No data	-	No
35	McDonald	2012	Australia	Snakes	40-60	No data	77 occasions	12	77	Sealed road	1	1 hour after sunset	Both directions driven	No
36	Mackinnon *et al.*	2005	Ontario, Canada	Reptiles	40-60	No data	April – October (over 2 years)	14	12.2	No data	1	Daylight hours	-	No
37	Malo *et al.*	2004	Spain	Vertebrates	No data	No data	Over 13 years	No data	3253	Motorway	No data	No data	Data taken from database on traffic collisions	Yes
38	Markolt *et al.*	2012	Hungary	Large mammals	No data	No data	Over 7 years	No data	223	Highway	1	No data	Data taken from State motorway management Company database	No
39	Mkanda & Chansa	2010	Zambia	Vertebrates	No data	No data	No data	29	~80	Highway	No data	No data	-	Yes
40	Meunier *et al.*	2000	France	Raptors	60-70	No data	7 periods, 2 months apart	12	2772	Motorway & secondary roads	No data	3 different hours of day	Alternated driving direction	Yes
41	Mohammadi *et al.*	2011	Iran	Long-eared hedgehog *(Hemiechinus auritus)*	No data	No data	No data	1 day	No data	No data	No data	No data	-	No
42	Neumann *et al.*	2012	Sweden	Moose *(Alces alces)*	No data	No data	No data	24	Part of study area	No data	No data	No data	Data taken from police reports	Yes

#	Author	Year	Where	Species	Speed (km h^{-1})	# of observers	Sampling frequency (when)	Sampling frequency (months)	Sampling distance (km)	Road type	# of transects	Time of day (start)	Other	Traffic count
43	Orlowski	2008	Poland	Birds	20-50	No data	Bi-weekly	26	48.8	No data	15	Afternoon	-	Yes
44	Quintero-Angel *et al.*	2012	Columbia	Snakes	Walk	2	Bi-monthly	5	No data	No data	No data	No data	-	Yes
45	Ramp *et al.*	2005	NSW Australia	Mammals	60	1	5 days a week	168	40	No data	1	Twice a day	-	Yes
46	Rodda	1990	Venezuela	Iguanas	No data	No data	No data	14	~1000 (per month)	Highway	No data	No data	-	No
47	Romin & Dalton	1992	Utah, USA	Mule deer (*Odocoileus hemionus*)	65	No data	January & February	2	9.7	Dirt road	1	No data	-	No
48	Russell *et al.*	2009	Pennsylvania, USA	Bats	Walk	2	Arbitrary days	3	5	Highway	1	Dusk & dawn	-	No
49	Saeki & MacDonald	2004	Japan	Raccoon dog *(Nyctereutus procyonoides viverrinus)*	No data	No data	Several times a day	36	627.3	National expressways	44	No data	Data collated from Japan Highway Corporation during routine road checks	Yes
50	Santos *et al.*	2011	Review	Vertebrates	No data	No data	Daily	No data	No data	No data	4	No data	-	Yes
51	Serrano *et al.*	2002	Spain	Large/medium sized mammals	No data	No data	Weekly	24	55	Freeways	2	No data	-	Yes
52	Siegfried	1966	South Africa	Birds	Slowly	2	Twice daily	24	14.5	Paved	1	08:00-17:00	-	No
53	Seiler	2005	Sweden	Moose *(Alces alces)*	No data	No data	Daily	108	Part of study area	No data	Numerous	No data	Data taken from police reports	Yes
55	Seshadri *et al.*	2009	India	Amphibians	No data	No data	Daily	4 days	25	No data	1	06:30-08:30	-	-
56	Slater	2002	Wales, UK	Mammals	No data	2	Bi-weekly	12	68	No data	1	Dawn onwards	Four 2 km lengths walked by other staff	No
57	Smit & Meijer	1999	Holland	Vertebrates	No data	No data	~Daily	96	No data	National highways	No data	No data	Conducted by road inspectors	No
58	Smith-Patten & Patten	2008	Kansas, USA	Mammals (medium sized)	No data	No data	Bi-monthly	36	No data	No data	No data	Daylight hours	Surveys were opportunistic.	No

#	Author	Year	Where	Species	Speed (km h^{-1})	# of observers	Sampling frequency (when)	Sampling frequency (months)	Sampling distance (km)	Road type	# of transects	Time of day (start)	Other	Traffic count
59	Snow *et al.*	2011	California, USA	San Clement Island Fox *(Urocyon littoralis clementae)*	56	No data	4-7 times per week	29	32.2	Paved & gravel	6	No data	-	Yes
60	Stoner	1925	Iowa, USA	Vertebrates	~40	2	4 days	~2	508.6	Paved, gravel & dirt	Many	No data	-	No
61	Sutherland *et al.*	2010	North Carolina, USA	Amphibians	48–56	No data	Daily over 2 months for 2 years	2	144	No data	2	Night	-	Yes
62	Taylor & Goldingay	2004	Australia	Vertebrates	70-80	No data	20 weekly	12	100.3	Major highway	3	No data	-	Yes

APPENDIX B: The vertebrate roadkill species detected over three ecological seasons on the 100 km section of paved road and the 20 km section of unpaved road in the GMTFCA, South Africa.

APPENDIX B: The vertebrate roadkill species detected over three ecological seasons on the 100 km section of paved road and the 20 km section of unpaved road in the GMTFCA, South Africa. (Activity: C = Crepuscular, D = Diurnal, N = Nocturnal, B = Both diurnal and nocturnal, U = Unknown; Branch 1998, Hockey *et al*. 2005, Skinner & Chimimba 2005, Carruthers & du Preez 2011). The top three species with highest roadkill numbers for three taxa (Reptilia, Aves and Mammalia) are highlighted in bold. The Amphibia top roadkill species only is highlighted. 'Absent' denotes the number of roadkill per species that had disappeared with 24 hours.

Class	No.	Order	Family	Scientific name	Common Name	Activity	Hot/dry	Hot/wet	Cold/dry	Total	Absent
Amphibia	1	Anura	Breviciptidae	*Breviceps adspersus*	Bushveld Rain Frog	N	0	1	0	1	1
	2	**Anura**	**Bufonidae**	***Amietophrynus garmani***	**Eastern Olive Toad**	**N**	**37**	**4**	**0**	**41**	**31**
	3	Anura	Rhacophorinae	*Chiromantis xerampalena*	Southern Foam Nest Frog	N	2	0	0	2	1
	4	Anura	Unknown	*Unknown*	Unidentified frog	U	1	2	0	3	3
Reptilia	1	Testudines	Testudinidae	*Geochelone pardalis*	Leopard Tortoise	D	1	2	0	3	3
	2	Testudines	Pelomedusidae	*Pelusios sinuatus*	Serrated Hinged Terrapin	D	0	2	0	2	2
	3	Squamata	Boidae	*Python natalensis*	Southern African Python	D	0	3	0	3	1
	4	Squamata	Atractaspididae	*Atractaspis bibronii*	Bibron's Burrowing Asp	N	4	6	0	10	10
	5	Squamata	Atractaspididae	*Atractaspis duerdeni*	Duerden's Burrowing Asp	N	0	4	0	4	4
	6	Squamata	Atractaspididae	*Xenocalamus transvaalensis*	Transvaal Quill-Snouted Snake	D	1	1	0	2	2
	7	Squamata	Colubridae	*Dasypeltis scabra*	Rhombic Egg Eater	N	4	2	0	6	5
	8	Squamata	Colubridae	*Dispholidus typus*	Boomslang	D	0	3	0	3	3
	9	**Squamata**	**Colubridae**	***Lamprophis fuliginosus***	**Brown House Snake**	**N**	**9**	**13**	**0**	**22**	**22**
	10	Squamata	Colubridae	*Mehelya nyassae*	Black File Snake	N	0	1	0	1	0
	11	Squamata	Colubridae	*Philothamnus semivariegatus*	Spotted Bush Snake	D	0	1	0	1	1
	12	Squamata	Colubridae	*Prosymna bivittata*	Two-striped Shovel Snout	N	1	1	0	2	0
	13	Squamata	Colubridae	*Prosymna sundevalli*	Sundevall's Shovel-Snout	N	7	2	0	9	9
	14	Squamata	Colubridae	*Psammophis mossambicus*	Olive Grass Snake	D	0	1	0	1	1
	15	Squamata	Colubridae	*Psammophis subtaeniatus*	Stripe-bellied Sand Snake	D	7	2	0	9	8
	16	Squamata	Colubridae	*Pseudaspis cana*	Mole Snake	N	1	0	0	1	1

Class	No.	Order	Family	Scientific name	Common Name	Activity	Hot/dry	Hot/wet	Cold/dry	Total	Absent
Reptilia	17	Squamata	Colubridae	*Rhamphiophis rostratus*	Rufous Beaked Snake	D	0	2	1	3	2
	18	Squamata	Colubridae	*Telescopus semiannulatus*	Eastern Tiger Snake	N	1	1	1	3	3
	20	Squamata	Elapidae	*Dendroaspis polyelpis*	Black Mamba	D	0	2	0	2	2
	21	Squamata	Elapidae	*Elapsoidea boulengeri*	Boulenger's Garter Snake	N	0	1	0	1	0
	22	Squamata	Elapidae	*Naja annulifera*	Snouted Cobra	N	2	0	0	2	2
	23	**Squamata**	**Elapidae**	***Naja mossambica***	**Mozambique Spitting Cobra**	**N**	**7**	**15**	**2**	**24**	**15**
	24	Squamata	Viperidae	*Bitis arientans arientans*	Puff Adder	C	1	3	0	4	4
	25	Squamata	Viperidae	*Bitus caudalis*	Horned Adder	C	6	6	2	14	13
	26	Squamata	Viperidae	*Causus rhombeatus*	Rhombic Night Adder	N	8	5	0	13	11
	27	Squamata	Unknown	*Unknown*	Snake	U	2	0	0	2	2
	28	Squamata	Lacertidae	*Heliobolus lugubrisus*	Bushveld Lizard	D	1	0	0	1	0
	29	Squamata	Lacertidae	*Nucras intertexta*	Spotted Sandveld Lizard	C	4	0	1	5	4
	30	Squamata	Lacertidae	*Pedioplanis lineoocellata*	Spotted Sand Lizard	C	0	0	1	1	1
	31	Squamata	Gerrhosauridae	*Gerrhosaurus nigrolineatus*	Black-lined Plated Lizard	D	9	9	0	18	15
	32	Squamata	Varanidae	*Varanus albigularia albigularis*	Rock Monitor	D	1	3	0	4	2
	33	Squamata	Agamidae	*Agama armata*	Peter's Ground Agama	D	8	1	0	9	9
	34	**Squamata**	**Chamaeleonidae**	***Chamaeleo dilepsis***	**Flap-neck Chameleon**	**D**	**4**	**41**	**0**	**45**	**39**
	35	Squamata	Gekkonidae	*Chondrodactylus turneri*	Turners Thick-toed Gecko	N	2	0	0	2	0
	36	Squamata	Unknown	*Unknown*	Reptile	U	0	1	0	1	0
Aves	1	Galliformes	Phasianidae	*Dendroperdix sephaena*	Crested Francolin	D	1	3	5	9	7
	2	Galliformes	Phasianidae	*Pternisris natalensis*	Natal Spurfowl	D	4	5	4	13	11
	3	Galliformes	Phasianidae	*Coturnix coturnix*	Common Quail	D	1	2	0	3	2
	4	**Galliformes**	**Numididae**	***Numida meleagris***	**Helmeted Guineafowl**	**C**	**18**	**44**	**7**	**69**	**60**
	5	Turniciformes	Turnicidae	*Turnix sylvatica*	Kurrichane Button-quail	C	1	0	1	2	2
	6	Piciformes	Lybiidae	*Tricholaema leucomelas*	Acacia Pied Barbet	D	0	0	1	1	1
	7	Bucertiformes	Bucerotidae	*Tockus erythrohynchus*	Red-billed Hornbill	D	0	2	1	3	2
	8	Bucertiformes	Bucerotidae	*Tockus leucomelas*	Southern Yellow-billed Hornbill	D	1	2	5	8	6
	9	Coraciiformes	Coraciidae	*Coracias garrulus*	European Roller	D	0	3	0	3	1

Class	No.	Order	Family	Scientific name	Common Name	Activity	Hot/dry	Hot/wet	Cold/dry	Total	Absent
Aves	10	Coraciiformes	Coraciidae	*Coracias caudatus*	Lilac-breasted Roller	D	0	4	0	4	4
	11	Coraciiformes	Coraciidae	*Coracias naevia*	Purple Roller	D	1	0	0	1	1
	12	Coraciiformes	Dacelonidae	*Halcyon senegalensis*	Woodland Kingfisher	D	1	0	0	1	1
	13	Coraciiformes	Dacelonidae	*Halcyon albiventris*	Brown Hooded Kingfisher	D	1	0	0	1	1
	14	Coraciiformes	Meropidae	*Merops pusillus*	Little Bee-Eater	D	0	1	0	1	1
	15	Coraciiformes	Meropidae	*Merops apiaster*	European Bee-eater	D	1	0	0	1	1
	16	Coraciiformes	Meropidae	*Merops nubicoides*	Southern Carmine Bee-eater	D	0	7	0	2	8
	17	Culcliformes	Centropodidae	*Centropus burchelii*	Burchell's Coucal	D	1	1	1	3	3
	18	Strigiformes	Tytonidae	*Tyto alba*	Barn Owl	N	0	2	0	2	2
	19	Strigiformes	Strigidae	*Bubo africanus*	Spotted Eagle Owl	N	1	6	1	8	7
	20	Strigiformes	Strigidae	*Strix woodfordii*	African Wood Owl	N	1	0	0	1	1
	21	Strigiformes	Strigidae	*Glaucidium perlatum*	Pearl-spotted Owlet	N	1	0	2	3	3
	22	Strigiformes	Caprimulgidae	*Caprimulgus pectoralis*	Fiery-necked Nightjar	C	3	5	0	8	6
	23	Strigiformes	Caprimulgidae	*Caprimulgus tristigma*	Freckled Nightjar	N	0	4	0	4	3
	24	Strigiformes	Caprimulgidae	*Caprimulgus fossii*	Square-tailed Nightjar	N	0	4	0	4	1
	25	**Strigiformes**	**Caprimulgidae**	***Caprimulgus rufigena***	**Rufous-cheeked Nightjar**	**N**	**10**	**17**	**1**	**28**	**19**
	26	Strigiformes	Caprimulgidae	*Caprimulgus europaeus*	European Nightjar	N	0	8	0	8	8
	27	Strigiformes	Caprimulgidae	*Macrodipteryx vexillarius*	Pennant-winged Nightjar	N	0	4	0	4	4
	28	Strigiformes	Caprimulgidae	*Unknown*	Unidentified Nightjar	N	4	9	2	15	10
	29	Columbiformes	Columbidae	*Streptopelia senegalensis*	Laughing Dove	D	6	2	0	8	6
	30	Columbiformes	Columbidae	*Streptopelia capicola*	Cape Turtle Dove	C	4	0	0	4	2
	31	Columbiformes	Columbidae	*Streptopelia decipiens*	Red-eyed Dove	D	1	1	0	2	1
	32	Columbiformes	Columbidae	*Turtur chalcospilos*	Emerald Spotted Wood Dove	D	1	0	0	1	1
	33	Columbiformes	Columbidae	*Oena capensis*	Namaqua Dove	D	2	1	0	3	3
	34	Columbiformes	Columbidae	*Streptopelia*	Unidentified Dove	D	3	0	2	5	2
	35	Gruiformes	Otididae	*Ardeotis kori*	Kori Bustard	D	1	0	0	1	0
	36	Gruiformes	Otididae	*Lophotis ruficrista*	Red-crested Korhaan	D	4	3	0	7	6
	37	Charadriiformes	Burhinidae	*Burhinus capensis*	Spotted Thick Knee	N	3	5	0	8	7
	38	Charadriiformes	Charadriidae	*Chadradius tricollaris*	Three-banded Plover	B	1	0	0	1	1

Class	No.	Order	Family	Scientific name	Common Name	Activity	Hot/dry	Hot/wet	Cold/dry	Total	Absent
Aves	39	Charadriiformes	Glareolidae	*Rhinoptilus chalcopterus*	Bronze-Winged Courser	N	0	2	0	2	1
	40	Falconiformes	Accipitridae	*Accipiter tachiro*	African Goshawk	D	0	1	0	1	0
	41	Falconiformes	Accipitridae	*Buteo vulpinus*	Steppe Buzzard	D	0	1	0	1	0
	42	Falconiformes	Accipitridae	*Aquila wahlbergi*	Wahlberg's Eagle	D	1	0	0	1	0
	43	**Passeriformes**	**Malaconotidae**	***Tchagra senegala***	**Black-crowned Tchagra**	**D**	**1**	**0**	**20**	**21**	**17**
	44	Passeriformes	Malaconotidae	*Tchagra australis*	Brown-crowned Tchagra	D	4	2	0	6	4
	45	Passeriformes	Malaconotidae	*Tchagra*	Unidentified Tchagra	D	0	0	1	1	1
	46	Passeriformes	Malaconotidae	*Prionops plumatus*	White-crested Helmet Shrike	D	1	2	0	3	3
	47	Passeriformes	Malaconotidae	*Batis molitor*	Chinspot Batis	D	0	0	1	1	1
	48	Passeriformes	Corvidae	*Corvus albus*	Pied Crow	D	1	1	0	2	1
	49	Passeriformes	Laniidae	*Lanius collurio*	Red-backed Shrike	D	0	3	0	3	2
	50	Passeriformes	Laniidae	*Eurocephalus anguitimens*	Southern White-crowned Shrike	D	0	3	0	3	2
	51	Passeriformes	Paridae	*Anthoscopus minutus*	Cape Penduline-Tit	D	1	0	0	1	1
	52	Passeriformes	Paridae	*Anthoscopus caroli*	Grey Penduline Tit	D	0	1	0	1	1
	53	Passeriformes	Hirundinidae	*Hirundo rustica*	Barn Swallow	D	3	9	0	12	10
	54	Passeriformes	Hirundinidae	*Hirundo abyssinica*	Lesser-striped Swallow	D	6	0	0	6	6
	55	Passeriformes	Sylviidae	*Sylvietta rufescens*	Long-billed Crombec	D	1	0	0	1	1
	56	Passeriformes	Sylviidae	*Eromomela icteropygialis*	Yellow-bellied Eremomela	D	0	1	1	2	2
	57	Passeriformes	Cisticolidae	*Cisticola chiniana*	Rattling Cisticola	D	0	0	1	1	0
	58	Passeriformes	Cisticolidae	*Cisticola aridulus*	Desert Cisticola	D	0	1	0	1	1
	59	Passeriformes	Cisticolidae	*Cisticola*	Unidentified Cisticola	D	1	0	3	4	3
	60	Passeriformes	Cisticolidae	*Prinia flavicans*	Black-chested Prinia	D	0	1	1	2	2
	61	Passeriformes	Cisticolidae	*Heliolais erythropterus*	Red-winged Warbler	D	0	1	0	1	1
	62	Passeriformes	Alaudidae	*Mirafra sabota*	Sabota Lark	D	2	7	3	12	11
	63	Passeriformes	Alaudidae	*Unknown*	Unidentified Lark	D	0	0	1	1	1
	64	Passeriformes	Muscicapidae	*Psophocichla litsitsirupa*	Groundscraper Thrush	D	1	0	0	1	1
	65	Passeriformes	Muscicapidae	*Melaenornis pammelaina*	Southern Black Flycatcher	D	0	1	0	1	1
	66	Passeriformes	Muscicapidae	*Cercotrichas leucophrys*	White-browed Scrub Robin	D	1	1	0	2	2
	67	Passeriformes	Nectariniidae	*Cinnyris talatala*	White-bellied Sunbird	D	1	0	0	1	1

Class	No.	Order	Family	Scientific name	Common Name	Activity	Hot/dry	Hot/wet	Cold/dry	Total	Absent
Aves	68	Passeriformes	Ploceidae	*Sporopipes squamifrons*	Scaly-feathered Finch	D	2	0	1	3	3
	69	Passeriformes	Ploceidae	*Plocepasser mahali*	White-browed Sparrow-Weaver	D	0	4	1	5	3
	70	Passeriformes	Ploceidae	*Anaplectes melanotis*	Red-headed Weaver	D	3	1	0	4	3
	71	Passeriformes	Ploceidae	*Quelea erythrops*	Red-headed Quelea	D	0	0	1	1	0
	72	Passeriformes	Ploceidae	*Quelea quelea*	Red-billed Quelea	D	7	1	0	8	8
	73	Passeriformes	Estrildidae	*Amadina fasciata*	Cut-throat Finch	D	2	1	0	3	3
	74	Passeriformes	Estrildidae	*Granatina grantina*	Violet-eared Waxbill	D	0	1	0	1	1
	75	Passeriformes	Estrildidae	*Uraeginthus angolensis*	Blue waxbill	D	3	1	1	5	5
	76	Passeriformes	Estrildidae	*Pytilia melba*	Green-winged Pytilia	D	1	1	6	8	8
	77	Passeriformes	Estrildidae	*Logonosticta senegala*	Red-billed Fire Finch	D	1	0	0	1	1
	78	Passeriformes	Passeridae	*Passer domesticus*	House Sparrow	D	1	0	0	1	1
	79	Passeriformes	Passeridae	*Passer diffusus*	Southern Grey-headed Sparrow	D	3	0	0	3	3
	80	Passeriformes	Passeridae	*Petronia superciliaris*	Yellow-throated Petronia	D	0	2	0	2	2
	81	Passeriformes	Fringillidae	*Crithagra mozambica*	Yellow-fronted Canary	D	0	1	0	1	2
	82	Passeriformes	Fringillidae	*Serinus atrogularis*	Black-throated Canary	D	2	0	0	2	1
	83	Passeriformes	Fringillidae	*Crithagra Flaviventris*	Yellow Canary	D	0	1	0	1	1
	84	Passeriformes	Fringillidae	*Emberiza tahapisi*	Cinnamon-breasted Bunting	D	1	13	0	14	9
	85	Passeriformes	Fringillidae	*Emberiza capensis*	Golden-breasted Bunting	D	0	5	1	6	5
	86	Unknown	Unknown	*Unknown*	Unidentified Bird	U	9	5	3	17	11
Mammalia	1	Macroscelidea	Macroscelididae	*Elephantulus intufi*	Bushveld elephant shrew	C	1	0	0	1	1
	2	**Lagomopha**	**Leporidae**	***Lepus saxatilis***	**Scrub hare**	**N**	**37**	**26**	**55**	**118**	**93**
						(female:male:unidentified ratio: 21:46:51)					
	3	Rodentia	Bathyergidae	*Cryptomys hottentotus*	African mole-rat	N	0	1	0	1	0
	4	Rodentia	Hystricidae	*Hystrix africaeaustralis*	Cape porcupine	N	2	1	3	6	6
	5	Rodentia	Pedetidae	*Pedetes capensis*	Spring hare	N	1	0	5	6	4
	6	Rodentia	Sciuridae	*Paraxerus cepapi*	Tree squirrel	C	0	2	0	2	2
	7	Rodentia	Sciuridae	*Xerus inauris*	Southern African ground squirrel	D	3	4	0	7	5
	8	Rodentia	Muridae	*Acomys spinosissimus*	Spiny mouse	N	0	1	0	1	1

Class	No.	Order	Family	Scientific name	Common Name	Activity	Hot/dry	Hot/wet	Cold/dry	Total	Absent
Mammalia	9	Rodentia	Muridae	*Lemniscomys rosalia*	Single striped mouse	D	1	0	1	2	2
	10	Rodentia	Muridae	*Mus minutoides*	Pygmy mouse	N	4	0	0	4	2
	11	Rodentia	Muridae	*Mastomys natalensis sensu lato*	Natal multimammate mouse	N	0	1	0	1	1
	12	Rodentia	Muridae	*Aethomy chrysophilus*	Red veld rat	N	6	4	0	10	7
	13	Rodentia	Muridae	*Aethomys namaquensis*	Namaqua rock mouse	N	2	2	0	4	3
	14	Rodentia	Muridae	*Otomys irroratus sensu lato*	Vlei rat	C	0	1	0	1	1
	15	**Rodentia**	**Muridae**	***Tatara leucogaster***	**Bushveld gerbil**	**N**	**4**	**7**	**10**	**21**	**18**
	16	Rodentia	Muridae	*Cricetomys gambianus*	Gambian giant rat	N	1	0	0	1	1
	17	Rodentia	Muridae	*Saccostomus campestris*	Pouched mouse	N	1	0	0	1	1
	18	Rodentia	Muridae	*Steatomys pratensis*	Fat mouse	N	2	0	0	2	2
	19	Rodentia	Muridae	*Rattus rattus*	Black rat	N	0	1	0	1	0
	20	Rodentia	Unknown	*Unknown*	Unidentified rodent	U	13	2	1	16	11
	21	Primates	Galagidea	*Otolemur crassicaudatus*	Greater galago	N	0	1	1	2	2
	22	Primates	Galagidea	*Galago moholi*	South African galago	N	1	0	0	1	1
	23	Primates	Cercopithecidae	*Papio hamadryas*	Chacma baboon	D	1	1	1	3	3
	24	Eulipotyphla	Soricidae	*Crocidura hirta*	Lesser red musk shrew	B	2	1	0	3	3
	25	Chiroptera	Nycteridae	*Nycteris thebaica*	Egyptian slit-faced bat	N	1	1	0	2	2
	26	Chiroptera	Rhinolophidae	*Rhinolophus fumigates*	Ruppell’s horseshoe bat	N	1	4	1	6	6
	27	Carnivora	Hyaenidae	*Proteles cristatus*	Aardwolf	N	0	1	1	2	1
	28	Carnivora	Hyaenidae	*Hyaena brunnea*	Brown hyaena	N	1	0	1	2	1
	29	Carnivora	Hyaenidae	*Crocuta crocuta*	Spotted hyaena	N	1	0	0	1	1
	30	Carnivora	Felidae	*Caracal caracal*	Caracal	N	0	0	1	1	0
	31	Carnivora	Felidae	*Felis lybica*	African wild cat	N	1	0	0	1	0
	32	Carnivora	Felidae	*Felis silvestris catus.*	Domestic cat	D	1	0	0	1	1
	33	**Carnivora**	**Viverridae**	***Civettictis civetta***	**African civet**	**N**	**4**	**3**	**9**	**16**	**14**
	34	Carnivora	Viverridae	*Genetta tigrina*	South African large-spotted genet	N	0	0	1	1	1
	35	Carnivora	Herpestidae	*Galerella nigrata*	Slender mongoose	D	2	0	3	5	3
	36	Carnivora	Herpestidae	*Mungos mungo*	Banded mongoose	D	0	1	0	1	0
	37	Carnivora	Canidae	*Octocyon megalotis*	Bat-eared fox	B	0	2	2	4	2

Class	No.	Order	Family	Scientific name	Common Name	Activity	Hot/dry	Hot/wet	Cold/dry	Total	Absent
Mammalia	38	Carnivora	Canidae	*Canis mesomelas*	Black-backed jackal	B	2	1	3	6	1
	39	Carnivora	Canidae	*Mellivora capensis*	Honey badger	N	1	0	0	1	0
	40	Carnivora	Canidae	*Canis domesticus*	Domestic dog	D	0	0	1	1	0
	41	Suiformes	Suidae	*Phacochoerus africanus*	Warthog	D	1	1	0	2	2
	42	Ruminantia	Bovidae	*Tragelaphus strepsiceros*	Greater kudu	D	0	0	2	2	2
	43	Ruminantia	Bovidae	*Sylvicapra grimmia*	Common duiker	D	0	0	3	3	3
	44	Ruminantia	Bovidae	*Raphicerus campestris*	Steenbok	D	2	0	1	3	2
	45	Ruminantia	Bovidae	*Aepyceros melampus*	Impala	D	0	1	0	1	1
	46	Ruminantia	Bovidae	*Unknown*	Unidentified antelope	U	1	2	8	11	11
Unknown	1	Unknown	Unknown	*Unknown*	Unidentified mammal	U	12	0	0	12	3

APPENDIX C: Caprimulgidae roadkill detected over three ecological seasons on the 100 km section of paved road and the 20 km section of unpaved road in the GMTFCA, South Africa.

APPENDIX C: Caprimulgidae roadkill detected over three ecological seasons on the 100 km section of paved road and the 20 km section of unpaved road in the GMTFCA, South Africa. Data show the relationship between activity peak and seasonal peak for roadkill (highlighted in bold) for the six nightjar species detected as roadkill, as well as favoured habitat and percentage of habitat where the roadkill was observed.

Caprimulgidae		**Season**							
Scientific Name	**Common Name**	**Hot/dry**	**Hot/wet**	**Cold/dry**	**Total**	**Activity peak**	**Favoured habitat**	**Roadkill habitat**	**Other comments**
Caprimulgus pectoralis	Fiery-necked Nightjar	3	**5**	0	8	April – October	Favours *Vachellia*	40% *Vachellia* / 60% *Mopane*	Less frequently found as roadkill
Caprimulgus tristigma	Freckled Nightjar	0	**4**	0	4	May-April	Favours *Mopane* and escarpments	100% *Mopane*	Frequently found as roadkill
Caprimulgus fossii	Square-tailed Nightjar	0	**4**	0	4	October - November	Favours *Vachellia* and *Mopane*	100% *Mopane*	-
Caprimulgus rufigena	Rufous-cheeked Nightjar	10	**17**	1	28	August to May	Favours Mopane and open habitat	65% open *Mopane* / 35% other	Highest nightjar roadkill species
Caprimulgus europaeus	European Nightjar	0	**8**	0	8	December to March	Favours *Vachellia* and *Mopane*	50% *Mopane* / 7% *Vachellia* / 43% other	Frequently found as roadkill
Macrodipteryx vexillarius	Pennant-winged Nightjar	0	**4**	0	4	September to February	Avoids *Mopane* and favours *Vachellia* and open areas	100% open grasslands	Frequently found as roadkill
Caprimulgidae	Unidentified Nightjar	4	**9**	2	15	-	-	47% *Mopane*/ 17% *Vachellia* / 37% other	-

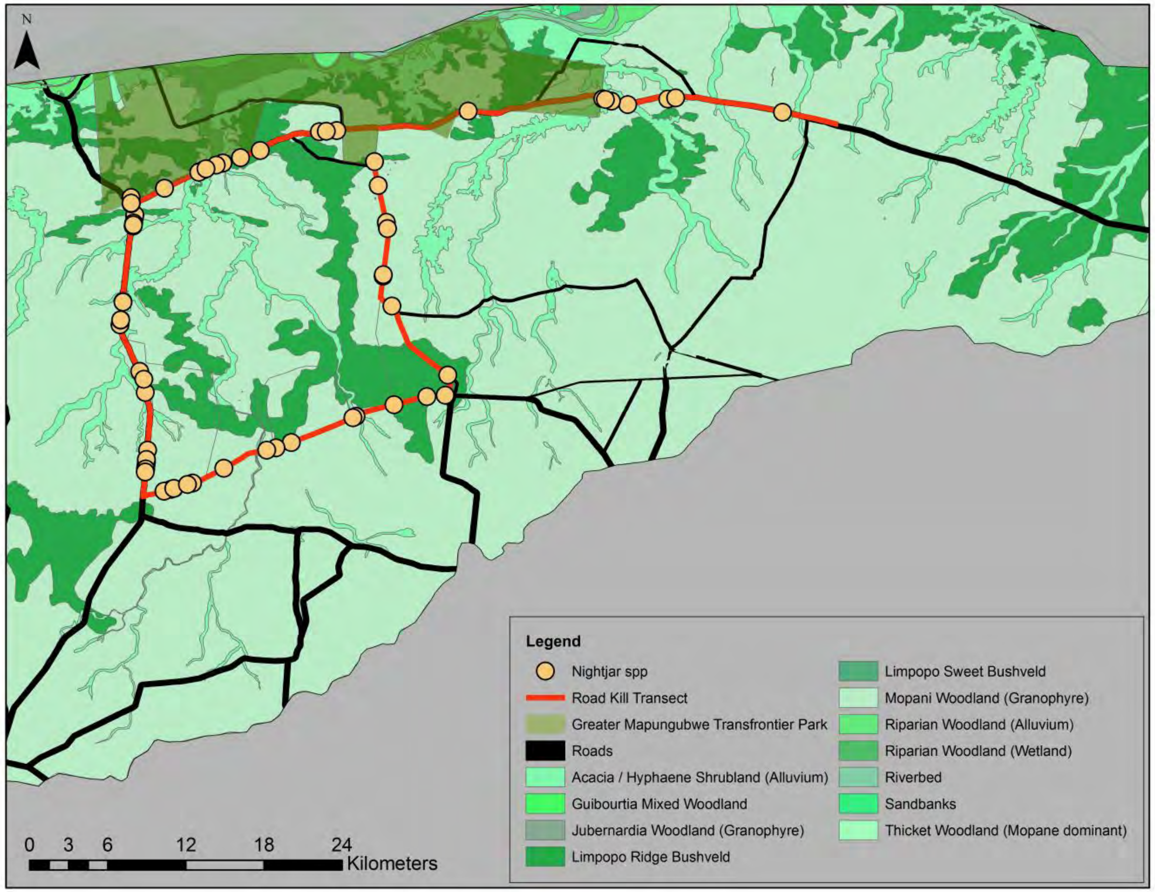

Figure 1: A vegetation map illustrating the location on the transects (100 km paved road and 20 km unpaved road) of nightjar (Caprimulgidae) roadkill detected across the three ecological seasons in the GMTCA, South Africa. GIS data source: GeoNetwork (2000); Peace Parks Foundation (2010). (ArcGIS 9.3; map units: decimal degrees; not projected).

APPENDIX D: The live vertebrate species observed during the roadkill transects either on the road verge or crossing the road over three ecological seasons on the 100 km section of paved road in the GMTFCA, South Africa.

APPENDIX D: The live vertebrate species observed during the roadkill transects either on the road verge or crossing the road over three ecological seasons on the 100 km section of paved road in the GMTFCA, South Africa.

Class	Order	Family	Scientific name	Common Name	Hot/dry	Hot/wet	Cold/dry	Total
Amphibia	Anura	Bufonidae	*Amietophrynus garmani*	Eastern Olive Toad	0	1	0	1
Reptilia	Testudines	Pelomedusidae	*Pelusios sinuatus*	Serrated Hinged Terrapin	2	0	0	2
	Testudines	Testudinidae	*Geochelone pardalis*	Leopard Tortoise	1	5	0	6
	Squamata	Viperidae	*Bitis arientans arientans*	Puff Adder	0	1	0	1
	Squamata	Gerrhosauridae	*Gerrhosaurus nigrolineatus*	Black-lined Plated Lizard	2	12	1	15
	Squamata	Agamidae	*Agama armata*	Peter's Ground Agama	1	1	0	2
	Squamata	Chamaeleonidae	*Chamaeleo dilepsis*	Flap-neck Chameleon	5	75	0	80
	Squamata	Unknown	*Unknown*	Unidentified snakes	0	2	7	9
Aves	Galliformes	Numididae	*Numida meleagris*	Helmeted Guineafowl	11	22	41	74
	Bucertiformes	Bucerotidae	*Bucorvus leadbeateri*	Southern Ground Hornbill	2	0	0	2
	Falconiformes	Accipitridae	*Accipiter tachiro*	African Goshawk	0	1	0	1
	Falconiformes	Accipitridae	*Buteo vulpinus*	Steppe Buzzard	0	1	0	1
	Falconiformes	Accipitridae	*Polemaetus bellicosus*	Martial eagle	1	1	0	2
	Falconiformes	Unknown	*Unknown*	Bird of Prey	0	8	36	44
	Falconiformes	Accipitridae	*Aquila wahlbergi*	Wahlberg's Eagle	1	0	0	1
	Passeriformes	Corvidae	*Corvus albus*	Pied Crow	0	4	6	10
Mammalia	Rodentia	Sciuridae	*Paraxerus cepapi*	Tree squirrel	0	1	0	1
	Lagomopha	Leporidae	*Lepus saxatilis*	Scrub hare	18	2	27	47
	Rodentia	Pedetidae	*Pedetes capensis*	Spring hare	0	0	3	3
	Proboscidia	Elephantidae	*Loxodonta africana*	African elephant (breeding herd)	1	0	1	2

Class	Order	Family	Scientific name	Common Name	Hot/dry	Hot/wet	Cold/dry	Total
Mammalia	Primates	Cercopithecidae	*Papio hamadryas*	Chacma baboon (troop)	48	52	69	169
	Carnivora	Herpestidae	*Mungos mungo*	Banded mongoose (troop)	2	5	3	10
	Carnivora	Viverridae	*Civettictis civetta*	African civet	2	0	2	4
	Carnivora	Hyaenidae	*Proteles cristatus*	Aardwolf	1	0	1	2
	Carnivora	Hyaenidae	*Hyaena brunnea*	Brown hyaena	3	0	3	6
	Carnivora	Felidae	*Felis lybica*	African wild cat	1	0	2	3
	Carnivora	Felidae	*Acinonyx jubatus*	Cheetah	1	0	0	1
	Ruminantia	Bovidae	*Sylvicapra grimmia*	Common duiker	1	1	3	4
	Ruminantia	Bovidae	*Kobus ellipsiprymnus*	Waterbuck (herd)	2	1	7	10
	Ruminantia	Bovidae	*Aepyceros melampus*	Impala (herd)	0	1	15	16
	Ruminantia	Bovidae	*Tragelaphus strepsiceros*	Greater kudu (herd)	3	0	60	63
	Ruminantia	Bovidae	*Raphicerus campestris*	Steenbok	5	1	9	15
	Suiformes	Suidae	*Phacochoerus africanus*	Warthog	4	6	79	89

APPENDIX E: A comparison between the number of roadkill detected for the four vertebrate taxa across the three ecological seasons with the number of roadkill that had disappeared 24 hours later in the GMTFCA, South Africa.

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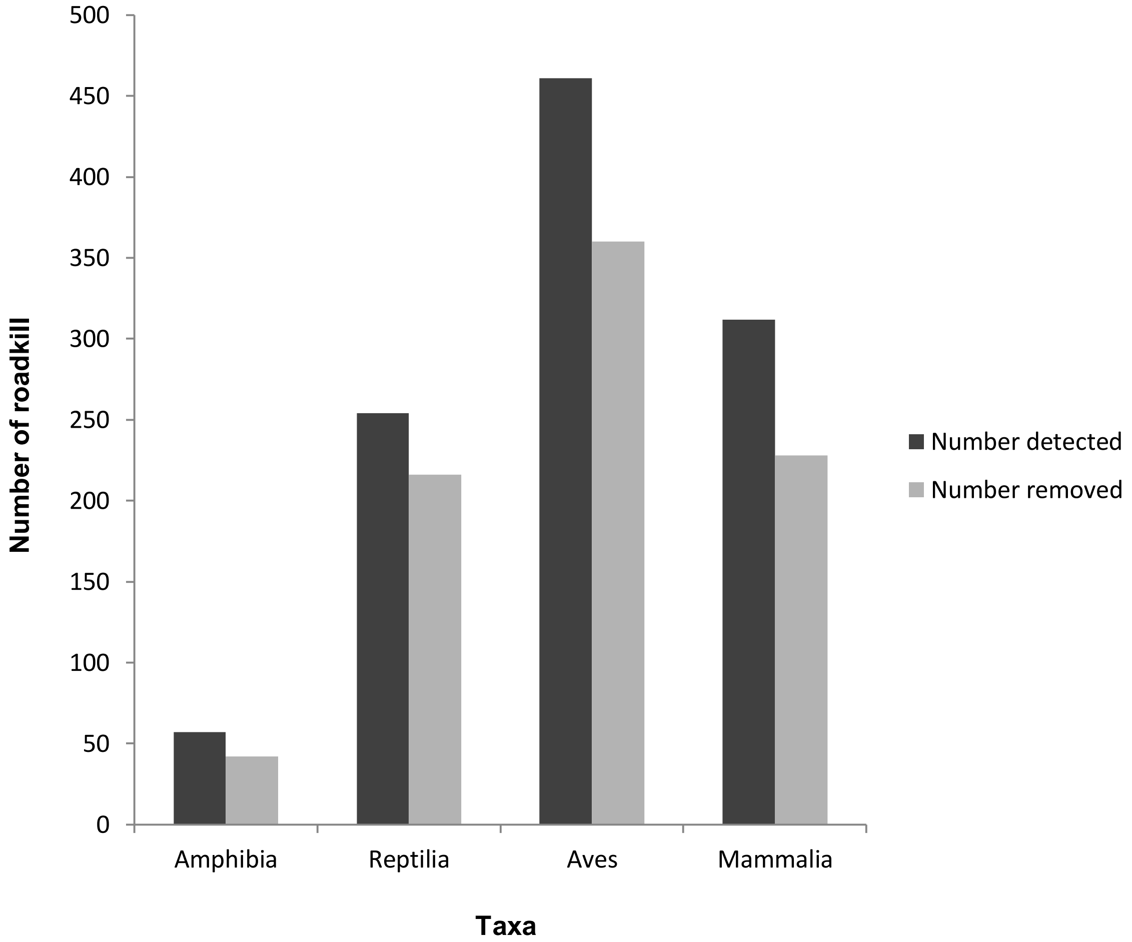

APPENDIX F: A series of vegetation maps illustrating the location of roadkill detected for each vertebrate group in each of the three ecological seasons on the 100 km paved road and 20 km unpaved road in the GMTCA, South Africa.

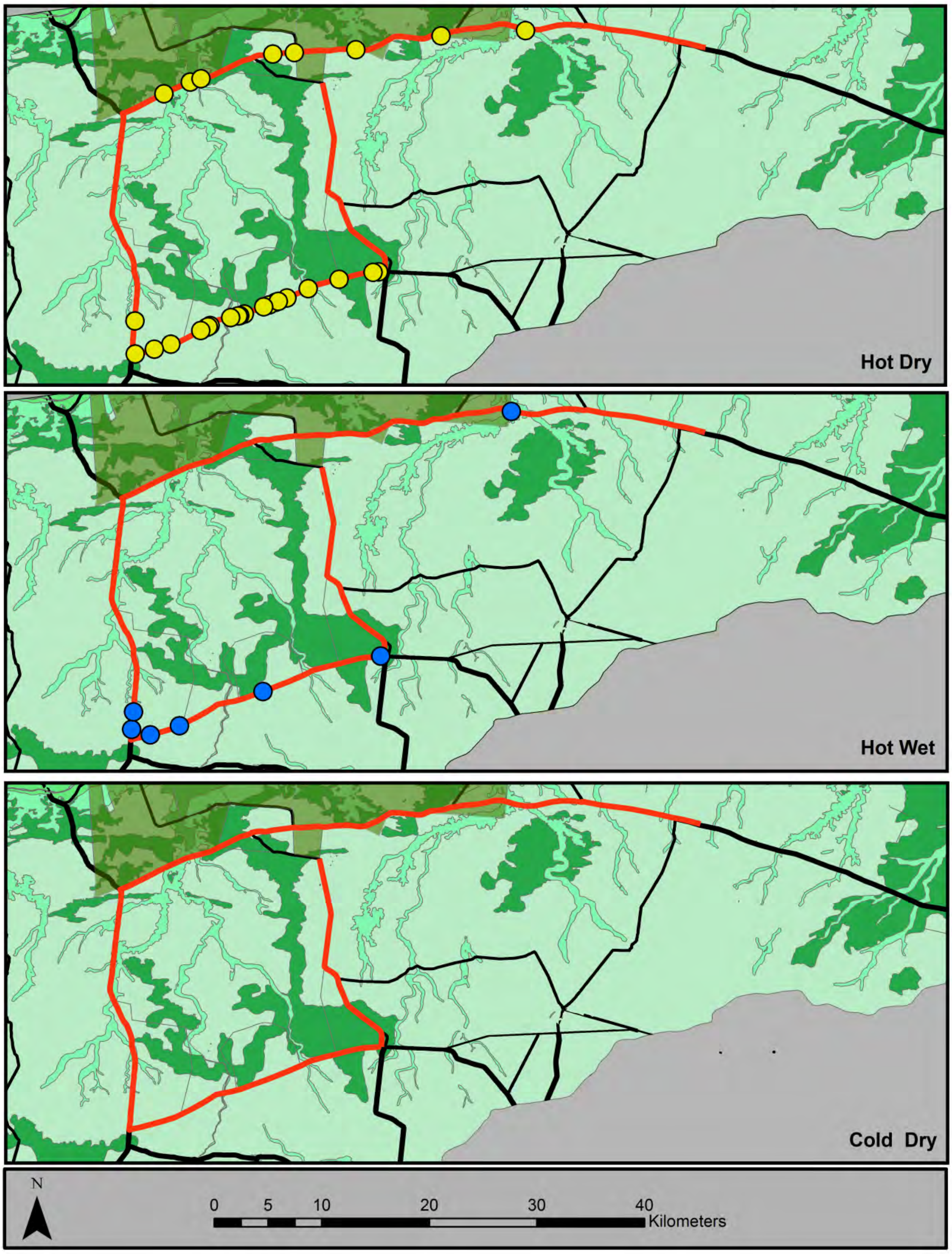

Figure 1: Three vegetation maps illustrating the location on the transects (100 km paved road and 20 km unpaved road) of Amphibia roadkill detected during the (a) hot/dry, (b) the hot/wet and (c) the cold/dry seasons in the GMTCA, South Africa. GIS data source: GeoNetwork (2000); Peace Parks Foundation (2010). (ArcGIS 9.3; map units: decimal degrees; not projected).

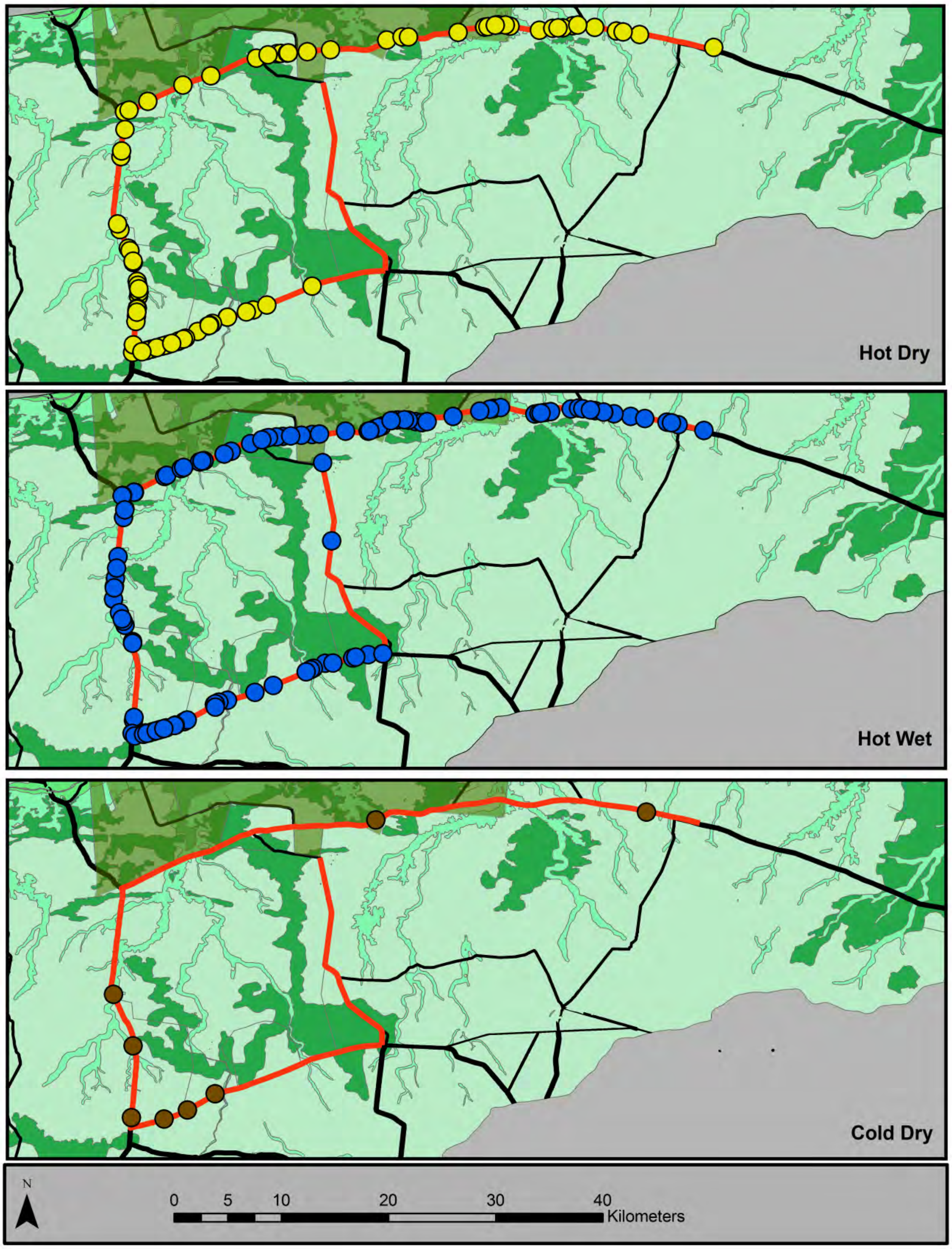

Figure 2: Three vegetation maps illustrating the location on the transects (100 km paved road and 20 km unpaved road) of Reptilia roadkill detected during the (a) hot/dry, (b) the hot/wet and (c) the cold/dry seasons in the GMTCA, South Africa. GIS data source: GeoNetwork (2000); Peace Parks Foundation (2010). (ArcGIS 9.3; map units: decimal degrees; not projected).

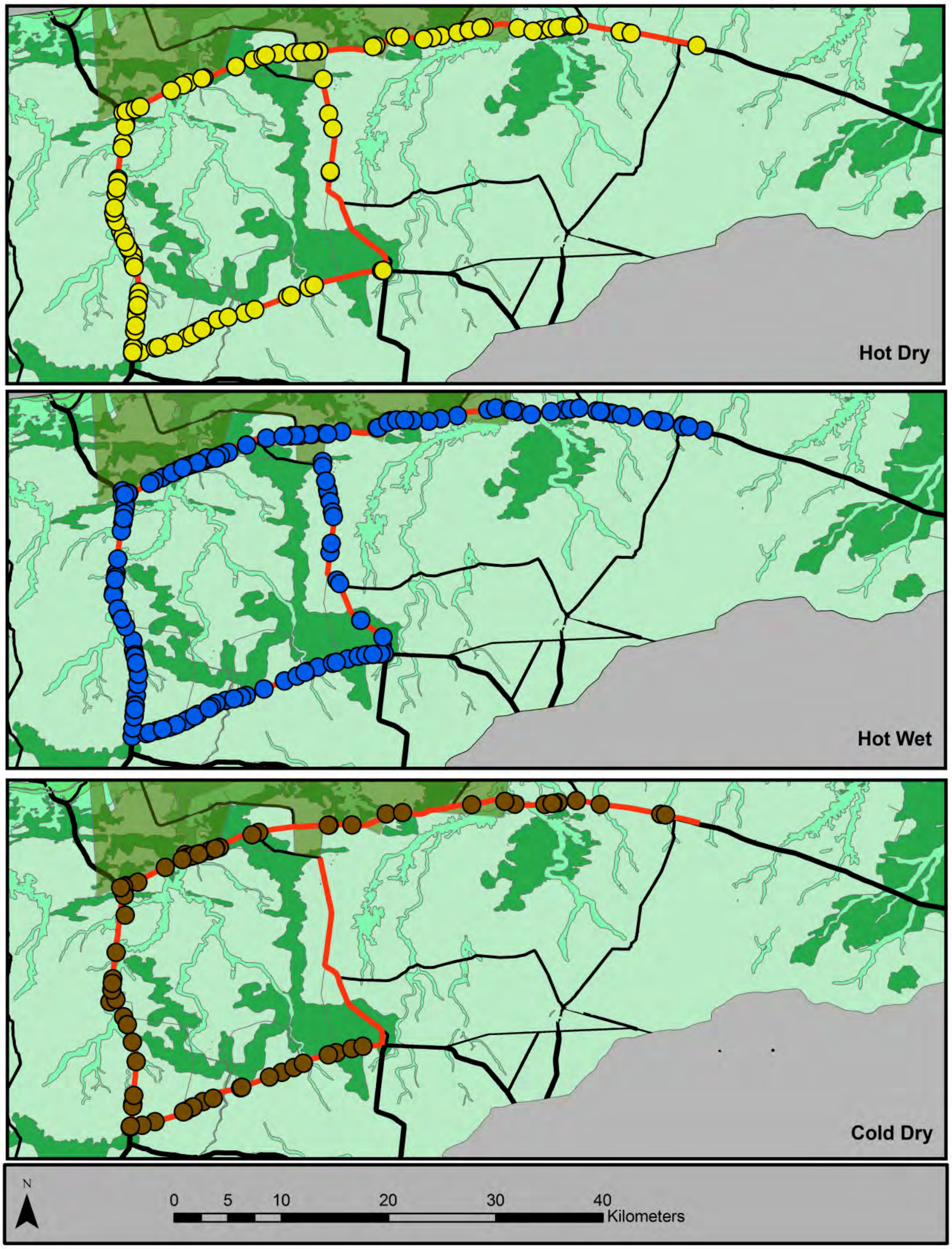

Figure 3: Three vegetation maps illustrating the location on the transects (100 km paved road and 20 km unpaved road) of Aves roadkill detected during the (a) hot/dry, (b) the hot/wet and (c) the cold/dry seasons in the GMTCA, South Africa. GIS data source: GeoNetwork (2000); Peace Parks Foundation (2010). (ArcGIS 9.3; map units: decimal degrees; not projected).

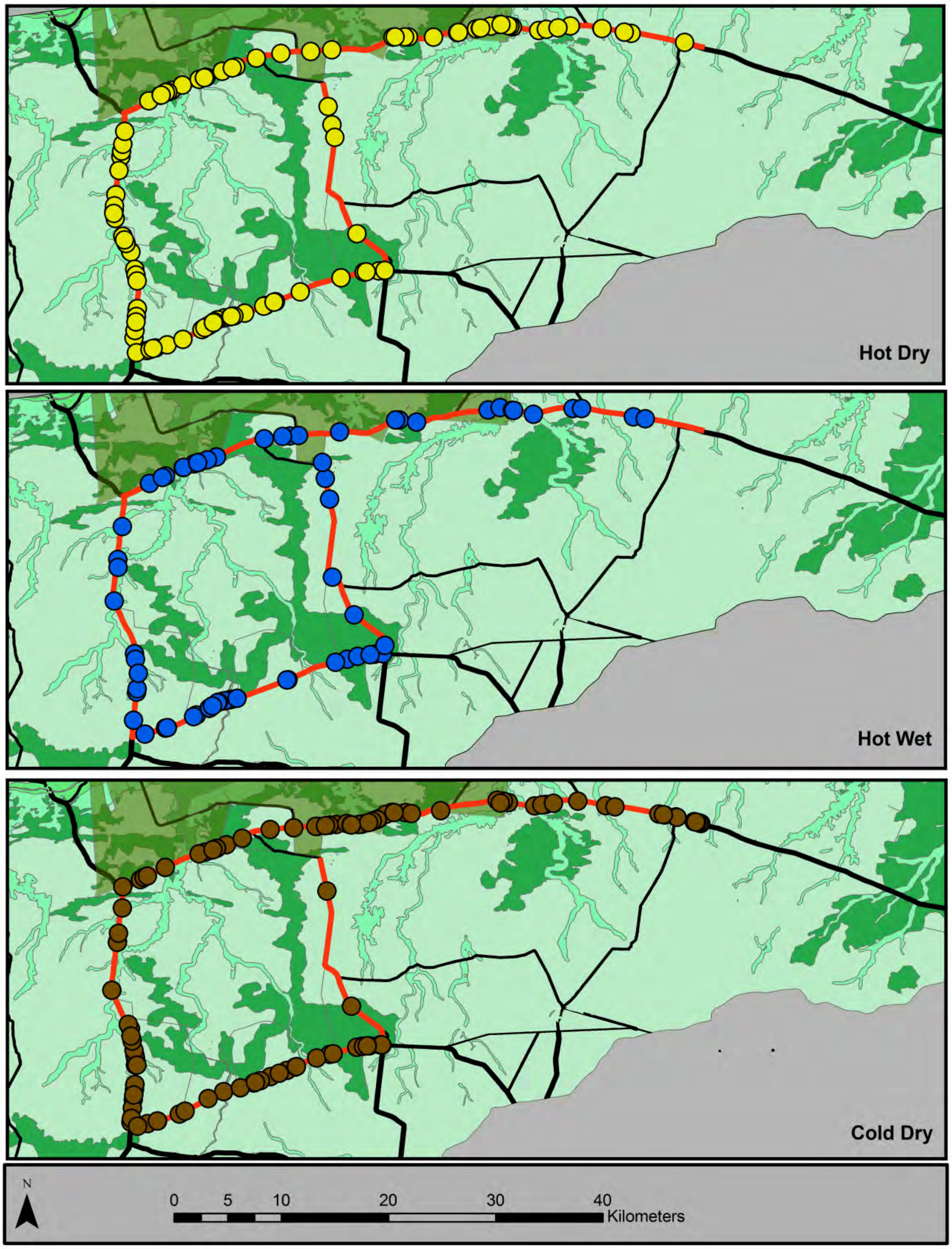

Figure 4: Three vegetation maps illustrating the location on the transects (100 km paved road and 20 km unpaved road) of Mammalia roadkill detected during the (a) hot/dry, (b) the hot/wet and (c) the cold/dry seasons in the GMTCA, South Africa. GIS data source: GeoNetwork (2000); Peace Parks Foundation (2010). (ArcGIS 9.3; map units: decimal degrees; not projected).

APPENDIX G: A series of vegetation maps illustrating the location of the top roadkill species detected for each vertebrate group across the three ecological seasons on the 100 km paved road and 20 km unpaved road in the GMTCA, South Africa.

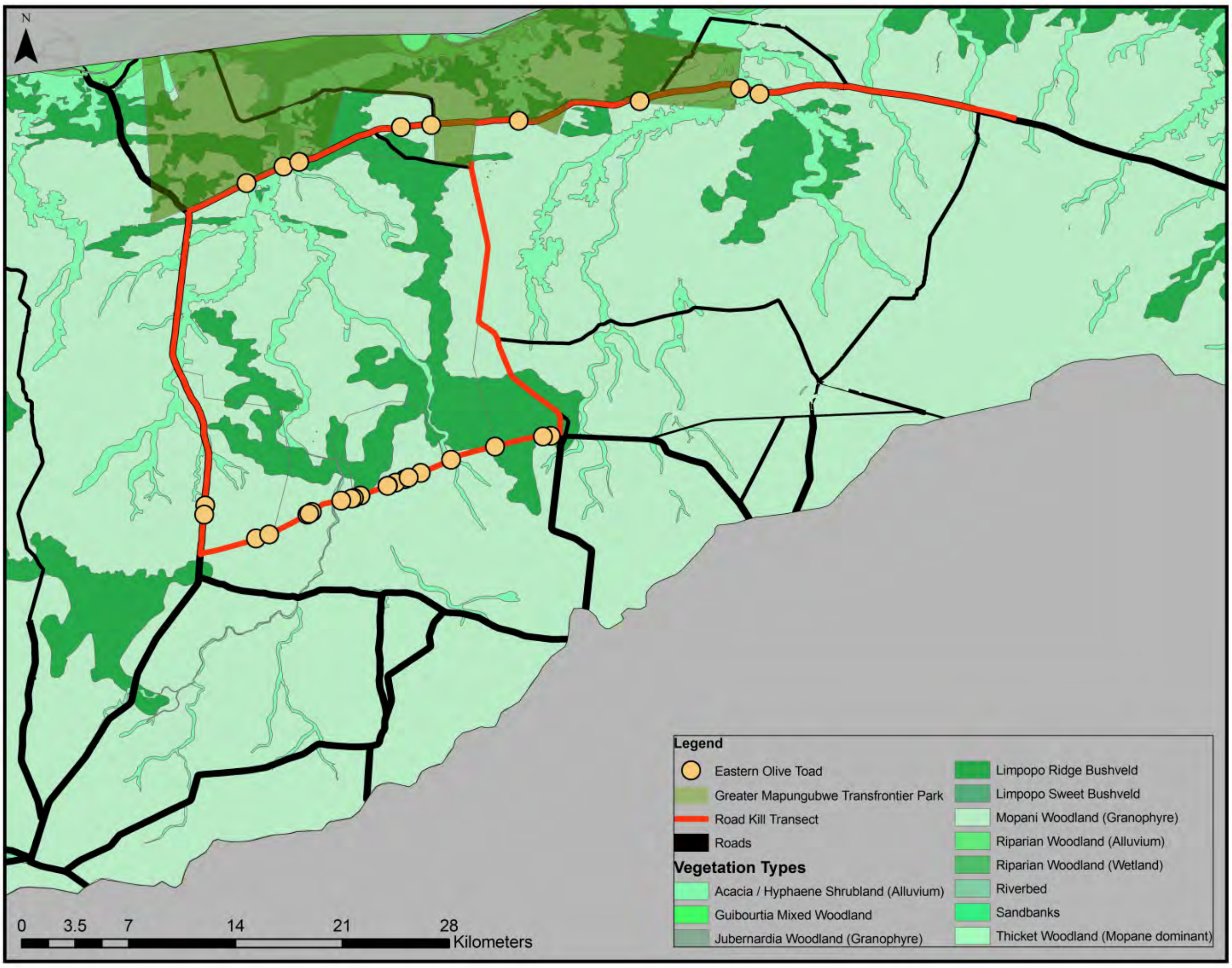

Figure 1: A vegetation map illustrating the location on the transects (100 km paved road and 20 km unpaved road) of Eastern Olive Toad roadkill across the three ecological seasons in the GMTCA, South Africa. GIS data source: GeoNetwork (2000); Peace Parks Foundation (2010). (ArcGIS 9.3; map units: decimal degrees; not projected).

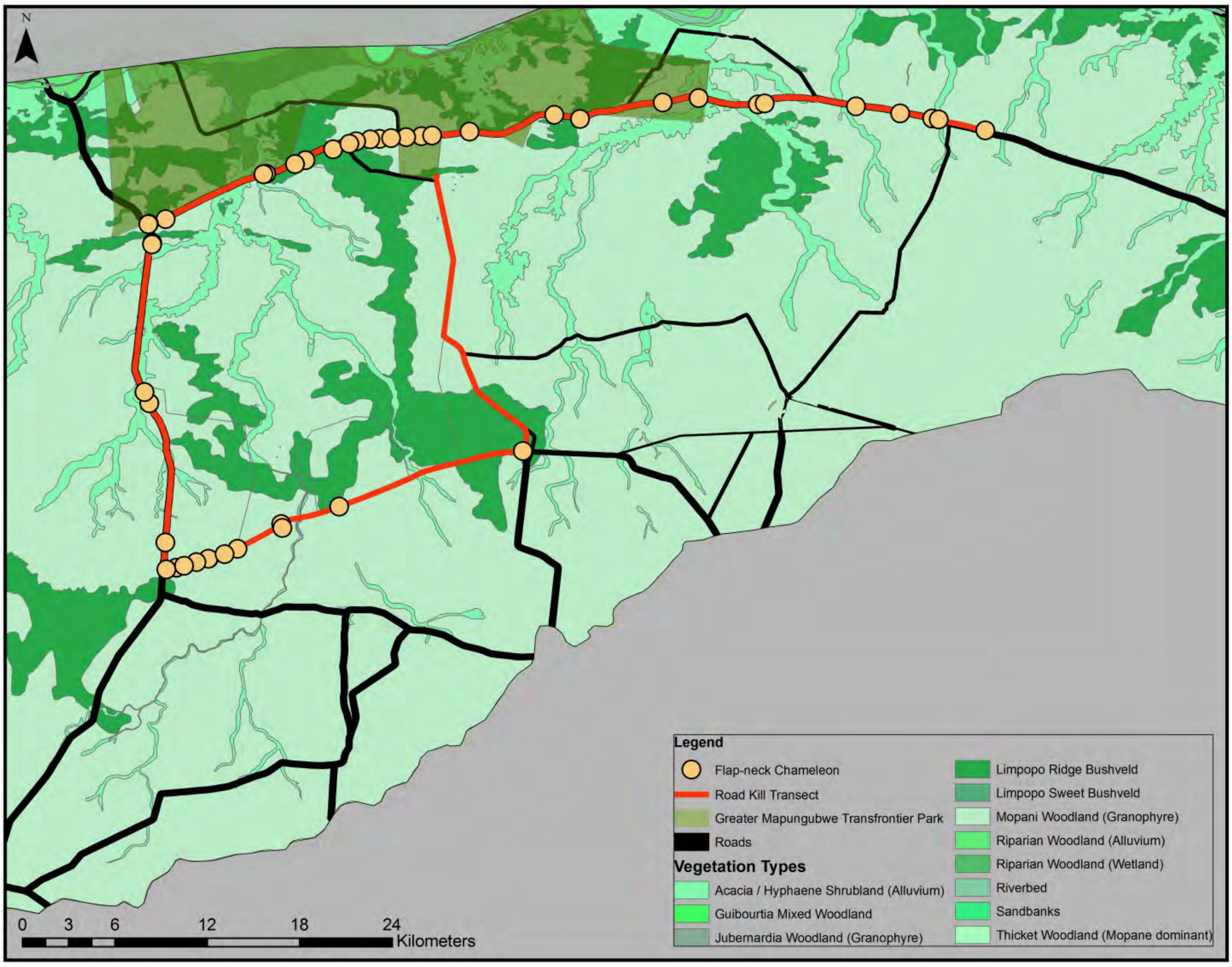

Figure 2: A vegetation map illustrating the location on the transects (100 km paved road and 20 km unpaved road) of Flap-neck Chameleon roadkill across the three ecological seasons in the GMTCA, South Africa. GIS data source: GeoNetwork (2000); Peace Parks Foundation (2010). (ArcGIS 9.3; map units: decimal degrees; not projected).

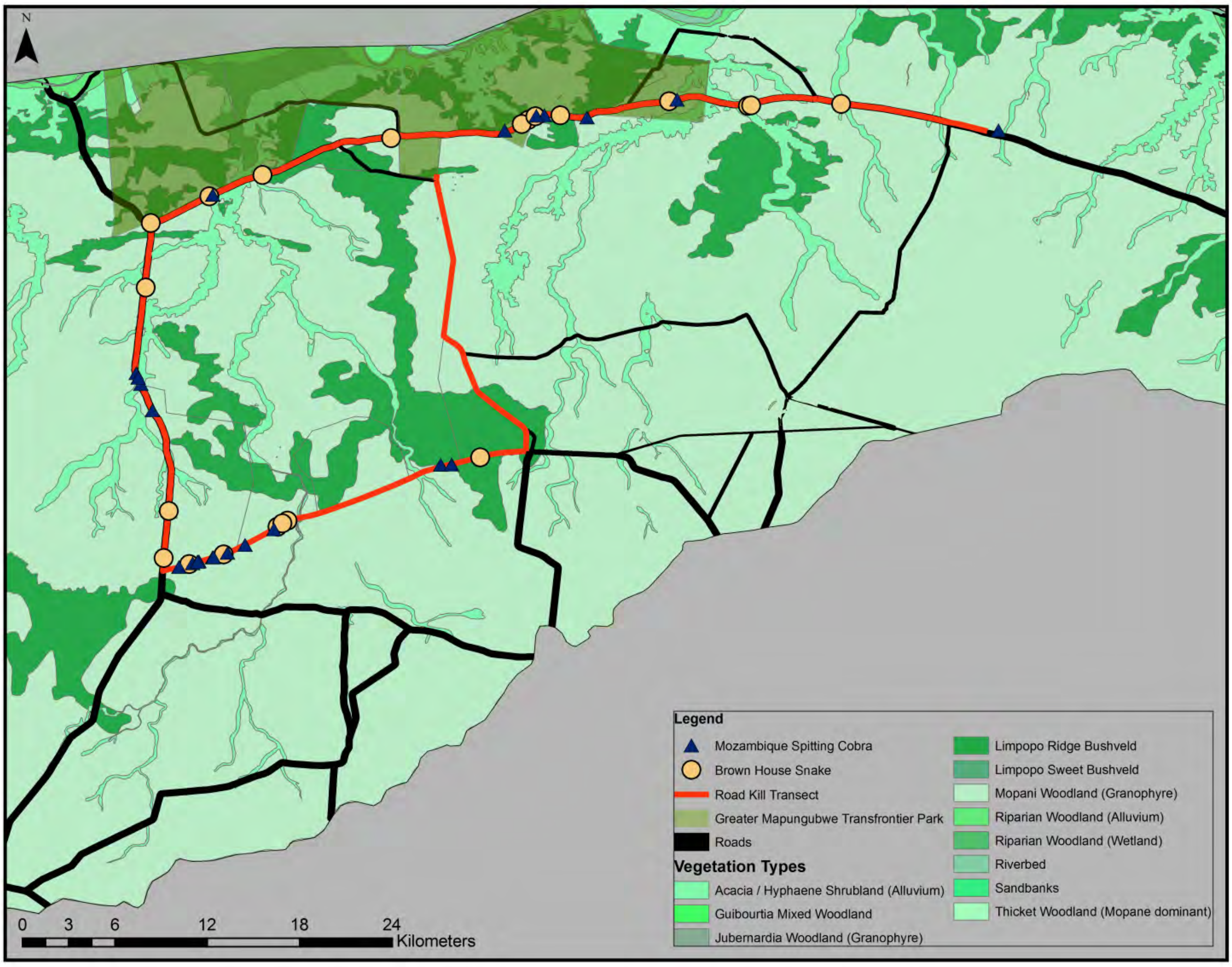

Figure 3: A vegetation map illustrating the location on the transects (100 km paved road and 20 km unpaved road) of Mozambique Spitting Cobra and Brown House Snake roadkill across the three ecological seasons in the GMTCA, South Africa. GIS data source: GeoNetwork (2000); Peace Parks Foundation (2010). (ArcGIS 9.3; map units: decimal degrees; not projected).

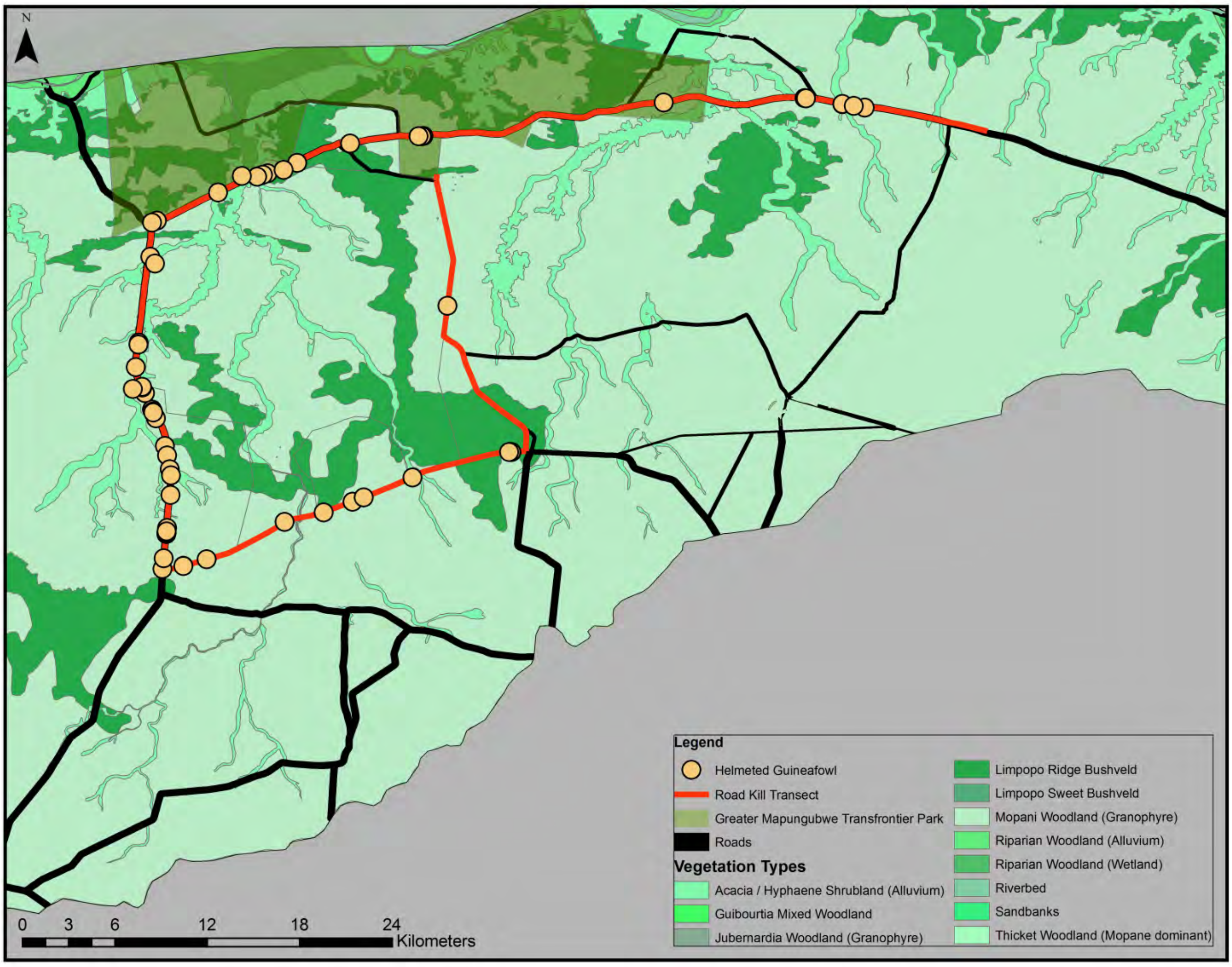

Figure 4: A vegetation map illustrating the location on the transects (100 km paved road and 20 km unpaved road) of Helmeted Guineafowl roadkill across the three ecological seasons in the GMTCA, South Africa. GIS data source: GeoNetwork (2000); Peace Parks Foundation (2010). (ArcGIS 9.3; map units: decimal degrees; not projected).

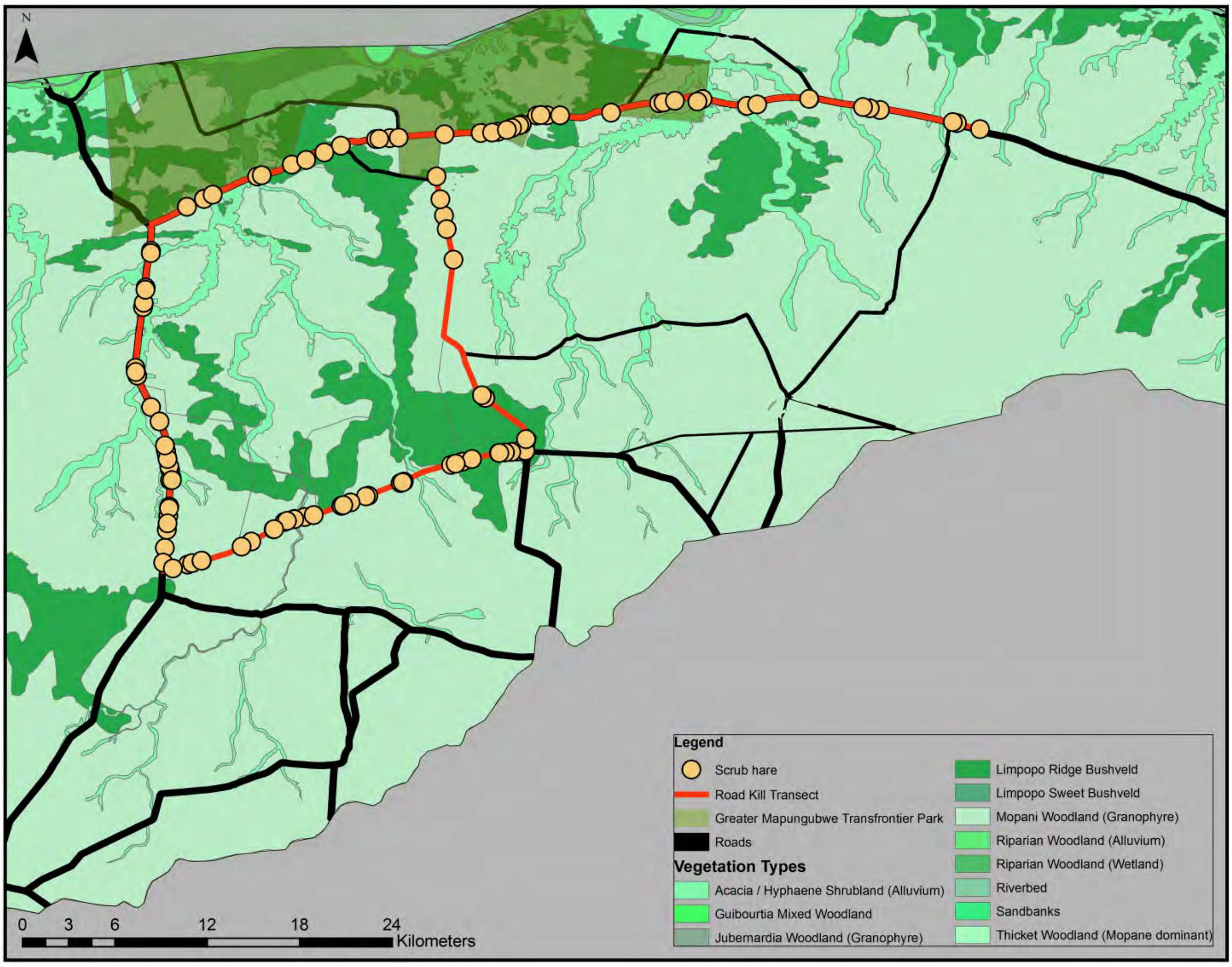

Figure 5: A vegetation map illustrating the location on the transects (100 km paved road and 20 km unpaved road) of scrub hare roadkill across the three ecological seasons in the GMTCA, South Africa. GIS data source: GeoNetwork (2000); Peace Parks Foundation (2010). (ArcGIS 9.3; map units: decimal degrees; not projected).

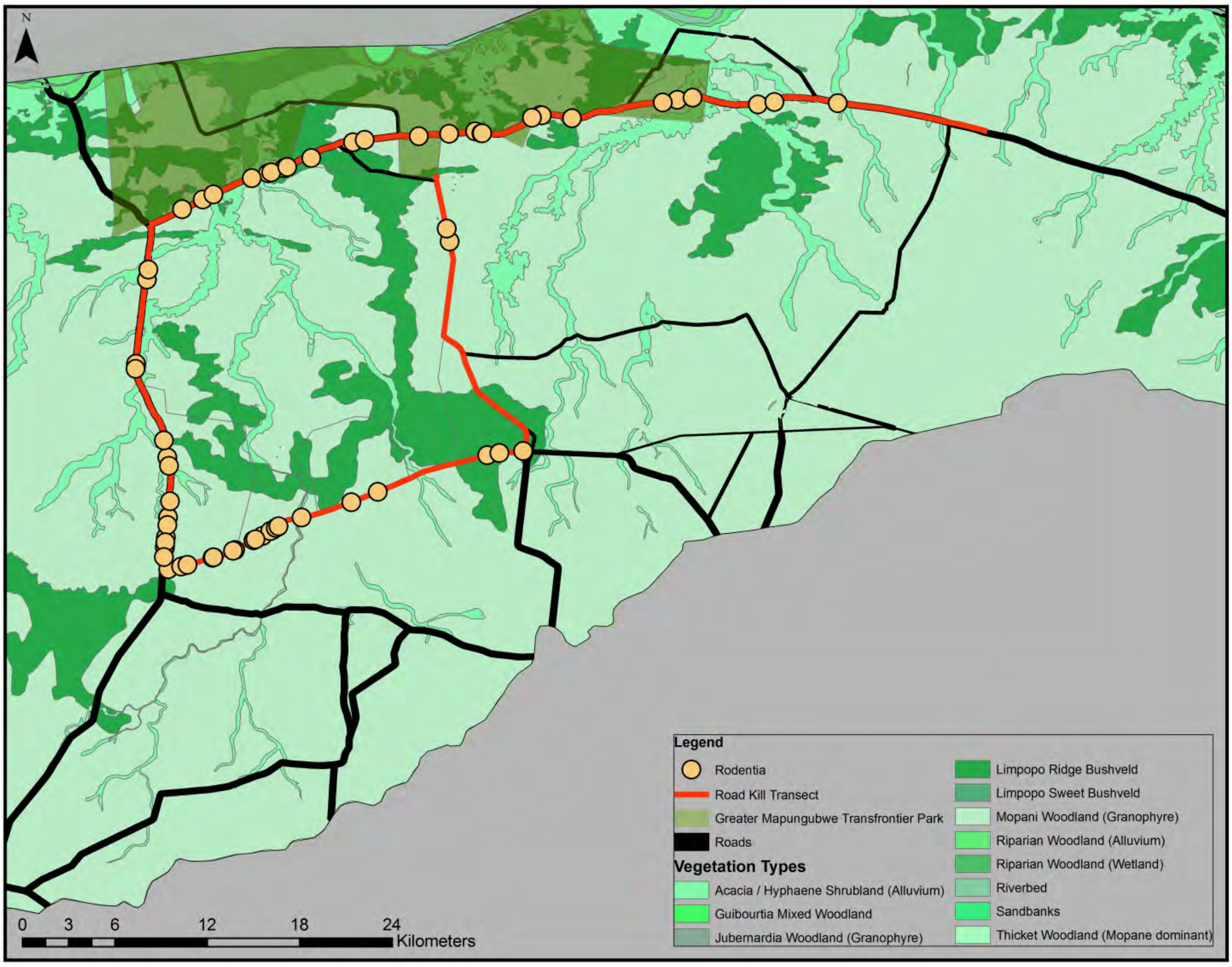

Figure 6: A vegetation map illustrating the location on the transects (100 km paved road and 20 km unpaved road) of Rodentia roadkill across the three ecological seasons in the GMTCA, South Africa. GIS data source: GeoNetwork (2000); Peace Parks Foundation (2010). (ArcGIS 9.3; map units: decimal degrees; not projected).

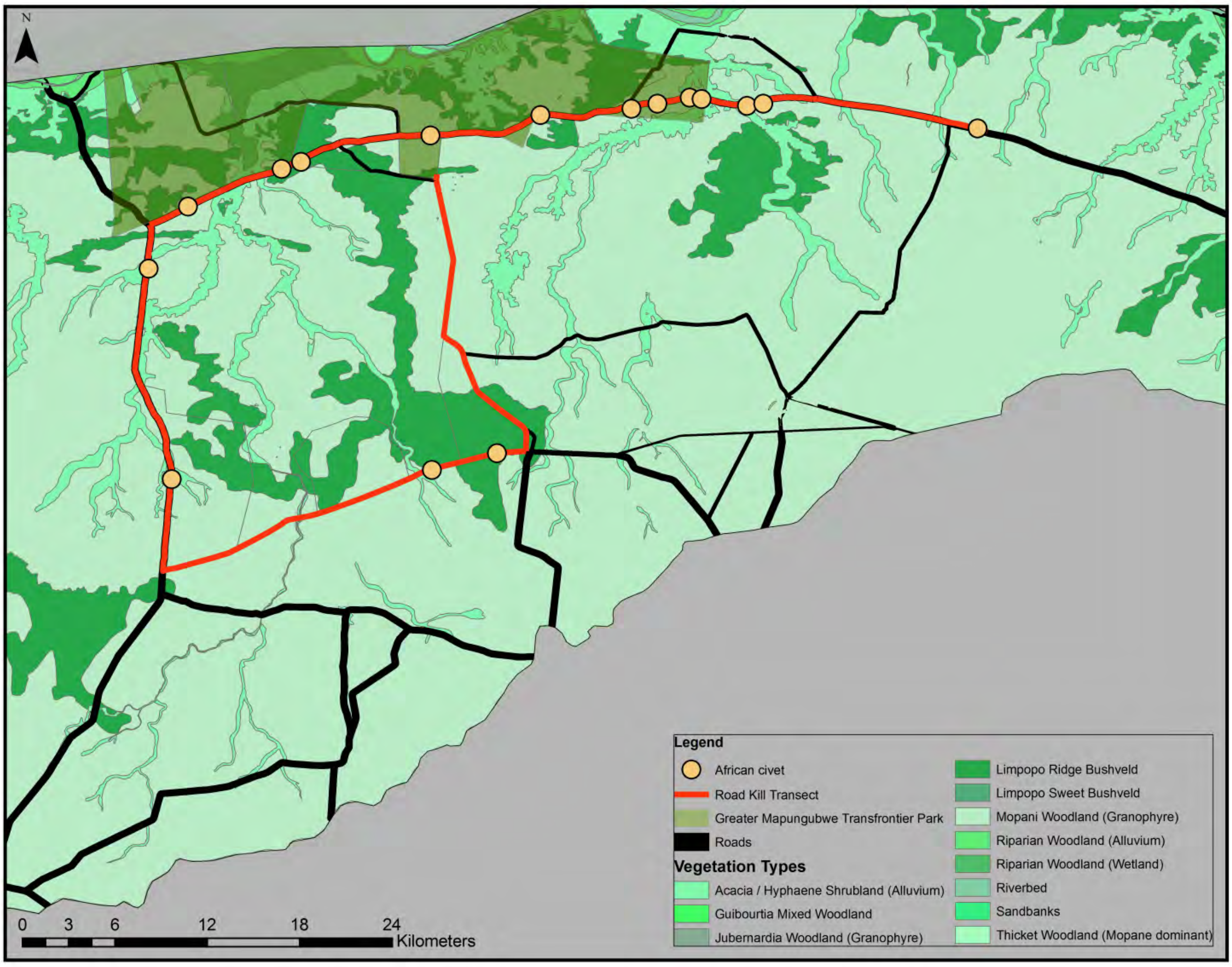

Figure 7: A vegetation map illustrating the location on the transects (100 km paved road and 20 km unpaved road) of African civet roadkill across the three ecological seasons in the GMTCA, South Africa. GIS data source: GeoNetwork (2000); Peace Parks Foundation (2010). (ArcGIS 9.3; map units: decimal degrees; not projected).

APPENDIX H: Roadkill data collection sheet

APPENDIX G: Roadkill data collection sheet

ROADKILL DETECTION SHEET			
Date:	Sunrise:	Temperature min (12:00)	Comments:
Day of week:	Sunset:	Temperature max (12:00)	
Start time:	Moon phase:	Cloud cover:	
End time:	Moonrise:	Wind:	
Start km:	Moonset:	Humidity (12:00):	
End km:	Rainfall:	Recorder:	

Transect # (direction)	**Time roadkill observed**	**Roadkill/live observation**	**Species**	**Condition (A/B, 1-5)**	**GPS S**	**GPS E**	**km from start**	**Type of Fence N / E**	**Type of Fence S / W**	**Vegetation N /E**	**Vegetation S /W**	**Grass density N /E**	**Max. average Grass Height N/E**	**inseed / no seed (other conditions)**	**Grass density S /W**	**Max. average Grass Height S/W**	**inseed / no seed (other conditions)**	**Paved / unpaved**	**Distance (M) of roadkill from verge**	**Distance between road and fence line N/E**	**Distance between road and fence line S/W**	**Area description / road characteristics**	**Visual / presence of live animal**