ECOLOGY AND HABITAT UTILIZATION OF LEOPARD TORTOISE (*STIGMOCHELYS PARDALIS*) IN SOUTHERN KRUGER NATIONAL PARK

by

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Dedication

To my wife and family, for all their patience and continuous support.

Declaration

I **Raydan Raymond Khosa** hereby declare that the dissertation, with the title: **ECOLOGY AND HABITAT UTILIZATION OF LEOPARD TORTOISE (STIGMOCHELYS PARDALIS) IN SOUTHERN KRUGER NATIONAL PARK** which I hereby submit for the degree of **MSc Nature Conservation** at the University of South Africa, is my own work and has not previously been submitted by me for a degree at this or any other institution.

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I declare that during my study I adhered to the Research Ethics Policy of the University of South Africa, received ethics approval for the duration of my study prior to the commencement of data gathering, and have not acted outside the approval conditions.

I declare that the content of my dissertation/thesis has been submitted through an electronic plagiarism detection program before the final submission for examination.

Student signature: ____________________ Date: ____13 April 2023___________

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Summary

This study investigated seasonal changes in habitat selection and movement patterns for *Stigmochelys pardalis* in the southern Kruger National Park. The aim of the study was to collect information on the ecology of *S. pardalis* in the KNP to facilitate conservation of this species by park authorities. Since no existing research is available for *S. pardalis* in KNP, this study also aims to provide baseline data on the ecology and habitat utilisation of *S. pardalis*. South Africa has the most diverse tortoise fauna of any country in the world, containing six genera and 13 species. This study focused only on *S. pardalis*, the largest and most abundant species of tortoise in the KNP. Seven *S. pardalis* were fitted with radio transmitters for monitoring their habitat selection and daily distances travelled over a 12-month period, covering both a warm wet and cold dry season. Data were used to estimate seasonal home range sizes, daily distances travelled and movement activity across three daily periods. Findings indicated seasonal shifts in home range utilization and daily distances travelled, with longer daily distances travelled and larger home range sizes in the warm wet months, compared to the cool dry months. Warm wet season daily distances travelled were typically between 20 and 120 m, and dry season distances were rarely further than 80 m, being mostly within the 20-80 m range. The effects that environmental variables (temperature, rainfall and photoperiod) had on daily distances travelled were also investigated and results show that the study tortoises travelled longer distances in the early morning and late afternoon periods when ambient temperatures are not too hot or too cold. Although the study tortoises moved around on warm nights, their distances travelled decreased during the cold period when temperatures were at their lowest. Daily distances travelled were further during the warm wet season for all daily periods and could be attributed to increases in daily temperatures and rainfall, which results in tortoises no longer bromating and becoming active after the cold, resource scarce dry season.

Key Terms

Leopard tortoise; ecology; habitat utilization; daily distances, daily activity patterns; seasonal

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CHAPTER 1

INTRODUCTION

The Order *Chelonii* is one of the oldest reptile lineages dating back to around 220 million years ago (Gaffney 1990). Today, tortoises are found across Europe, Asia, Africa and the Americas (Bonin et al. 2006, TTWG 2017). Tortoises are important components of many ecosystems where they play a role in seed dispersal (Loehr 2002) and are a food source for other species, including man (Thompson & Henshilwood 2014). Sub-Saharan Africa is home to the greatest diversity of terrestrial tortoises in the world, housing at least one-third of the world's tortoise genera (Hofmeyr et al. 2019, TTWG 2017). According to Hofmeyr et al. (2014) and the TTWG (2017), South Africa has the highest tortoise species diversity worldwide comprising of six genera (*Stigmochelys, Chersina, Chersobius, Homopus, Psammobates* and *Kinixys*) with 17 species currently acknowledged, of which five species are truly endemic (*Homopus areolatus, H. femoralis, Chersobius boulengeri, C. signatus, Psammobates geometricus*) (Bates et al*.,* 2014). In Kruger National Park, where the study was conducted, two tortoise species are known to occur, *Stigmochely pardalis* and *K. spekii*. Although there are a few records in the literature for *K. natalensis* in the KNP, this is yet to be confirmed genetically and could be *K. spekii* as the species have similar appearances (Hofmeyr et al. 2014).

Listed as one of the most threatened animal taxa globally, 10% of tortoise species are classified as Critically Endangered (IUCN 2019). Tortoises are important indicators of environmental condition, their presence and the health of their populations in natural environments being indicative of the quality of the areas they inhabit. When tortoise populations show signs of distress, this will have potential future impacts on other species co-habiting with them (Hofmeyr et al. 2014). Understanding tortoise ecology allows researchers to understand their role in the environment and how the environment affects them, allowing wildlife managers to ensure they are sufficiently conserved.

For conservation planning, it is important to understand how animals utilize the habitats and resources available to them. Large parts of north-eastern South Africa are threatened by habitat destruction and alteration (Bickford et al. 2010, Reading et al. 2010). The well-being of species in protected areas, such as the Kruger National Park (KNP), are of great importance as these are a few of the remaining refuges where species are protected. Human population growth and the demands this has on the environment for space and resources, especially in rural areas bordering wildlife areas, has serious implications for the natural environment. Due to poverty and the need for resources, many people living in these impoverished communities look to protected areas for sources of protein and firewood (Personal. obs.). Syndicates that export ivory, rhino horn and living animals for the pet trade take advantage of people living in communities that border on protected areas, exploiting local knowledge to gain access to these products (Personal. obs.).

Additional impacts to the natural environment and species diversity include climate change (Harvell et al. 2002, Reading et al. 2010), habitat fragmentation (Blaustein et al. 1994, Araujo et al. 2006), and the introduction of alien invasive species (Kambourova-Ivanova et al. 2012, Warnecke et al. 2012). Responsible management practices are essential to mitigate the impacts of the various threats to the natural environment, especially now that the effects of climate change are being experienced in many natural areas (Harvell et al. 2002, Reading et al. 2010).

The Leopard tortoise (*S. pardalis*) is widely distributed throughout its range in Africa, occurring as far north as Ethiopia and as far south as South Africa (Boycott & Bourquin 2000; Hofmeyr et al. 2014). *Stigmochelys pardalis* persists across a wide range of habitats from semi-arid to grassland and savannah habitats (Boycott & Bourquin 2000). They are highly adaptable and able to persist in a diverse range of conditions. Despite their widespread distribution and being classified as a species of Least Concern (TTWG 2017), very little is known about their ecology and how they utilize their habitats, especially in KNP.

The Leopard tortoise has an herbivorous diet (Hailey et al. 1998) as is the case for most tortoise species in South Africa. The Leopard tortoise have limited digging abilities (Boycott & Bourquin 2000) and use rock crevices and thickets for shelter during extreme weather conditions (Grobler 1982*;* Milton & Dean 1993). Leopard tortoise generally overnight under thickets (Rall 1985).

Stigmochelys pardalis are very active during the summer months and become inactive in winter when they brumate and hide under thickets until the cold winter months pass. Activities resume as temperatures increase, with *Stigmochelys pardalis* noticeably moving around more during the rainy season when they are seen on tar roads throughout the KNP, drinking water from small pools on the road surface (Personal. obs.). According to Branch et al. (1995), Leopard tortoise population densities are low in the west of South Africa due to shortages of moisture. South African distribution maps for Leopard tortoise show that they occur in the south-western part of South Africa, but as introduced species into the area (Hofmeyr et al. 2014).

The survival rate for Leopard tortoise, especially juveniles, in KNP is a concern, with road mortalities during the rainy season probably inflating the mortality rate above levels incurred through natural causes e.g. predation. Natural enemies of Leopard tortoises in the park, amongst others, include Southern Ground Hornbill, Honey Badger, Martial Eagle, Bateleur, Spotted Hyena, Lion and Leopard (Personal. obs.). According to Branch (2008) and Gutteridge (2008), Leopard tortoise are also killed by veld fires.

Although several studies have been completed on *S. pardalis* in Southern Africa and elsewhere in Africa, to date there are no recorded studies on the ecology of the species in Southern Kruger National Park (KNP). This study investigates seasonal changes in habitat utilisation, daily distances travelled and broad activity patterns for *S. pardalis* in the southwestern region of KNP. Data acquired will improve the knowledge base about the general ecology of this species, providing information about how this tortoise species utilizes its available habitat in the study area. Consequently, this research will facilitate the management of *S. pardalis* in the park and could contribute towards reptile management plans and the conservation of tortoises in general.

Habitat utilization, inclusive of movement and activity patterns represent core concepts in understanding the function of tortoises and other animals in their ecosystems. It is well-known that tortoises play an important role in seed dispersal, and thus facilitate vegetation stability (Branch 1994). It thus seems that if *S. pardalis* in the KNP fulfils an important ecological function, that a better understanding of how they accomplish this function will benefit conservation action to improve their protection inside the KNP.

The objectives for this study are to use GPS technology to map the seasonal home range utilization and daily movement patterns of Leopard tortoises (*S. pardalis*) in southwestern KNP for one dry season and one warm wet season. Captured individuals will be categorized by age class and sex to determine if there are seasonal differences in home range utilisation and daily movement patterns across the various categories. Various environmental variables (including temperature, rainfall and photoperiod) will also be collected to determine habitat selectivity by the various tortoises, and to investigate the effects of the variables on tortoise movement patterns.

This dissertation is structured as follows: Chapter 2 examines available literature on tortoise distribution and life history. Chapter 3 describes the study area. Chapter 4 describes the methodology used for data collection and analyses of collected data. Chapter 5 investigates home range characteristics and utilisation by Leopard tortoises. Chapter 6 looks at seasonal and daily distances travelled and thermoregulatory behaviour. Chapter 7 concludes the dissertation and provides information and recommendations for management on how to conserve and manage tortoises.

CHAPTER 2

LITERATURE REVIEW

2.1 Tortoise distribution and life history

The Order *Chelonii* is one of the oldest reptile lineages dating back to around 220 million years ago (Gaffney 1990). The Testunidae (Suborder Cryptodira) is represented by all the terrestrial tortoises, and there are 40 species worldwide (TTWG 2017). Today, tortoises are found across Europe, Asia, Africa and the Americas (Bonin et al. 2006, TTWG 2017). Tortoises are important components of many ecosystems where they play a vital role in the distribution of seeds (Loehr 2002) and provide food for other species, including man (Thompson & Henshilwood 2014).

The Leopard tortoise (*Stigmochelys pardalis*) has a variety of distributions from arid and semi-arid areas to wetter grassveld, savannah and bushveld (Boycott & Bourquin 2000). This species has the largest distribution of all tortoises in Africa and is found in South Sudan, Ethiopia, Angola, Namibia, and South Africa (Greig & Burdett 1976, Bonin et al. 2006, Branch 2008, Hofmeyr et al. 2014). In some areas Leopard tortoises are colloquially called mountain tortoises because they frequent mountainous terrain (Hofmeyr et al. 2005; Bonin et al. 2006; Hofmeyr et al. 2014).

2.2 Tortoises of southern Africa

In Southern Africa, Testunidae (Suborder Cryptodira), are represented by 12 species and two sub species (Boycott & Bourquin 2000). The former Cape Province had three species that were endemic to the region, while a fourth species is found in the former Orange Free State and Transvaal. The Karoo region is regarded as a centre of endemism (Boycott & Bourquin 2000); however, due to land use practices, conservation of tortoises in the Karoo biome is a major concern (Lombard 1995).

Leopard tortoises (*S. pardalis*) have a mean body mass of between 8 - 12 kg (maximum 43 kg) and out of the 12 species of tortoises occurring in southern Africa, *S. pardalis* is the largest (Greig & Burdett 1976; Branch 2008). Leopard tortoises found in the Karoo region are much larger than those from KwaZulu-Natal, Limpopo and Swaziland *(*Boycott & Bourquin 2000, Branch 2008*).*

2.3 Leopard tortoise (*Stigmochelys pardalis*) morphology and reproduction

The genus name *Stigmochelys* is derived from the Greek words *stigma* which refers to their markings and *chelone* which is the word for tortoise. The binomen for the species is *pardalis* which comes from the Greek word *pardos* which means spotted and refers to the markings on their shells (Branch 2008). The name Leopard tortoise was thus given to resemble the body colouration of this tortoise (Emmett & Pattrick 2010). With age the shell of S. *pardalis* loses its colour and becomes a drab brown (Gutteridge 2008).

Stigmochelys pardalis is one of two large-bodied tortoises in Africa, with a body size that varies with region; it is very large in the northernmost and southernmost parts of its range (up to 40 kg in mass and 700 mm in carapace length; Branch 2008) with a much smaller size in intermediate regions such as Kenya (Fritz et al. 2010). This variation in size has been ascribed to habitat, with individuals having a larger size in mesic, rather than in semi-arid regions (Baker et al. 2015).

Leopard tortoises have a mean length of 15 cm (Gutteridge 2008). The plastron is concave on males (known as the plastron cavity) to protect them from falling off the backs of females during mating (Gutteridge 2008). Females have a flat belly compared to males to allow room for egg development (Gutteridge 2008).

Tortoise shells are divided into two, the carapace which is the upper part, and the plastron which is the lower part. The shell is protected by scales made of prominent growth rings that develop as the tortoise ages (Emmett & Patrick 2010). Leopard tortoises have hooked horny beaks for cropping vegetation that they consume. Their front limbs contain five claws, and each hind limb has 2 to 3 buttock tubercles (Branch 2008). Leopard tortoises are the only tortoises that can swim (Emmett & Pattrick 2010).

Leopard tortoise normally live from 30 - 75 years in captivity, but there a record for a 100-year-old tortoise (Boycott & Bourquin 2000; Branch 2008). Leopard tortoises become sexually active between 12 and 15 years of age, with females growing faster and weighing more than males do (Lambert 1995, Branch 2008, Fritz et al. 2010). Males have longer tails compared to females (Gutteridge 2008). During the breeding season, males will fight over females, aggressively bumping into and butting their competitors (Gutteridge 2008). Male tortoises follow females over long distances until they become submissive, after which mating will occur. When mating, the male usually makes grunting vocalizations (Gutteridge 2008). Breeding usually take place between May and October, and although females cannot burrow, they dig relatively shallow holes (ground nests) when they are ready to lay eggs. Females soften the soil by releasing moisture in the form of urine from bursa, which also serve as moisture reservoirs for tortoises during the dry season, while digging with their hind legs. From 5 to 7 clutches of between 5 and 30 eggs are deposited into ground nests that are oriented towards the sun (Branch 2008). Incubation takes from 8 to 15 months depending on ambient temperatures (Bonin et al.; Branch 2008). Hatchlings weigh between 23 and 50 g and reach lengths of between 40- and 50-mm. Ambient temperatures of between 26 and 30 ^{o}C result in the formation of males, whereas 31 to 34 ^{o}C results in females (Emmett & Pattrick 2010). It takes ~8 years for tortoises to each a weight of 1 kg (Branch 2008).

According to Branch (2008), Leopard tortoise eggs, hatchlings and juveniles have numerous predators such as monitor lizards, storks, crows, small carnivores, black backed jackal, ground hornbills, leopard, puff adder and ants. People collect tortoises for food, with Sangomas or Soothsayers collecting them for medicinal purposes (Personal. obs.). Habitat destruction leads to declines in tortoise numbers as the removal and destruction of vegetation cover causes young tortoises to become exposed, making them vulnerable to predation (Milton et al. 1996). In the Karoo region, threats to tortoises include competition with livestock for resources, habitat fragmentation and electric fencing that kills them (Beck 2010; Drabik-Hamshare 2016). Tortoises are also collected for the pet trade throughout the sub-region, resulting in declining tortoise populations (IUCN 2019). In general, South African terrestrial tortoises are also threatened by habitat degradation, encroaching alien vegetation, overgrazing by livestock and runaway fires (Boycott and Bourquin 2000).

2.4 Leopard tortoise (*Stigmochelys pardalis*) distribution and habitat

Tortoises can travel long distances and remain without food during drought periods. They can survive in areas with severe climatic conditions such as the semi-arid deserts of Africa and North America (Nagy & Medica 1986, Peterson 1996, Hailey & Loveridge 1997, McMaster & Downs 2006, Sadeghayobi et al. 2011).

The distribution range of *S. pardalis* falls mainly in the Savannah biome, including the KNP, but in South Africa it also occurs in a variety of other vegetation types, such as the Nama Karoo, Succulent Karoo, Grassland, Albany thicket and Fynbos biomes (Hofmeyr et al. 2014). *Stigmochelys pardalis* is not endemic to South Africa, and its range extends further north into Namibia, Botswana, Zimbabwe, Mozambique, and as far north as Ethiopia (TTWG 2017). Although Boycott & Bourquin (1998) indicate that *S. pardalis* are unlikely to be found in mountainous areas, several researchers have found them occurring in such areas (Archer 1968, 1971; Grobler 1982; McMaster 2001).

There are several regions in South Africa where more than one tortoise species occurs in the same region and are sympatric. However, some tortoise species occupy the same habitat and are thus syntopic (Pianka 1974). Co-existing species must differ in the way they use resources to avoid competitive exclusion; such differences may include the use of microhabitats, activity cycles, or food preferences (Pianka 1974). Luiselli (2006) reviewed evidence for resource partitioning in tortoises and predicted that interspecific competition would be low in tortoises, due to several of their life history traits. In particular, he based his hypothesis on most tortoises being generalist feeders, making food readily available, which reduces competition.

The co-existence of two tortoise species, *S. pardalis* and *C. angulata* has been studied in the Addo Elephant National Park (Mason et al. 2000). This study focused on tortoise biomass and the possible effects of this on their habitat use, rather than on niche separation of the two species. Population density estimates were substantially higher for *S. pardalis* (0.85 tortoises/ha) compared to *C. angulata* (0.12 tortoises/ha), suggesting that the habitat was more suitable for *S. pardalis* than for *C. angulata*. Due to the large body size of *S. pardalis*, their estimated biomass in the study area amounted to 6.02 kg/ha, which was equivalent to the combined biomass of all non-mega herbivore species in the region. Such a high biomass may imply that these tortoises can have a profound impact on their habitat, but this impact is reduced by the low metabolic requirements associated with ectothermic animals, compared to the high energy requirements of mammalian endotherms (Mason et al. 2000).

The KNP, where the current study has been done is home to at least two tortoise species, *S. pardalis* and *K. spekii*. Although there are a few records in the literature for *K. natalensis* in the KNP (Hofmeyr et al. 2014), there is reason to doubt if these specimens have been correctly identified. *Kinixys* spp. are often misidentified due to variations in the colour patterns of different species that overlap, with the young of *K. spekii* often incorrectly identified as *K. natalensis*. An extensive genetic survey has not yet identified any *K. natalensis* in or near the KNP (Personal. Comm.; M.D. Hofmeyr; July 12, 2019).

2.5 Leopard tortoise (*Stigmochelys pardalis*) ecology

Tortoises are known to be herbivorous or omnivorous, with the omnivorous tortoises feeding on carrion, insects, slugs and small prey (Hailey 1997; Hailey et al. 2001; Loehr 2006). Tortoises also feed on soils, shells and small stones to supplement nutrient deficiencies, including a lack of magnesium (Milton 1992; Esque & Peters 1994; Walde et al. 2007; Hazard et al. 2010; Moore & Dornburg 2014).

Stigmochelys pardalis have a predominately (98%) herbivorous diet consisting of a variety of plants including fruits, berries, forbs, thistles, grasses, and succulents. They have been observed gnawing on bones and feeding on hyena droppings to obtain calcium, which aids with the development of their shells and hardens eggshells (Branch 2008). Milton (1992) found that *S. pardalis* in the southern Karoo feeds on grasses, succulents and forbs belonging to 26 plant families, with flowers, fruits and seeds comprising up to 67% of the plant fragments consumed. *Stigmochelys pardalis* is intermediate between generalist and specialist herbivores, showing preferences for specific grass and geophyte species (Mason et al. 1999). They also feed on ash and bone where there are limited resources to supplement a deficiency of calcium for shell formation (McMaster and Downs 2006; Schmidt 2006). *Stigmochelys pardalis* have a low metabolic rate and do not have the ability to store food (Peterson 1996; Hailey & Loveridge 1997; McMaster & Downs 2006; Sadeghayobi et al. 2011).

Stigmochelys pardalis activities are diverse during summer, compared to winter when they are mostly inactive and hide under thickets for prolonged periods of time (Personal. obs.). They are active during the day but hide under thickets and remain stationary during very hot or very cold weather conditions. After summer rains start falling, *S. pardalis* become active and spend most of their time feeding on emerging green vegetation such as shrubs and grasses (Branch 2008). They commonly drink water on or near tar roads that accumulated in small depressions, and take advantage of the green vegetation on road verges (Figure 1.1) (Personal. obs.).

Figure 2.1. Leopard tortoise (*Stigmochelys pardalis*) feeding (Karim 2008**).**

Stigmochelys pardalis is predominantly a solitary species that is only seen in pairs during the breeding season. During the wet summer months, they are active mainly during the cool early morning hours and the late afternoon periods and are often encountered while feeding or moving; during the afternoon periods they also search for shelter to overnight in (Personal. obs.).

Tortoises are important indicators of environmental conditions, their presence and the health of their populations in natural environments being indicative of the quality of the areas they inhabit (Branch 1984). When tortoise populations show signs of distress, this will have potential future impacts and knock-on effects for other species co-habiting with them (Personal. Comm.; A. Du Toit July 22, 2019).

Tortoises feed on a variety of plants and play a very important role in dispersing the undigested seeds of many of these plants through their faeces (Kerley et al. 1999; Loehr 2002). Some seeds that are consumed pass undigested through the gut of Leopard tortoises. These seeds are deposited in faeces under thickets where *S. pardalis* hide during the heat of the day or where they overnight. Undigested seeds germinate during the rainy season and begin to grow in the new sites where they are deposited.

Tortoise faeces is a valuable food source for other creatures such as francolins that scratch through their faeces to obtain undigested seeds. Butterflies, ants and other insects obtain moisture from tortoise droppings. Dung beetles also benefit from tortoise faeces by creating dung balls that they bury and lay their eggs in. These dung balls further contribute towards seed dispersal and contain undigested seeds that the tortoises fed on (Personal. obs.).

Stigmochelys pardalis have large territories of between 2 to 3 km^2 and are often seen moving within their home ranges (Gutteridge 2008). In the Karoo, the home range size of males and females do not differ, with both sexes moving longer distances in the summer rainfall season, compared to the dry winter months (McMaster & Downs 2009). The mean annual home range for all tortoises in the Karoo study was 205 ha (McMaster & Downs 2009). Another study in the semi-arid Karoo using GPS systems to record movements of *S. pardalis* over a 12-month period confirmed that sizes of home ranges for males and females (40.5 to 258.5 ha) did not differ (Drabik-Hamshare 2016). A short-term home range study of *S. pardalis* in open Savanna woodland in the Sengwa Wildlife Research Area in Zimbabwe produced a mean home range size of 26 ha, which is relatively small (Hailey & Coulson 1996). The small home range size can possibly be attributed to the study being over a short period of time, and the tortoises having a smaller body size than in the Karoo studies.

Stigmochelys pardalis travel long distances of between 5 and 10 km as observed when relocated and study animals returned to their home territories (Branch 2008). Movement patterns of *S. pardalis* have been studied in several regions of southern Africa (Bertram 1979; Mason & Weatherby 1995; Hailey & Coulson 1996; McMaster & Downs 2009; Drabik-Hamshare 2016), but not yet in the KNP. Based on the Zimbabwe study (Hailey & Coulson 1996) and other studies in the Albany Thicket biome of South Africa (Mason & Weatherby 1995), the Serengeti (Bertram 1979) and the Karoo (McMaster & Downs

2009), it is evident that Leopard tortoises in the semi-arid Karoo moved longer distances than in more mesic regions, possibly because food and water are scarce in the semi-arid Karoo region.

CHAPTER 3

STUDY AREA

3.1 History and location

Kruger National Park (KNP) was formally established in 1926 when the Sabi Game Reserve and the Shingwedzi Game Reserve were combined (Wikipedia contributors 2019). Currently KNP forms part of one of the largest protected area networks in Africa, combining conservation areas in South Africa, Zimbabwe and Mozambique into the Great Limpopo Transfrontier Park. Due to the substantial extent of the park, it was decided that the proposed study would take place within the confines of the southwestern region. The southwestern region is situated between latitudes 24°50’00” S to 25°30’00” S and longitudes 31°10’00” E to 31°36’00” E. Altitude for the southwestern region ranges from 300 to 800 metres above mean sea level (m.a.s.l.). This study was done in an area roughly 17 128 ha in size, between Skukuza, Afsaal and Pretoriuskop. (Figure 3.1).

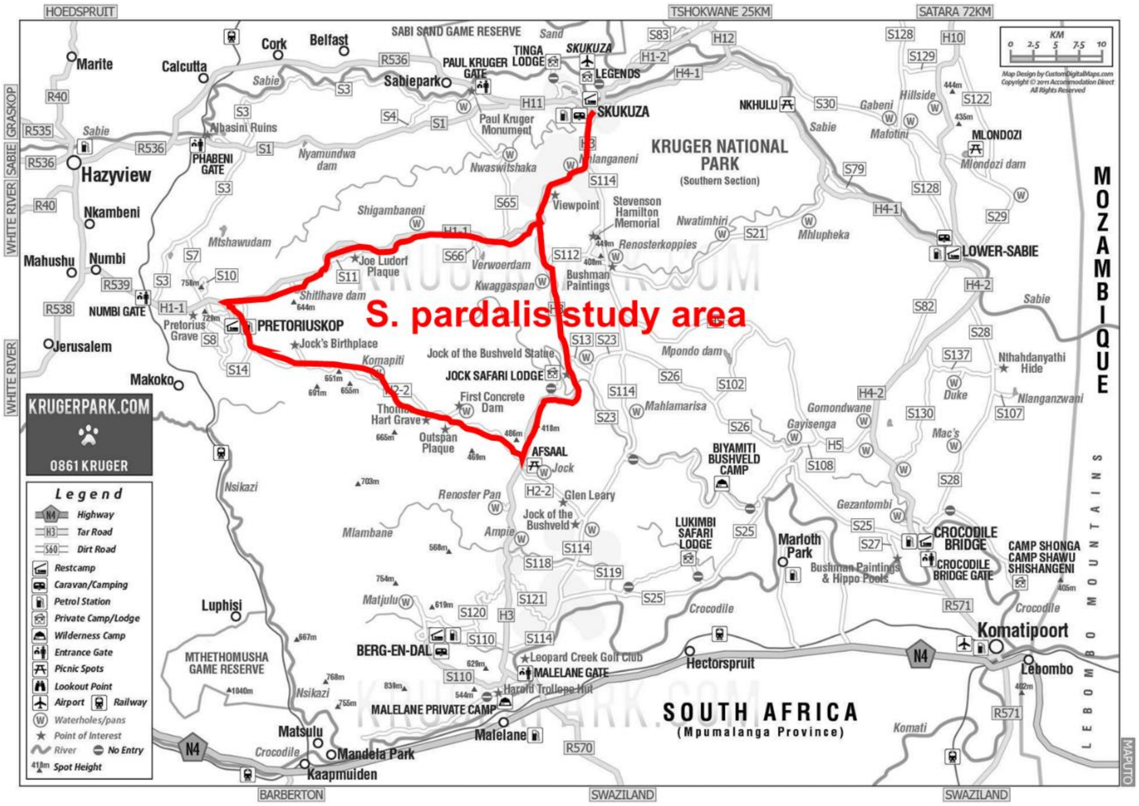

Figure 3.1. Map of the study area (~17 128 ha) in southwestern Kruger National Park.

3.2 Topography (Bristow et al. 1986)

Kruger National Park mainly slopes from the west towards the east, which is the direction of flow of the perennial rivers carrying surface water into and through the park. The mean height of the park is between 839 m.a.s.l. at Khandizwe near Malelane, to 442 m.a.s.l. at Punda Maria in the northern part of the park. The Central part of KNP is ~260 m.a.s.l. and the lowest point at Sabi gorge is ~122 m.a.s.l.

On the western boundary of the park the slope is west to east on the foothills of the Lebombo Mountains. The Shingwedzi gorge is 244 m.a.s.l., Olifants is 152 m.a.s.l., N’wanetsi is 152 m.a.s.l. and N’waswitsontso gorge is 183 m.a.s.l. The major rivers in the Park are the Crocodile river which flows along the southwestern boundary and forms the southern boundary of the park, and the Limpopo river that forms the northern boundary of the park. Between these extremities are the Sabie, Olifants, Letaba and Levuvhu rivers. Seasonal rivers in the Kruger National Park are Mbyamiti, Nwatindlopfu, Timbavati, Mphongolo, Nwaswitsontso, Tsendze, Shingwedzi and Shisha. All rivers drain into the Indian Ocean.

Three Sandveld areas occur in the Kruger National Park, at Pumbe (Eastern border between Satara and Olifants Camp), at Punda Maria, and at Nwambiya (on the northern part of the eastern boundary). The latter area has a vegetation community containing Jasmine pea or Sand camwood (*Baphia massaiensis*) that is very different from the rest of the Kruger National Park. This community has unique geology resulting in sandy soils called Aeolian that are millions of years old and that was deposited by wind into KNP from Mozambique (Personal. Comm.; N. Zambatis; September 11, 2021).

3.3 Geology and lithology

Kruger National Park has a variety of rock types ranging from ancient rocks that are 135 million years old, to more recent rocks that are 3.5 million years old. Ancient rocks include Granite and Gneiss with intrusions of Gabbro. As a result of moist conditions approximately 300 to 200 million years ago, Ecca shales were deposited onto the underlying Granite, Gneiss and Gabbro (Bristow et al. 1986).

The parks geology is bisected from north to south by a narrow sandstone outcrop. The western part of the KNP is granitic rock with its typical undulating landscape and scattered granite hills. Dolerite and gabbro intrusions within the granite area influence soils and landforms. The Lebombo Mountains in the eastern part of the park is comprised of a third major rock type called rhyolite, a light-coloured resistant lava that rises noticeably above the basalt plain on the western side of the park (Bristow et al. 1986).

Underlying geology for the southern section of KNP (Figure 3.2) includes Granite which forms the main intrusion, occurring mostly to the southwest. Gneiss occurs to the south of the Granite and is the next largest intrusion. Intermittently scattered in the Granite and

Gneiss intrusions are a series of Gabbro and Dolerite intrusions. Intrusions to the west of the southern section include Basalt, Arenite, Granophyre, Rhyolite and Shale.

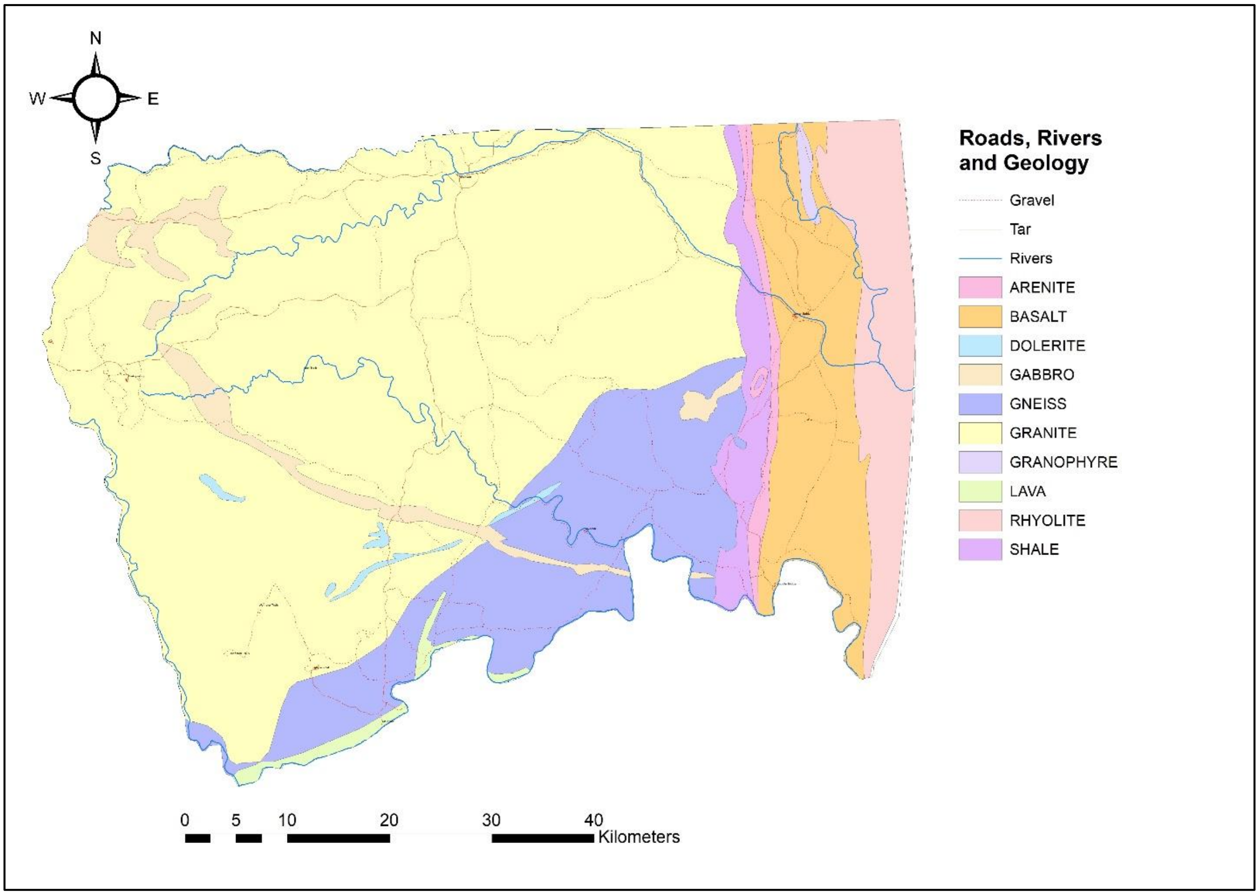

Figure 3.2. Map of the southern section of KNP depicting the underlying geology for the area.

Two main geological formations, the Basement Complex and Timbavati Gabbro underlie the study area in the southwestern region of KNP giving rise to the five ecozones found in the study area. Four of the five ecozones (Mixed Bush willow Woodlands, Pretoriuskop Sourveld, Malelane Mountain Bushveld, and Sabi/Crocodile Thorn Thickets) occur on Granite and Gneiss of the Nelspruit Suite, while Thornveld occurs on Gabbro (Mucina & Rutherford 2006).

Soils in the study area are formed by the weathering of underlying Granite, Gneiss and Gabbro rocks. Soils are mostly shallow and leached with a red to yellow-brown colour.

The main soils in the Pretoriuskop area are sand and sandy loam of the Glenrosa, Hutton and Clovelly soil types (Mucina & Rutherford 2006). Near Malelane, soils are mostly coarse sandy lithosols of the Glenrosa or Mispah soil types (Mucina & Rutherford 2006). Prominent hills with large boulders are a common in these areas. Lithology for the southwestern section of KNP is shown in Figure 3.3.

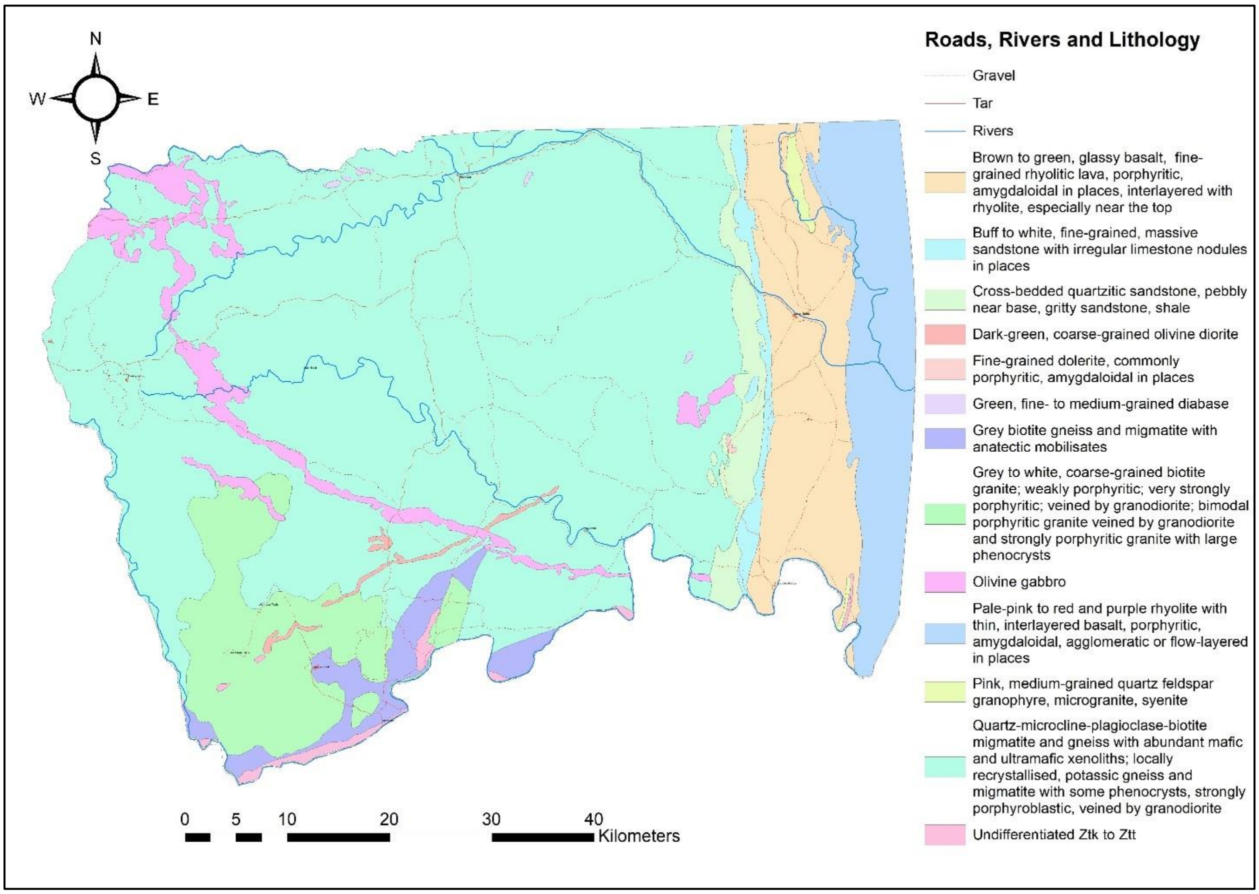

Figure 3.3. Map of the southern section of KNP depicting the lithology for the area.

3.4 Vegetation

One third of Kruger National Park lies within the tropical belt north of the Tropic of Capricorn. Plant life varies from subtropical to tropical. There are more than 2 000 plant species that occur in the Kruger National Park including 336 trees, 121 shrubs, 1 249 herbs, 235 grasses and 27 fern species (Venter & Gertenbach 1986).

The diversity of plant life in the Kruger National Park can be attributed to different rock formations that give rise to various soil types, differences in topography and variations in climate i.e., temperature and rainfall.

According to Mucina & Rutherford (2006), the southern section of the park has seven main veld types, SVI 3 Granite Lowveld, SVI 4 Delagoa Lowveld, SVI 5 Tshokwane-Hlane Basalt Lowveld, SVI 6 Gabbro Grassy Bushveld, SVI 10 Pretoriuskop Sour Bushveld, SVI 11 Malelane Mountain Bushveld, and SVI 15 Northern Lebombo Bushveld (Figure 3.4). Granite Lowveld is considered vulnerable while the other veld types in the southern section are listed as least threatened (Mucina & Rutherford 2006).

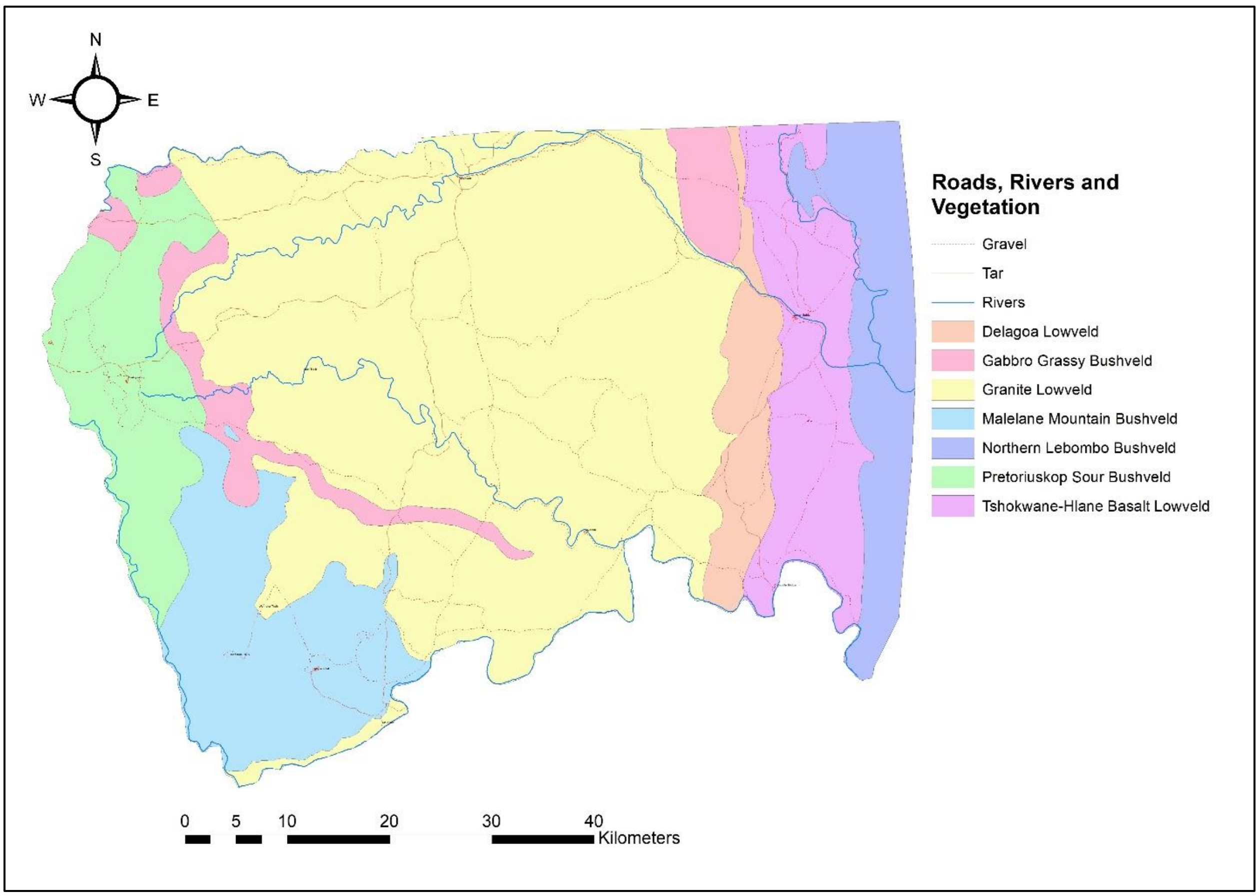

Figure 3.4**.** Map of the southern section of KNP depicting the vegetation found in the area (adapted from Mucina & Rutherford 2006).

Ecozones in KNP have unique assemblages of plants and dependent animals that are found in specific locations based on underlying geology, soil types, rainfall, and temperature (Gertenbach 1983). The five ecozones found in the southwestern section of KNP, the study area, with their associated vegetation is depicted in Figure 3.5.

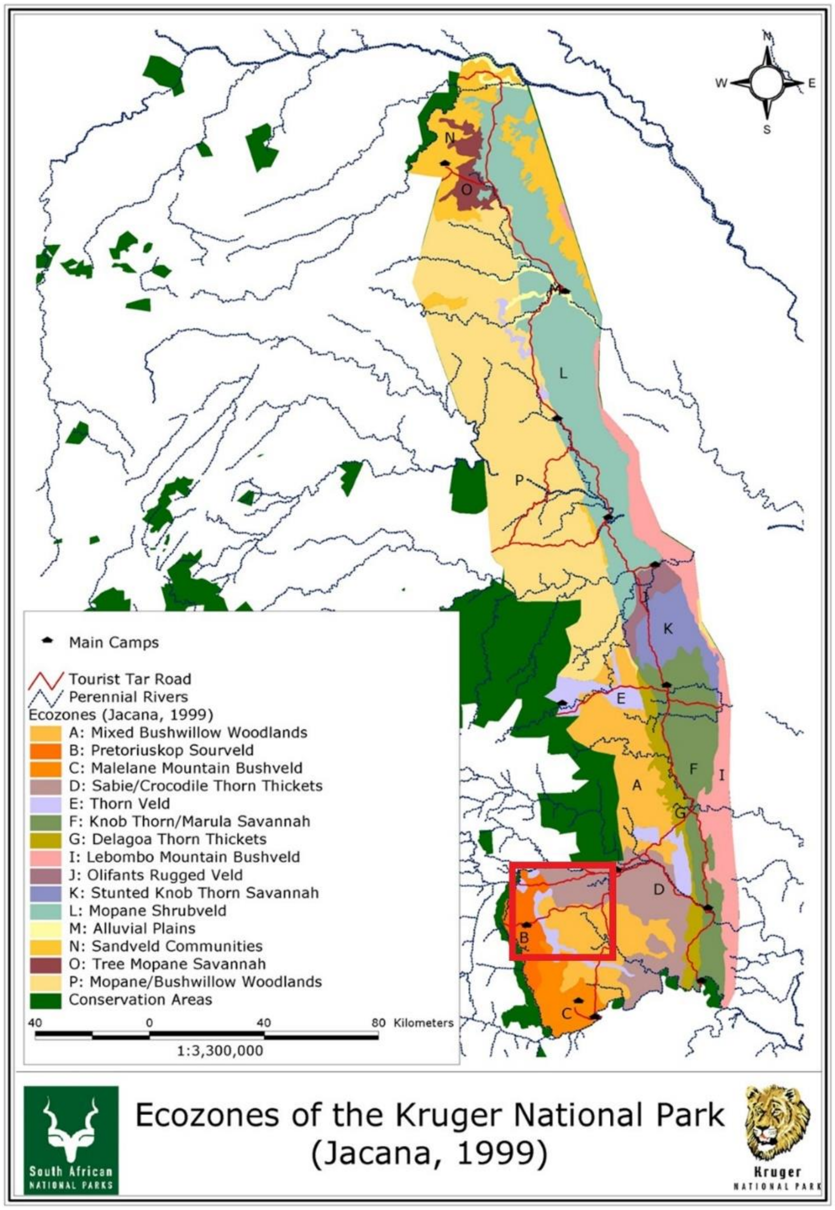

Figure 3.5. Map depicting the Ecozones found in KNP. The area within the red rectangle/square is the southwestern region of the park where the study was undertaken (Jacana 1999).

3.4.1 A: Mixed Bushwillow Woodlands (Gertenbach 1983; Venter & Gertenbach 1986)

These woodlands are found on Granite and Gneiss. Slope elements and associated woody plants occurring in this ecozone include:

- Crests/uplands characterised by *Balanites maughamii*, various *Combretum* spp. and *Sclerocarya birrea*;
- Seeplines characterised by *Terminalia sericea*;
- Midslopes characterised by various *Vachelia* spp. and *Senegalia* spp.;
- Footslopes characterised by *Bolusanthus speciosus*, *Euclea divinorum,* and mixed *Vachelia* spp. and *Senegalia* spp;
- Drainage lines characterised by *Diospyros mespiliformis* and *Combretum imberbe*.

Soils are deep, coarse and sandy on crests/uplands and in seeplines. Clay soils occur on midslopes, foot slopes and in drainage lines.

3.4.2 B: Pretoriuskop Sourveld (Gertenbach 1983; Venter & Gertenbach 1986)

This ecozone, like the Mixed Bushwillow Woodlands ecozone is also found on Granite and Gneiss. Slope elements and associated woody plants occurring in this ecozone include:

- Granite outcrops characterised by *Ficus abutilifolia*, *S. birrea*, and *Kirkia wilmsii*;
- Uplands characterised by *T. sericea*, *Dichrostachys cinerea*, various *Combretum* spp., *Albizia forbesii* and *Pterocarpus angolensis;*
- Seeplines characterised by *T. sericea*;
- Midslopes characterised by *Senegalia nigrescens*, various other *Senegalia* spp. and *Vachelia* spp., and *Pterocarpus rotundifolius*;
- Foot slopes characterised by *D. cinerea*, *Euclea divinorum*, *Senegalia nigrescens*, and various other *Senegalia* spp. and *Vachelia* spp.;
- Drainage lines characterised by *Ficus sycomorus*, *Spirostachys africana* and *D. cinerea.*

Soils in uplands and seeplines are coarse, reddish and sandy. Clay soils occur on midslopes, footslopes and in drainage lines.

Several thatch grass species (*Hyparrhenia* spp.) occur throughout this ecozone. Sour grass species such as *Aristida congesta* susp *congesta*, *Heteropogon contorsus*, *Hyparrhenia hirta* and *Pogonarthria squarrosa* dominate the ecozone. The Ecozone is dominated by tree species such as *Terminalia sericea* and *Dichrostachys cinerea*.

3.4.3 C: Malelane Mountain Bushveld (Gertenbach 1983; Venter & Gertenbach 1986)

This ecozone also occurs on Granite and Gneiss. Slope elements and associated woody plants occurring in this ecozone include:

- Rocky outcrops characterised by *F. abutilifolia* and *K. wilmsii*;
- Crests characterised by various *Combretum* spp.;
- Midslopes characterised by various *Combretum* spp.;
- Footslopes characterised by *E. divinorum* and *Adenium multiflorum*;
- Drainage lines characterised by *D. mespiliformis*, *S. africana* and *Phoenix reclinata.*

Soils on crests, midslopes and footslopes are predominantly coarse, reddish and sandy. Clay soils occur on footslopes and in drainage lines.

Granite outcrops and low mountains occur throughout this ecozone.

3.4.4 D: Sabi/Crocodile Thorn Thickets (Gertenbach 1983; Venter & Gertenbach 1986)

This ecozone occurs on Granite and Gneiss. Slope elements and associated woody plants occurring in this ecozone include:

- Crests characterised by various *Combretum* spp., *S. nigrescens*, *B. maughamii* and *S. birrea*;
- Seeplines characterised by *T. sericea*;
- Midslopes characterised by various *Senegalia* spp. and *Vachelia* spp, *Philenoptera violacea* and *D. cinerea*;
- Footslopes characterised by *E. divinorum* and *C. imberbe*;
- Drainage lines characterised by *S. africana*, *F. sycomorus* and *Kigelia africana*.

Soils on crests and in seeplines are sandy. Clay soils occur on midslopes, footslopes and in drainage lines.

Dolerite and rolling granite plains with shallow sandy soils on crests are characteristic features for this ecozone.

3.4.5 E: Thorn Veld (Gertenbach 1983; Venter & Gertenbach 1986)

This ecozone occurs on Gabbro. Slope elements and associated woody plants occurring in this ecozone include:

- Plains characterised by *Pterocarpus rotundifolius*, *Ziziphus mucronata*, *S. birrea* and *S. nigrescens*;
- Drainage lines characterised by *D. mespiliformis*, *F. sycomorus* and *E. divinorum.*

Dark clay soils predominate on plains and in drainage lines.

This ecozone is characterized by flat southern basalt and gabbro plains containing red clay soils.

3.5 Fauna

The different Ecozones found in the study area with their associated vegetation (refer section 3.4 above) creates a variety of habitats which support a rich diversity of animal species.

Common large mammal species found in the southwestern region of KNP include Elephant (*Loxodonta africana*)*,* White Rhinoceros (*Ceratotherium simum*)*,* Black Rhinoceros (*Diceros bicornis*)*,* Buffalo (*Syncerus caffer*)*, Giraffe* (*Giraffa camelopardalis*)*,* Burchell's Zebra (*Equus burchelli*)*,* Blue Wildebeest (*Connochaetes taurinus*)*, Kudu* (*Tragelaphus strepsiceros*)*,* Waterbuck (*Kobus ellipsiprymnus*)*,* Hippopotamus (*Hippopotamus amphibious*), Lion (*Panthera leo*)*,* Leopard (*Panthera pardus*)*,* Cheetah (*Acinonyx jubatus*)*,* Spotted Hyena (*Crocuta crocuta*), and African Wild Dog (*Lycaeon pictus*). Several small ungulate, small mammal, reptile, amphibian, bird, fish and insect species are also present throughout the region.

Various common birds found in the study area include the endangered Southern Ground Hornbill (*Bucorvus leadbeateri*), Kori bustard (*Ardeotis kori*), Saddle billed stork (*Ephippiorhysnchus senegalensis*), the Secretary bird (*Sagittarius serpentarius*), Ostrich (*Struthio camelus*), Black Bellied Bustard (*Eupodotis melanogaster*), Marabou stork (*Leptoptilos crumenifer*), Red Crested Korhaan (*Eupodotis ruficrista*), Swainson's spur fowl (*Francolinus swainsonii*), Natal spur fowl (*Francolinus natalensis*), Crested Francolin (*Francolinus sephaena*), Coqui Francolin (*Francolunus coqui*) and Helmeted Gunea fowl (*Numida meleagris*).

Owl species such as the Marsh Owl (*Asio capensis*), Spotted Eagle Owl (*Bubo africanus*), White-faced Owl (*Ptilopsus granti*), African Scops Owl (*Otus senegalensis*), Pearl spotted Owlet (*Glaucidium perlatum*), Barn Owl (*Tyto alba*), African Barred Owl (*Glaucidium capense*) and Verreaux's Eagle Owl (*Bubo lacteus*) are also present in the study area.

Birds of prey such as Martial Eagle (*Polemaetus bellicosuss*), Brown Snake Eagle (Circaetus *inereus*), Atelier Eagle (*Terathopius ecaudatus*), African Hawk Eagle (*Hieraaetus spilogaste*r), African Fish Eagle (Haliaeetus vocifer), African Harrier Hawk (*Polyboroides typus*), Gabar Goshawk (*Micronisus gabar*), Black winged Kite (*Elanus caeruleus*) and Tawny Eagle (*Aquila rapax*) are also regularly observed.

Vulture species include the Lappet Faced Vulture (*Torgos tracheliotus*), Hooded Vulture (*Necrosyrtes monachus*), white backed Vulture (*Gyps africanus*), White Headed Vulture (*Aegypius occipitalis*) and the vagrant Egyptian Vulture (*Neophron* P*ercnopterus*).

Artificial water points in the study area attract a variety of water birds such as White-faced Duck (*Dendrocygna viduata),* Knob-billed Duck (*Sarkidiornis melanotos*), African Darter (*Anhinga rufa*), Egyptian Goose (*Alopochen aegyptiaca)*, African Jacana (*Actophilornis africanus*), Black Crake (*Amaurornis flavirostris*), Rebilled teal (*Anas erythrorhyncha*), Green Backed Heron (*Butorides rufiventris*), Goliath Heron (*Ardea goliath*), Little Egret (*Egretta garzetta*), Grey Heron (*Ardea cinerea*), Spur winged Goose (*Plectropterus gambensis*), Hamerkop (*Scopus umbretta),* WaterThick-knee (*Burhinus vermiculatus*), Common sandpiper (*Tringa hypoleucos*), Common Greenshank (*Tringa nebularia*), Giant Kingfisher (*Ceryle maxima*) and Pied Kingfisher (*Ceryle rudis*).

Summer migrant birds include the Woodland Kingfisher (*Halcyon senegalensis*), Armour Falcon (*Falco amurensis*), White Stork (*Ciconia ciconia*), Grey Headed King Fisher (*Halcyon leucocephala*) and Little Bee-Eater (*Merops apiaster*).

Common butterflies include the Yellow Pansy (*Junonia hierta*), Blue Pansy (*Junonia oenone*), Common Diadem (*Hypolimnas misippus*), African Monarch (*Danaus chrysippus*), Painted Lady (*Vanessa cardui*), Brown-Veined White (*Belonois aurota*)*,* Broad-Bordered Grass Yellow (*Eurema brigitta*)*,* Citrus Swallowtail (*Papilio demodocus*)*,* Green banded Swallowtail (*Papilio nireus*), Scarlet Tip (*Colotis danae*)*,* Red Tip (*Colotis antevippe*) and Garden Acraea (*Acraea horta*).

A variety of spiders commonly encountered in the study area includes the Kite Spider (*Gasterracantha* spp.), Banded-Legged Orb-web Spider (*Nephila senegalensis*), Dew-Drop Spider (*Argyrodes* spp.), Common Baboon Spider (*Harpactira* spp.) and the venomous Black Button Spider (*Latrodectus renivulvatus*).

Reptiles occurring in the study area include the Nile Crocodile (*Crocodylys niloticus*), Serrated Hinged Terrapin (*Pelusios sinuatus*), Leopard Tortoise (*Stigmochelys pardalis*), Hinged-back Tortoise (*Kinixys spekii*), Water Monitor (*Varanus niloticus*) and Rock Monitor *(Varanus albigularis*). Venomous snakes include the Black Mamba (*Dendroaspis polylepis*), Mozambique Spitting Cobra (*Naja mossambica*), Puff Adder (*Bitis arietans*), Boomslang (*Dispholidus typus*), Snouted Cobra (*Naja annulifera*), Twig Snake (*Thelotornis capensis*), Stripe-belied Sand Snake (*Psammophis subtaeniatus*) while non-venomous snakes include the Southern African Rock Python (*Python natalensis*).

Amphibians found in the study area include the Mottled Olive Toad (*Bufo garmani*), Foam-nest Frog (*Chiromantis xeampelina*), Banded Rubber Frog (*Phrynomantis bifasciaus*), Bubbling Kassina (*Kassina senegalensis*), Giant Bullfrog (*Pyxicephalus adsprsus*), Bushveld Rain Frog (*Breviceps adspersus*) and the Common Platanna (*Xenopus laevis*).

3.6 Climate

The rainy season in the Kruger National Park starts in September/October and last until March/April (Venter & Gertenbach 1986). The dry winter season has very little rainfall, and occasionally no rainfall.

Mean rainfall and temperature figures for two prominent rest camps within the study area are as follows (Kruger National Park Scientific Services 2022):

- Skukuza - mean summer rainfall is 91.3 mm and mean summer temperature is 26.2 ^{o}C. Mean winter rainfall is 8.0 mm and mean winter temperature is 16.5 ^{o}C. The lowest mean rainfall of 7 mm is for August, and the lowest mean temperature of 5.6 ^{o}C is for May. The highest mean rainfall of 96 mm is for January, and the highest mean temperature of 31.3 ^{o}C is for March.
- Pretoriuskop – mean summer rainfall is 116 mm and temperature is 24.3 ^{o}C. Mean winter rainfall is 10.3 mm and temperature is 17.2 ^{o}C. The lowest mean rainfall of 9 mm and the lowest mean temperature of 9.3 ^{o}C is for June. The highest mean rainfall of 129 mm and the highest mean temperature of 30.6 ^{o}C is for January.

Rainfall and temperature for the study period (March 2019 to Feb 2020) is depicted in Figure 3.6. Rainfall data is an average of data collected from the Skukuza rest camp, which is the closest rest camp to the study area. Temperature data is also for Skukuza rest camp.

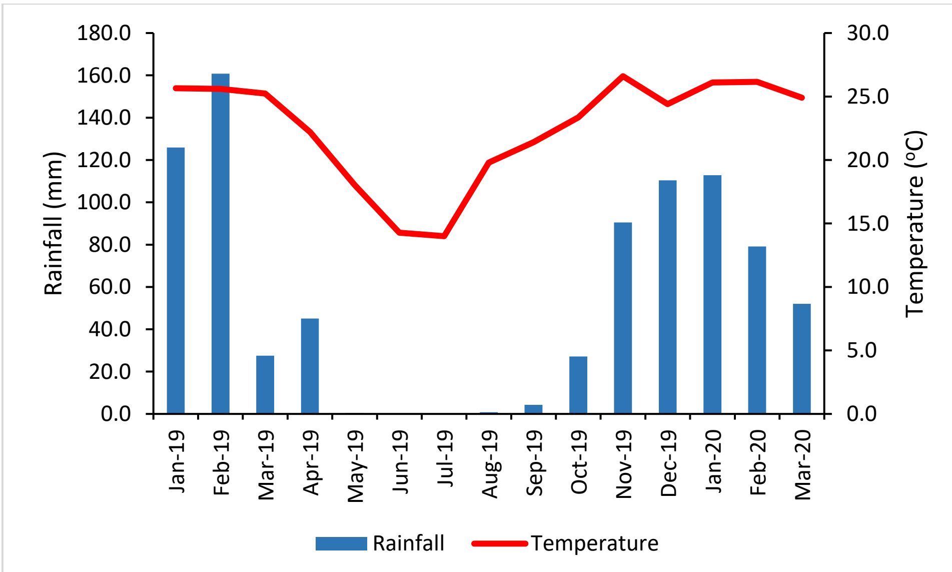

Figure 3.6. Climatogram for the study area showing mean rainfall, temperature and photoperiod for the study period (rainfall and temperature data are for Skukuza rest camp).

3.7 Study subjects

For this study seven tortoises were captured and fitted with transmitters. The tortoises were captured along the 'ring route' between Pretoriuskop rest camp, Skukuza rest camp and Afsaal picnic spot (Figure 3.7).

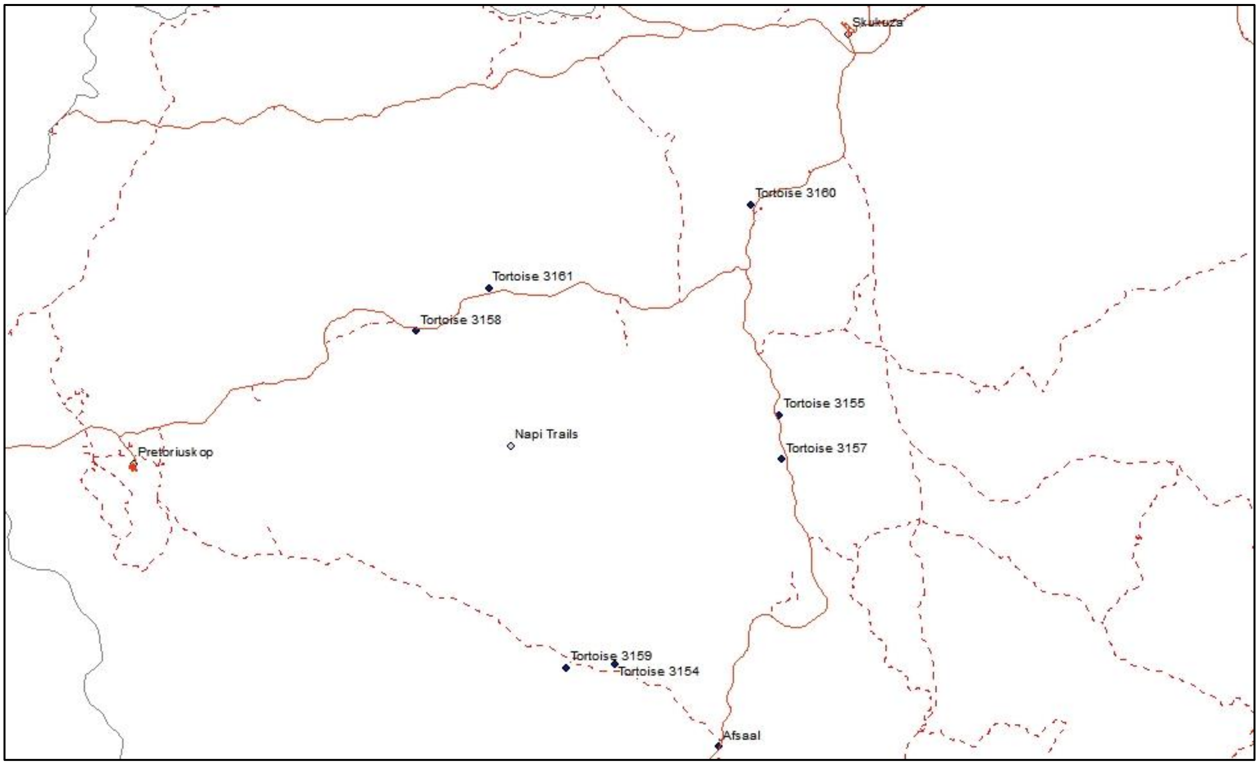

Figure 3.7. Rudimentary map showing locations of the Pretoriuskop and Skukuza rest camps, the Afsaal picnic spot and the seven tortoises that were used for this study**.**

Details pertaining to the seven study subjects are shown in Table 3.1. While a concerted effort was made to have an even distribution of males and females, we were only able to find two males that met the weight requirements (Millspaugh & Marzluff 2001). Random tortoises located in the study area after the study started were also identified and measured but were not used for any home range or movement analyses as they were not fitted with transmitters (Appendix C).

Table 3.1. Study subject table showing ID and various measurements recorded for the study tortoises.

Tortoise ID	Sex (M/F)	Mass (g)	Straight Carapace Length (mm)	Shell Width (mm)	Shell Height (mm)	Plastron Length (mm)	Curved Carapace Length (mm)
3159-1	F	5500.0	295.5	209.1	171.6	233.2	428.0
3160-2	M	1301.0	189.4	124.0	94.4	162.0	260.0
3154-3	F	3500.0	261.5	190.5	151.6	221.2	382.0
3157-4	F	3800.0	242.6	169.5	136.0	207.9	340.0
3155-5	F	3850.0	267.7	191.5	159.2	222.5	380.0
3161-6	M	5500.0	196.0	131.0	142.0	169.0	267.0
3158-7	F	920.0	171.0	118.0	96.0	148.0	238.0

CHAPTER 4

METHODOLOGY

The study animals were spread over the area where the study route followed the road from Pretoriuskop to Skukuza to Afsaal and back to Pretoriuskop as shown in Figure 3.7.

4.1 Radiotelemetry

UHF GPS tracking data loggers and VHF radio-transmitters were attached to seven *S. pardalis* individuals. Data was collected over 12 months to include both the warm wet and the cold dry season. According Millspaugh & Marzluff (2001), the transmitters or devices attached to a tortoise should not exceed 10% of its body mass, preferably no more than 8%. The combined weight of both the UHF and VHF components was 52 g. Therefore, only animals weighing more than the minimum threshold of 550 g were fitted with tracking equipment.

The following procedure was followed when attaching the transmitters:

1. Prior to attachment, the transmitters were tested to confirm that they worked and to select the best UHF/VHF frequencies for the specific habitat.
2. The UHF and VHF components were pre-positioned and secured with masking tape between the first left or first right costal and vertebral scutes of the tortoise's carapace, as flush to the carapace as possible. The tortoise was then turned on its back to make sure that it could right itself should it by chance fall onto its back when out in the field. If the tortoise could not right itself, the transmitters were moved, and the procedure was repeated until the animal could right itself (Figure 4.1).
3. The transmitters were attached with a soft, pliable, non-toxic glue (Sugru Mouldable Glue) in the pre-determined positions. Care was taken to ensure that no opening was left between the transmitter and carapace where vegetation could get stuck.

4. Finally, the transmitters were rechecked for proper operation before the tortoise was released at the exact GPS position where it was found.

Figure 4.1. A leopard tortoise (*Stigmochelys pardalis*) fitted with VHF and UHF transmitters for tracking and GPS data collection respectively.

4.2 Capturing, measuring, tracking, and collecting data for *S. pardalis*

Tortoise selection was done by driving (15 to 20 km/h) along the H1-1 road between Pretoriuskop and Skukuza, the H3 road between Skukuza and Afsaal, and the H2-2 road between Afsaal and Pretoriuskop. This route was traversed three times a day over a period of 14 days to locate the study tortoises. When a tortoise was encountered, it was immediately weighed (before it urinated or defecated, which would reduce its mass) and if it met the minimum weight requirements, its location was recorded using a Garmin 12 XL handheld GPS. A Swiss made Pesola® spring balance scale was used to weigh the tortoises to an accuracy of 0.1 grams. Tortoises meeting the minimum weight requirements were marked/numbered on one of their posterior scutes with a semi-permanent pen to distinguish them from other individuals caught on that day. All tortoises captured were either processed the same day or if caught too late during the day, were kept overnight in an holding pen measuring 4 x 4 m at the Pretoriuskop rest camp. The pen had a 30 cm high wire mesh apron to prevent tortoises from escaping the holding area. Captured animals were transported to the Pretoriuskop holding pen in plastic containers (650 mm long x 385 mm wide x 210 mm high) lined with moist grass to prevent dehydration. Captured animals were measured, marginal scutes were filed to permanently mark them using the Honegger system (Honegger 1979), and transmitters were attached. After this had been done, each tortoise was returned to the exact locality where it was found.

Morphometric data were collected from all captured tortoises following various sources. (Milton 1992, Kerley et al. 1999, Mason et al. 1999, Mason et al. 2000, Kabigumila 2001, Luiselli 2003, Luiselli 2006, and McMaster & Downs 2009). Vegetation variables were collected according to Chapman et al. (2011) and Bonham (2013). Environmental data collection was based on the recommendations of Hill et al. (2005), Chapman et al. (2011), and Greenacre & Primicerio (2013), while spatio-temporal data was collected according to Fortin and Dale (2006).

Each tortoise with a transmitter was located once a month for data collection using a Telonics TR-4 receiver and a Communications Specialists Inc. receiver with a four-element Yagis flexible antenna and a six-element foldable aluminum antenna. Data were downloaded from GPS units on the tortoises using an Africa Wildlife and Tracking transceiver that interfaced with the African Wildlife and Tracking (AWT) software application. Downloaded data were exported from the software application into Ms Excel format for further processing and analysis.

Figure 4.2. The researcher locating tortoises in the field with a four element Yagis antenna and Communications Specialists Inc. receiver.

The following field data were collected from all tortoises captured for this study (refer Appendix A).

- **Date** of recording.
- **Time** of recording,
- **Species** in this study only *Stigmochelys pardalis* was looked at – the data collection sheet was a standard sheet used for other related tortoise studies and was not modified,
- **ID** was the unique numeric sequential code/number allocated to each individual animal by the researcher,

- **VHF freq** was the unique VHF frequency of the transmitter fitted to the tortoise and that matched to the AWT no allocated by the manufacturer (African Wildlife tracking 2019),
- **AWT** no was the unique number allocated by the manufacturer (African Wildlife Tracking 2019) to the specific UHF and VHF components fitted onto the tortoise,
- **Cohort** was whether the animal was a male or female. Males and Females were distinguished based on tail length, the shape of the supracaudal scute and the presence or absence of a plastral concavity,
- **Straight-line carapace length (SCL)** measured from the tip of the front of the shell where the neck retracts to the bulge of the supracaudal scute – measured with Mitutoyo 300 mm vernier callipers,
- **Shell width (SW)** measured across the seam of the 6th and 7th marginal scutes and taken with Mitutoyo 300 mm vernier callipers,
- **Shell height (SH)** measured across the plastron and 3rd vertebral scute, taken with Mitutoyo 300 mm vernier callipers,
- **Plastron length (PL)** measured from the notch of the gular to the notch of the anal scutes, taken with Mitutoyo 300 mm Vernier Callipers,
- **Curved carapace length (CCL)** measured with a pliable tape measure from the tip of the front of the shell where the neck retracts to the tip of the supracaudal scute,
- **Latitude** was recorded using a Garmin Etrex 10 handheld GPS unit (manufactured by Garmin Ltd, Olathe, Kansas, United states),
- **Longitude** was recorded using a Garmin Etrex 10 handheld GPS unit (manufactured by Garmin Ltd, Olathe, Kansas, United States),
- **Mass** measurements of tortoises were restricted in the dry season due to the possibility that they may urinate and lose valuable water stores, taken using a Pesola® spring balance scale,
- **Sex** was recorded on capture. Males and females were distinguished based on tail length, the shape of the supracaudal scute and the presence or absence of plastral concavity,

- **Remarks** any random comments or notes about the animal and/or the environment it occurred in was recoded in this field i.e., scars, noticeable markings, close to a dam/water, evidence of previous fires etc.

The following additional habitat information was recorded whenever a study animal with a transmitter was located (refer to Appendix B).

- **Date** of recording,
- **Time** of recording,
- **Species** was *stigmochelys pardalis* (as mentioned previously, for this study only *Stigmochelys pardalis* was looked at),
- **ID** was the unique numeric sequential code/number allocated to each individual by the researcher,
- **Weathe**r**,** a visual observation of the sky was made, and general weather conditions were recorded as either sun (no clouds) or percentage cloud cover if cloudy (estimated cloud cover was based on how much of the sky was covered in cloud using increments of 10%), and rain (if it was raining),
- **Resting/active,** codes for recording this parameter include Rr for resting in a refuge, Asn for when the animal was active in the sun, and Asd for when the was active in shade,
- **Refuge,** related to the previous variable and indicates the type of refuge the tortoise was resting in i.e., G for grass, Sh for under Shrubs, Cr for in a rocky crevice, and Bu for in a burrow,
- **Active behavior** refers to what the animal was doing while being observed (this data was collected once the animal resumed its normal activity after being alerted to the presence of the observer) and included the active behavior categories basking (B), walking (W), feeding (F), males fighting (Fi), courtship (C), and nesting (N),
- **Food type** was linked to the feeding (F) category and was for recording what the tortoise consumed if it was observed feeding. Food type categories included grass (G), shrubs (Sh), herbs (H), fungi (Fu), moss (M), insects (I), bones (B), faeces (F), and soil (S),

- **Food species** were recorded for the food types consumed where possible and identifiable,
- **Dominant vegetation,** in a 5 m radius around the tortoise being monitored, the dominant vegetation type was recorded as either grasses (G), shrubs (Sh), herbs (H) or trees (T),
- **% Vegetation cover,** in a 5 m radius around the tortoise being monitored the percentage of vegetation cover where there was no visible soil/ground was recorded in 10% increments i.e., if half of the area being looked at was covered then a value of 50% was allocated to this variable,
- **Mean vegetation height (cm),** in a 5 m radius around the tortoise being monitored the mean height of vegetation was recorded as one of three categories, low < 30 cm, medium 30 to 100 cm and high >100 cm,
- **% Rocky cover**, in a 5 m radius around the tortoise being monitored, the amount of rocks covering the area was estimated as a percentage,
- **Latitude** was recorded using a Garmin Etrex 10 handheld GPS unit (manufactured by Garmin Ltd, Olathe, Kansas, United States),
- **Longitude** was recorded using a Garmin Etrex 10 handheld GPS unit (manufactured by Garmin Ltd, Olathe, Kansas, United States).

The transmitters fitted onto the tortoises were able to collect temperature and rate of travel data.

Data were also collected from all non-transmittered *S. pardalis* that were encountered opportunistically. Weight, shell measurements, habitat characteristics, and GPS location were recorded for each animal (Appendix C). These tortoises were also permanently marked using the Honegger system (Honegger 1979). This information will add to the current knowledge about population structure and habitat use of the species in the study area.

Scute filing of tortoises to mark them permanently is a standard procedure used by tortoise biologists when doing population studies or when there is a need to identify individuals (Loehr et al. 2006; Keswick & Hofmeyr 2013). A triangular-shaped file was used to make notches into the marginal scutes according to the Honegger system (Appendix D). The scutes were filed deep enough so that the number allocated to the tortoise can be read even if a dead tortoise is found with no scutes on the shell.

At the end of the study, all working transmitters attached to tortoises were removed, and the tortoises were released unharmed.

4.3 Activity and habitat analyses

The daily distances travelled by all study tortoises during the warm wet and cold dry seasons was calculated to determine the mean daily travel distance per season. For the daily movement patterns, the GPS locations that were collected for all tortoises were sorted by date/time. A day was defined as the 24-hour period starting at 00:00 on a particular date and ending after 23:59 on the same date.

To compare movements and distances travelled in a particular day, each day was split into the following time periods:

- Night	From 00:00 to 05:59 and from 18:00 to 23:59
- Morning	From 06:00 to 11:59
- Afternoon	From 12:00 to 17:59.

For thermoregulatory related movements and distances travelled, each day was split into the hottest and coldest periods using mean temperature data to indicate these periods for the study area:

- Cold	From 02:00 to 06:00
- Hot	From 12:00 to 16:00

Since GPS locations were collected at five hourly intervals (on the hour) that incremented daily i.e., each day the times incremented by one hour due to the odd (five) hourly data download protocol used, by the end of the study data was collected spanning all hours of a day.

Chronological GPS locations/points for a particular day were joined together into ‘route’ segments/arcs that were collectively combined into a day range for that day. The route segments for a day were added into the various periods if more than three hours of any five-hour route fell into a particular time period.

At the end of the study period, all GPS waypoints for the various tortoises were extracted and analysed for seasonal home range size determination and daily seasonal distances travelled analyses. Mean daily distances were calculated for the warm wet season (1 November to 30 April) and the cold dry season (1 May to 31 October) using QGIS and ARCMAP 10.2 (Khan & Mohihiuddin 2018).

4.4 Statistical analyses

Home range size was calculated from daily data collected over ~12 months and included both the cold dry and warm wet seasons - the Animal Movement Extension to ArcView was used to calculate displacement of individuals between successive locations, and to estimate annual home range sizes, as well as seasonal home range utilization. We estimated home range sizes in hectares using both minimum convex polygons and 95% and 50% fixed kernel estimates. Seasonal habitat parameters for all telemetered tortoises, age/size categories and sexes were tabulated and graphed using histograms for visual comparison.

Relationships between home range size and rainfall, and home range size and tortoise weight were also assessed using Spearman correlation tests. Using temperature data collected by the transmitters, we investigated whether there was a relationship between temperature and daily movements.

Microsoft Excell and the SPSS statistics software program was used to test for normality and to analyse data (Lee & Peters 2016).

CHAPTER 5

HOME RANGE CHARACTERISTICS AND UTILISATION

5.1 Introduction

The term “home range” is described as the area traversed by individuals while they perform their normal daily activities, which include food gathering, water acquisition, mating and caring for their young (Burt 1943; Apps 1992; Baard 1995, Powell & Mitchell 2012). Animal home ranges must be sufficiently large to cater for the animals nutritional and breeding requirements (Carnaby 2006). A home range is usually bigger than a territory since it includes the entire area that is required by the animal for its survival (Carnaby 2006; Gaustestad 2011). Home ranges are often too big to defend, unlike territories that can be patrolled and marked using urine, dung and various glandular secretions (Carnaby 2006). Territories are normally defended if the resources they contain are scarce or rich in nutrients (Apps 1992). Often home ranges contain overlapping territories that are marked and protected, providing information about the presence of territoriality to other animals moving through or living in the area (Carnaby 2006). According to Apps (1992), if the resources within an area are poor, unpalatable and scattered or unpredictably distributed, it will not be defended as it is not worth defending in terms of the energy required to do so, especially if other animals have no interest in the resources.

In areas where resources are limited, the sizes of home ranges are larger than in areas where resources are abundant (Rose & Judd 1975). Generally, the size of a tortoise’s home range depends on the available resources in the home range, which needs to be enough to ensure the survival of the animal during times when resource availability is at its lowest (Bertram 1979; Geffen & Mendelssohn 1988 1989; Lambiris et al. 1989). It has been suggested that home range sizes are also influenced by the type of habitat they occur in (Rose & Judd 1975). (According to Geffen & Mendelssohn (1988, 1989) and

Diemar (1992), tortoise species that live in areas with limited rainfall have larger home ranges compared to those found in temperate areas due to the differences in habitat quality. Studies have shown that *Stigmochelys pardalis* roam in the same limited area during the spring and winter, often using a single refuge site (McMaster & Downs 2006). Studies conducted in Zimbabwe at Sengwe investigated the home ranges and distances moved by *S. pardalis* and found that their home ranges were ~100 ha in size (Hailey & Coulson 1996). A study by Mason & Weatherby (1995) suggests that home ranges for female *S. pardalis* are larger compared to those of males in bushveld.

In this chapter the relationships between tortoise weight and home range size, and the relationship between rainfall and home range size was studied. Using GPS data, the home ranges were mapped and their sizes in hectares calculated.

5.2 Methods

Several methods can be used to calculate home ranges, including the grid cell approach, kernel density estimators (KDE) and low convex hull (LoCoH) (Tremain1027). For this study, the Minimum Convex Polygon (MCP) script/algorithm in Arcmap 10.2 (Khan & Mohihiuddin 2018) was used to determine home range sizes using the GPS locations stored on the transmitters of the study tortoises. Our justification for using MCP is that this method is what many other researchers use (Tremaine 2017), and for us to be able to compare our findings to theirs, we need to be consistent and use the same technique.

All home range maps were created to a 0.8 km scale for visual comparison of home range sizes and to prevent perceptual distortion. The transmitters on the study tortoises were preset to record GPS locations at 5-hour intervals. Recorded locations were used to create a series of home range maps using ArcView. Home range sizes were calculated from all daily data collected and included both the cold dry and warm wet seasons - the Animal Movement Extension to ArcView was used to calculate displacement of individuals between successive locations, and to estimate annual home range sizes, as well as seasonal home range utilisation.

Relationships between rainfall and home range size, and between tortoise weight and home range size were calculated using Spearman correlation tests.

5.3 Results

Due to transmitter failure only four of the tortoises produced useful data. Tortoise 3154 was tracked for four months, and tortoises 3159, 3160, and 3157 were tracked for six months per season. The results in this chapter are based on data from these four tortoises. Data from all other tortoises are shown in Appendix E.

5.3.1 Tortoise home range sizes and descriptions

5.3.1.1 Tortoise 3159

Tortoise 3159 lived along the road between Pretoriuskop and Afsaal, close to the Afsaal picnic spot. The combined home range size for this tortoise was 45.50 ha and spanned across the road to both the northeast and southwest of the road (Figure 5.1).

The mean vegetation cover in the home range was 48%. The mean height of the shrub and grass layer was 266 cm. There were no rocks or rocky outcrops in the home range.

The dominant woody plant species occurring in the home range were *Combretum apiculatum, Combretum hereroense, Terminalia sericea*, *Diospyros mespiliformis* and *Dischrostachys cinerea.*

Common grass species included *Hyperthelia dissoluta*, *Eragrostis superba, Heteropogon contortus*, *Themeda triandra* and *Enneapogon cenchroides.*

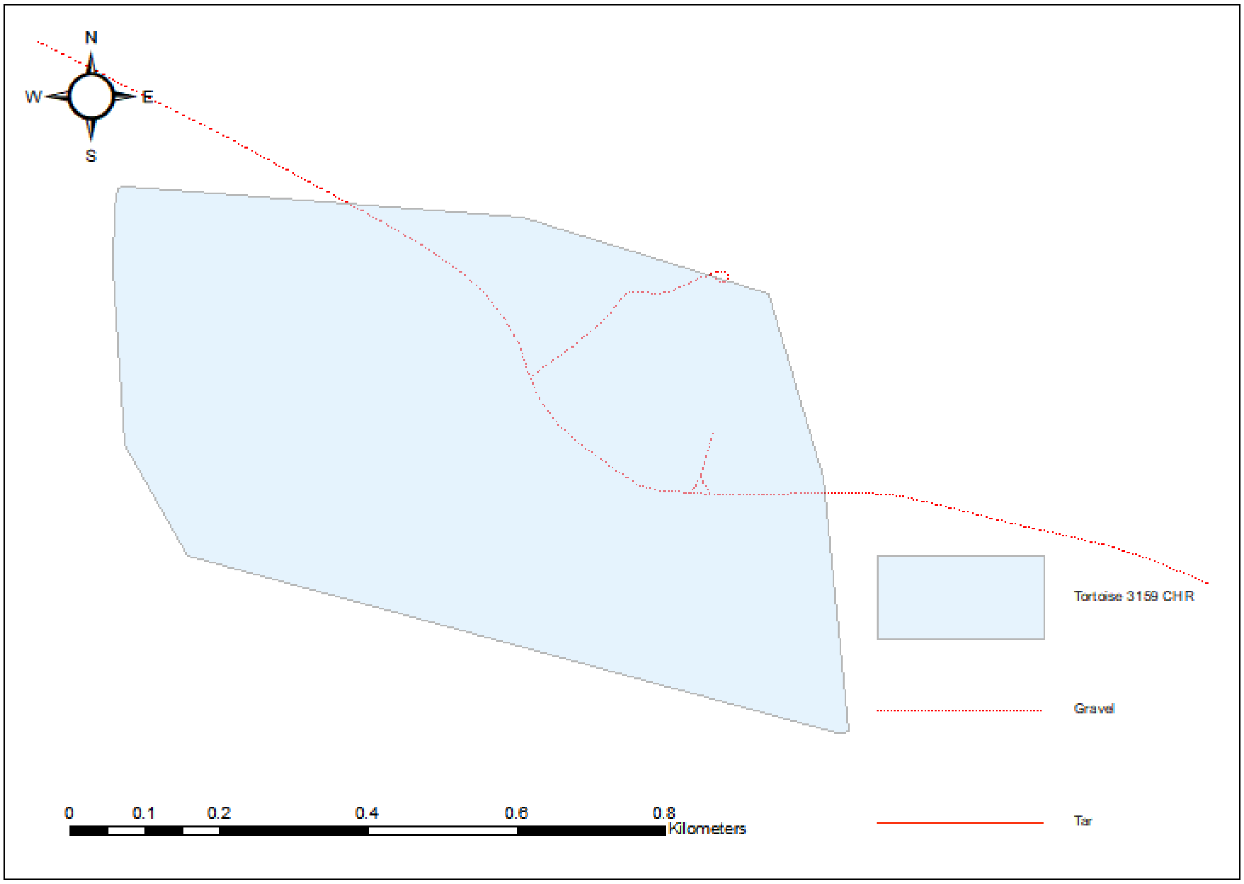

Figure 5.1. Combined home range for tortoise 3159. Home range size was 45.50 ha.

Seasonal home ranges for tortoise 3159 are depicted in Figure 5.2. The warm wet season home range was 45.50 ha in size and the cold dry season home range was 9.04 ha. The cold dry season home range was 19.87% of the combined/wet season home range size.

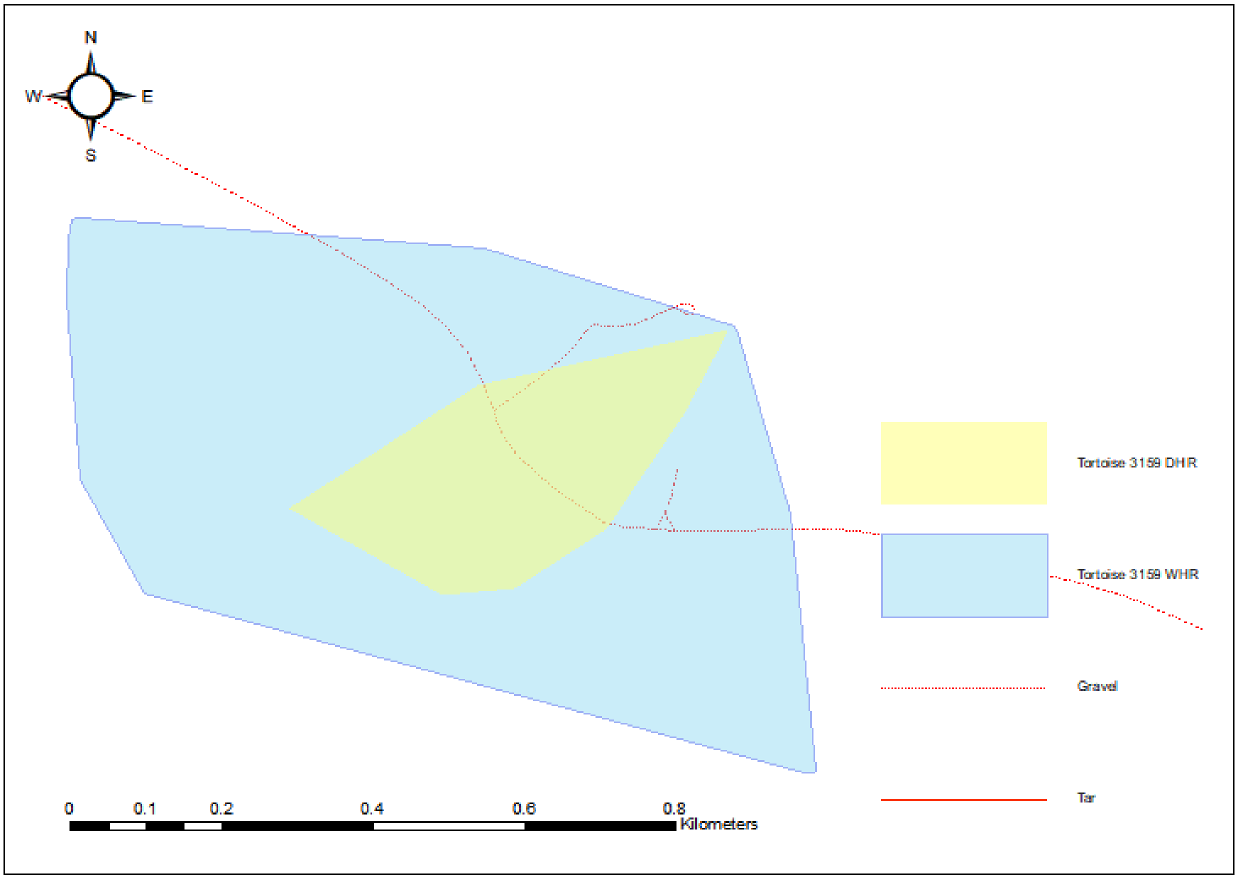

Figure 5.2. Warm wet and cold dry season home ranges for tortoise 3159. The warm wet season home range size was 45.50 ha and dry home range size was 9.04 ha**.**

5.3.1.2 Tortoise 3160

Tortoise 3160 lived along the road between Skukuza and Afsaal, The combined home range size for this tortoise was 29.87 ha and spanned across the road to both the southeast and northwest of the road (Figure 5.3).

The mean vegetation cover in the home range was 86%. The mean height of the shrub and grass layer was 321 cm. There were no rocks or rocky outcrops in the home range.

The dominant woody plant species occurring in the home range were *Combretum appiculatum*, *Combretum zeyheri, Terminalia sericea, Euclea natalensis* and

Dichrostachys cinerea. Common grass species included *Digitaria erianthra*, *Bothriochloa radicans*, *Themeda triandra*, *Panicum maximum* and *Setaria sphacelate.*

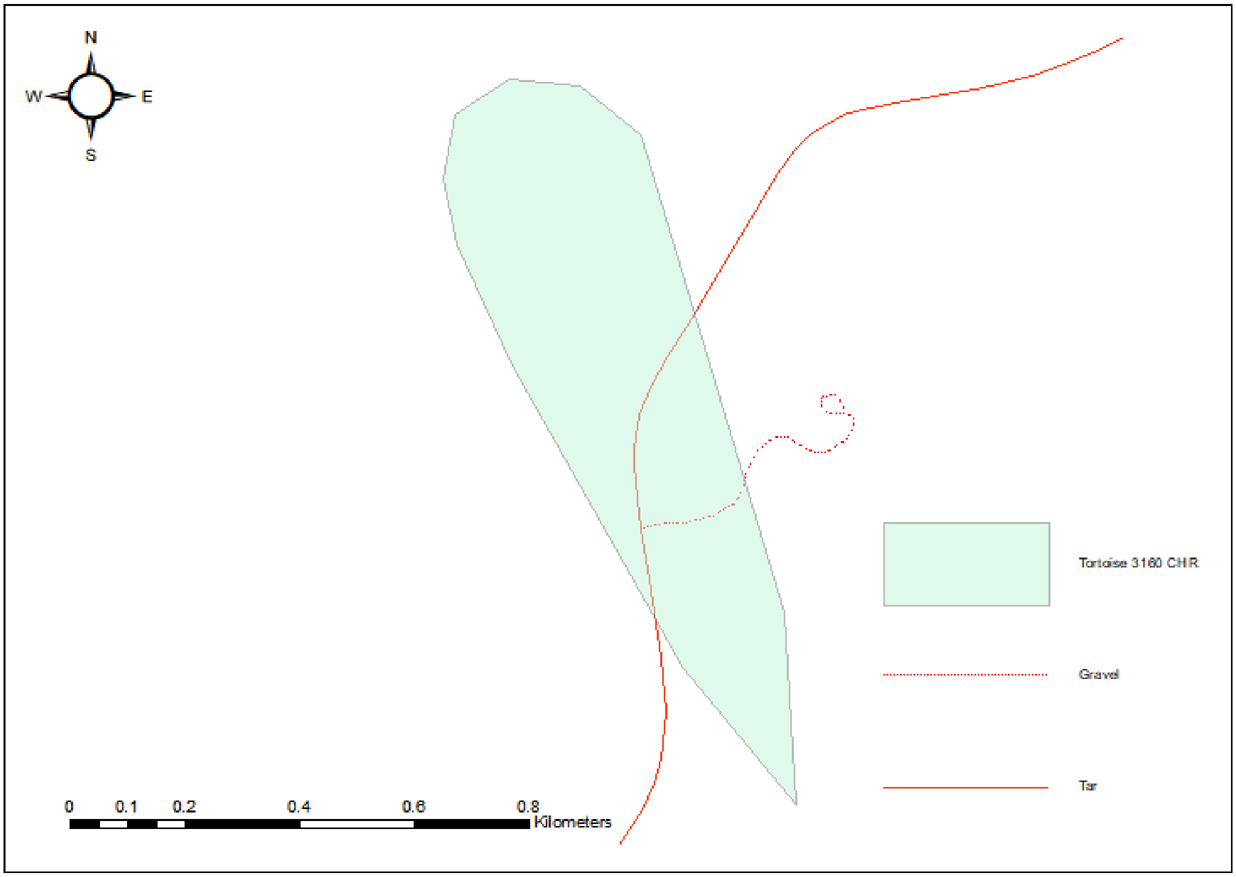

Figure 5.3. Combined home range for tortoise 3160. Home range size was 29.87 ha.

Seasonal home ranges for tortoise 3160 are depicted in Figure 5.4. The warm wet season home range was 29.87 ha in size and the cold dry season home range was 1.03 ha. The dry season home range was only 3.45% of the combined/warm wet season home range size.

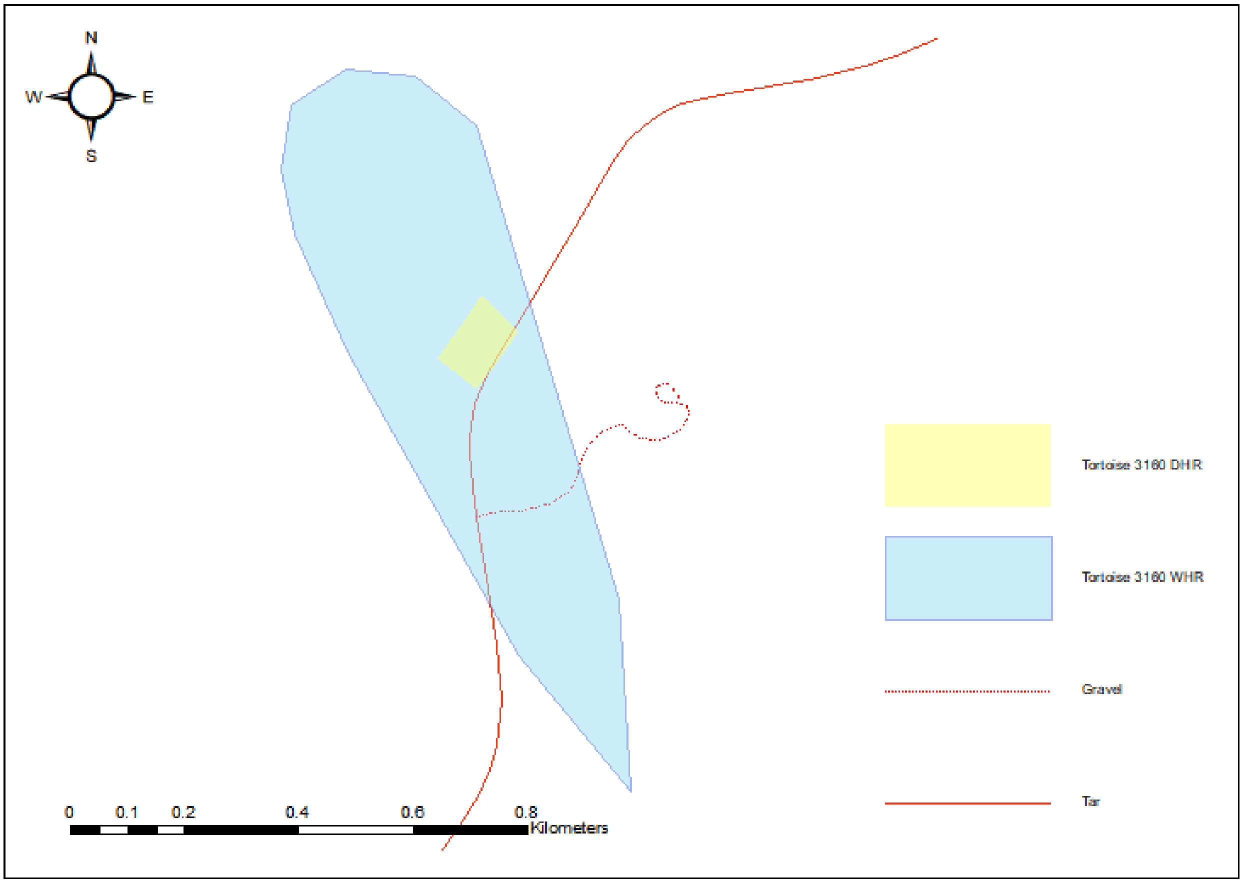

Figure 5.4. The warm wet and cold dry season home ranges for tortoise 3160. The warm wet season home range size was 29.87 ha and cold dry season home range size was 1.03 ha.

5.3.1.3 Tortoise 3154

Tortoise 3154 lived along the road between Pretoriuskop and Afsaal, close to the Afsaal picnic spot. The combined home range size for this tortoise was 21.97 ha and spanned across the road to both the north and south of the road, with the larger portion of the home range being to the north of the road (Figure 5.5).

The mean vegetation cover in the home range was 55%. The mean height of the shrub and grass layer was 75 cm. There were no rocks or rocky outcrops in the home range.

The dominant woody plant species occurring in the home range were *Terminalia sericea*, *Combretum appiculatum* and *Dichrostachys cinerea*. Common grass species included *Eragrostis superba*, *Themeda triandra* and *Heteropogon contortus.*

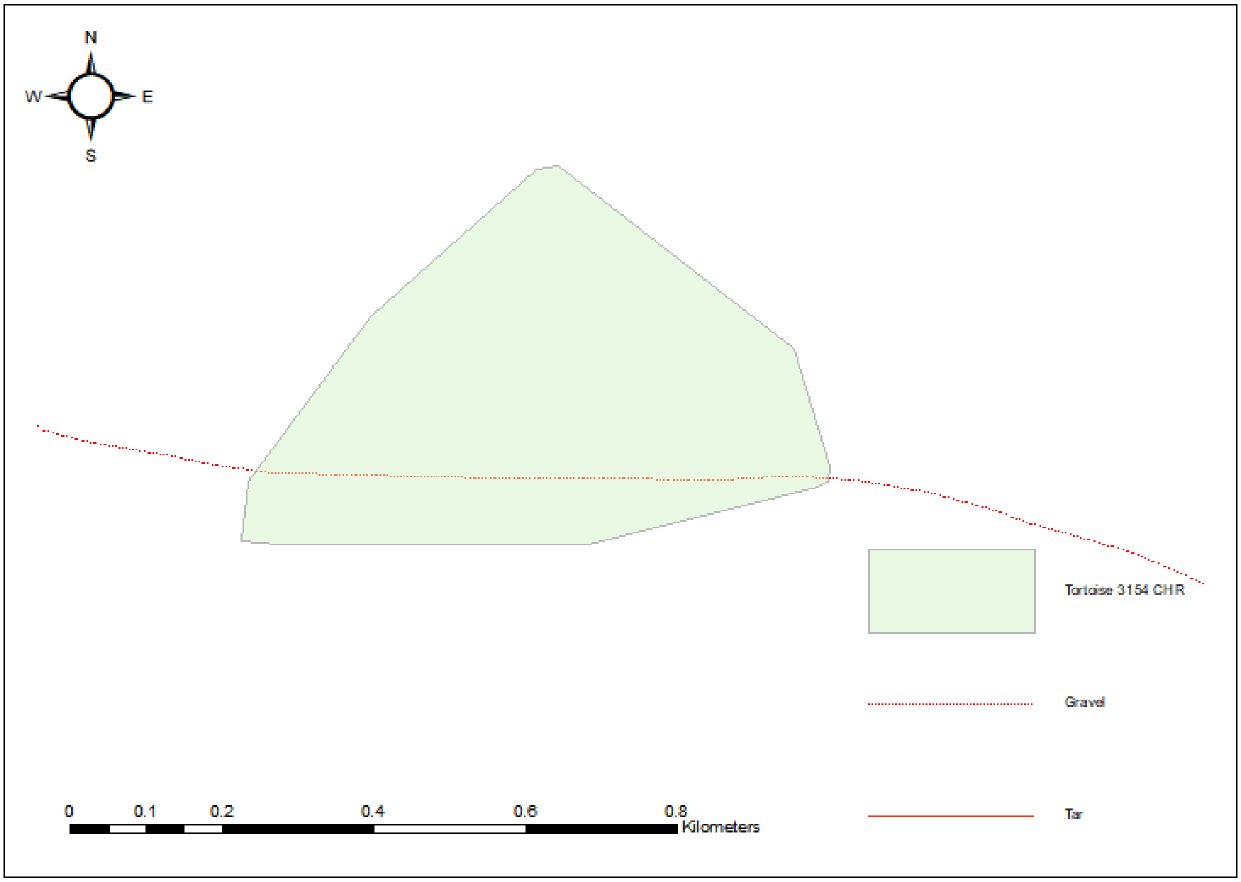

Figure 5.5. Combined home range for tortoise 3154. Home range size was 21.97 ha.

Seasonal home ranges for tortoise 3154 are depicted in Figure 5.6. The warm wet season home range was 16.73 ha in size and the cold dry season home range was 12.73 ha. The cold dry season home range was 57.94% of the combined home range size, and the warm wet season home range size was 76.15% of the combined home range size.

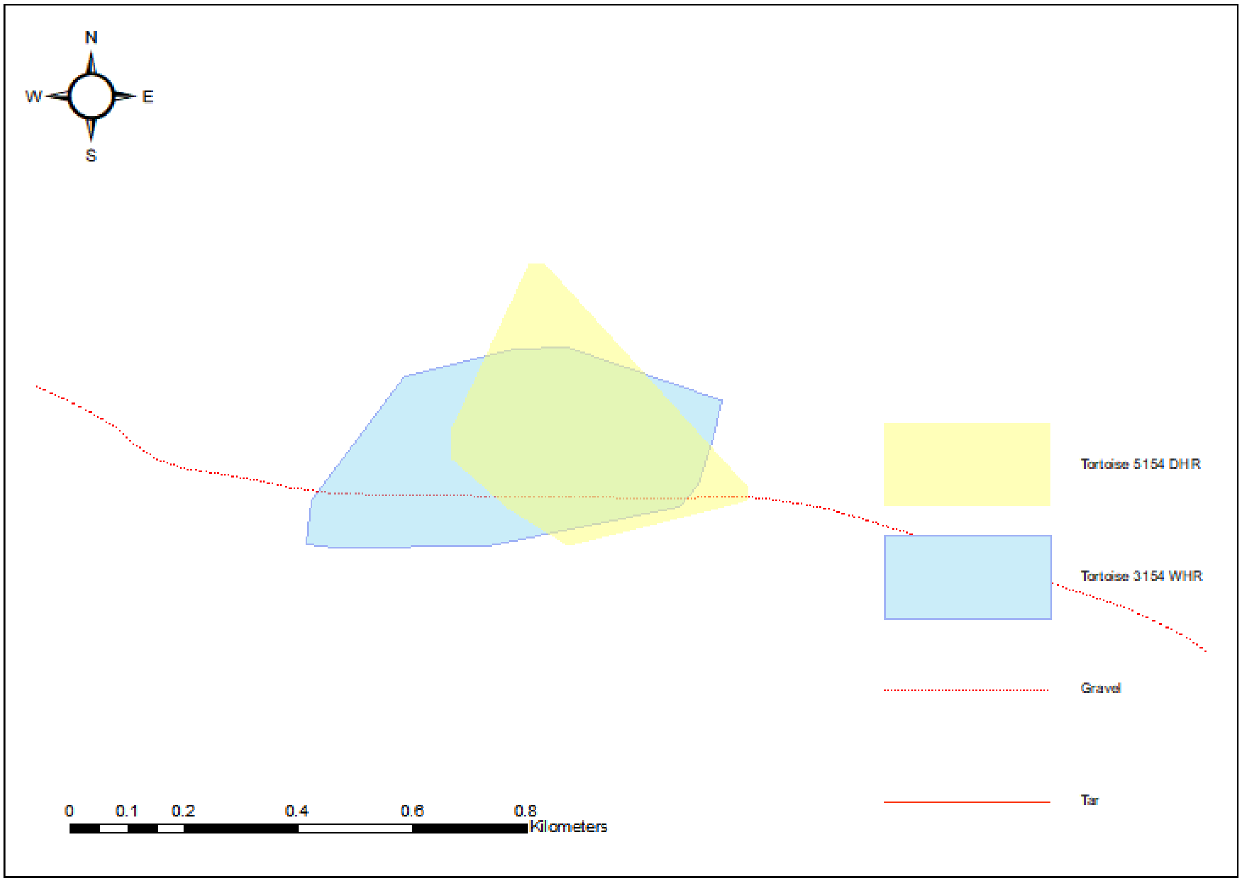

Figure 5.6. The warm wet and cold dry season home ranges for tortoise 3154. The wet season home range size was 16.73 ha and cold dry season home range size was 12.73 ha.

5.3.1.4 Tortoise 3157

Tortoise 3157 lived along the road between Skukuza and Afsaal. The combined home range size for this tortoise was 15.61 ha and spanned across the road to both the east and west of the road, with the larger portion of the home range being on the west side of the road (Figure 5.7).

The mean vegetation cover in the home range was 60%. The mean height of the shrub and grass layer was 321 cm. There were no rocks or rocky outcrops in the home range.

The dominant woody plant species occurring in the home range were *Combretum appiculatum*, *Euclea divinorum* and *Peltophorum africanum*. Common grass species included *Panicum maximum, Eragrostis rigidior, Digitaria erianthra*, *Hetergopogon contortus* and *Pogonothria squarrosa*.

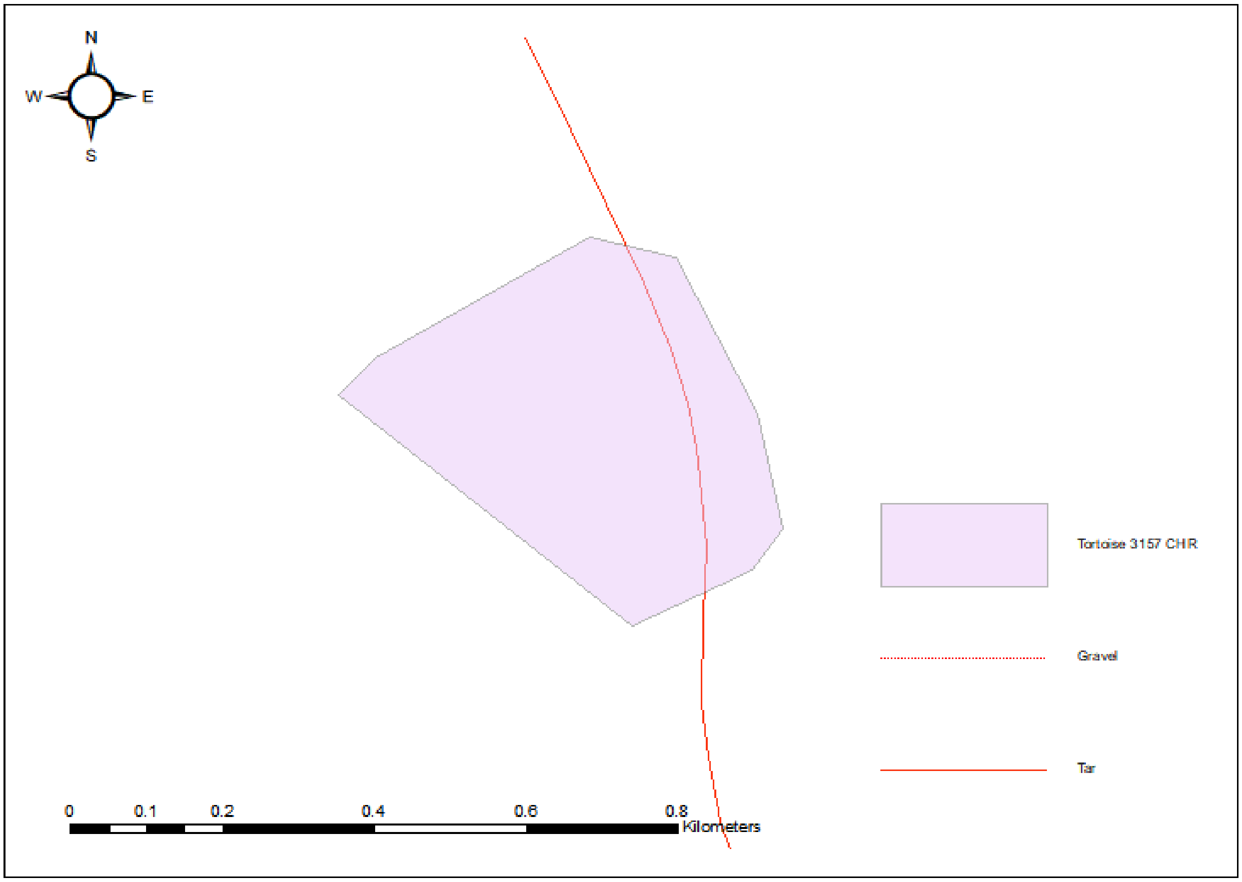

Figure 5.7. Combined home range for tortoise 3157. Home range size was 15.61 ha.

Seasonal home ranges for tortoise 3157 are depicted in Figure 5.8. The warm wet season home range was 15.22 ha in size and the cold dry season home range was 3.93 ha. The cold dry season home range size was 25.18% of the combined seasons home range size and the warm wet season home range size was 97.50% of the combined home range size.

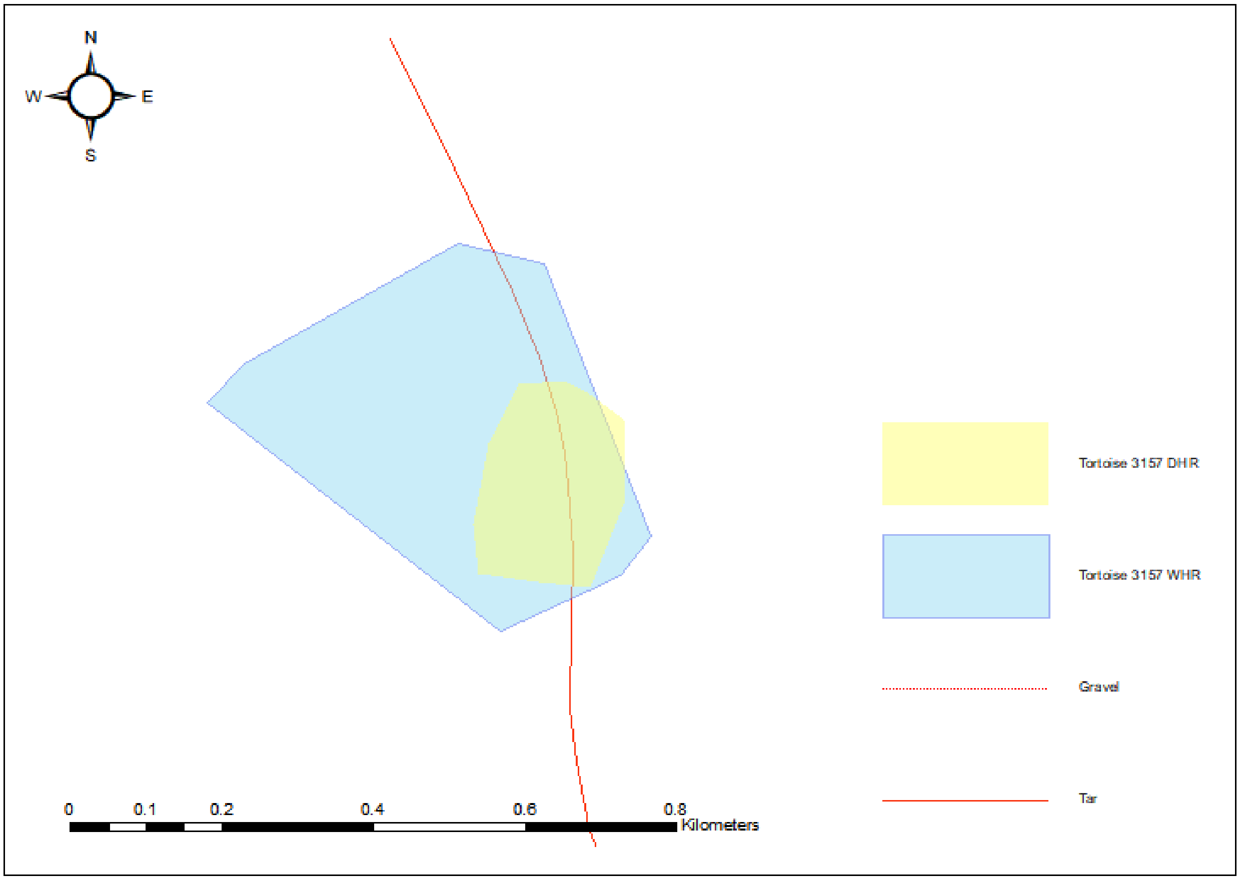

Figure 5.8. The warm wet and cold dry season home ranges for tortoise 3157. The warm wet season home range size was 15.22 ha and cold dry season home range size was 3.93 ha.

5.3.2 Proportional home range utilization by the study tortoises

The proportions of seasonal relative to annual home range size utilized by the seven tortoises is shown in Table 5.1 below.

Table 5.1. Annual and seasonal home range sizes with proportions utilized by the study animals.

Tortoise ID	Sex (M/F)	Combined HR Size (ha)	Dry HR		Wet HR	
			Size (ha)	Proportion of Combined (%)	Size (ha)	Proportion of Combined (%)
3159	F	45.50	9.04	19.87	45.50	100.00
3160	M	29.87	1.03	3.45	29.87	100.00
3154	F	21.97	12.73	57.94	16.73	76.15
3157	F	15.61	3.93	25.18	15.22	97.50
3155	F	4.33	3.07	70.90	2.63	60.74
3161	M	1.09	0.96	88.07	0.23	21.10
3158	F	3.03	1.64	54.13	1.86	61.39

5.3.3 Relationship between rainfall and home range size

The relationship between rainfall and home range size is based on findings from earlier studies and the current study indicated that home range size decreased with increasing rainfall (Figure 5.9). The data point for the high rainfall (900 mm) can be considered an outlier and removed, resulting in the regression analysis indicating a clear negative correlation between annual rainfall and home range size (Regression: $r^2 = 0.93$; $P < 0.01$; $N = 5$). The findings were statistically significant.

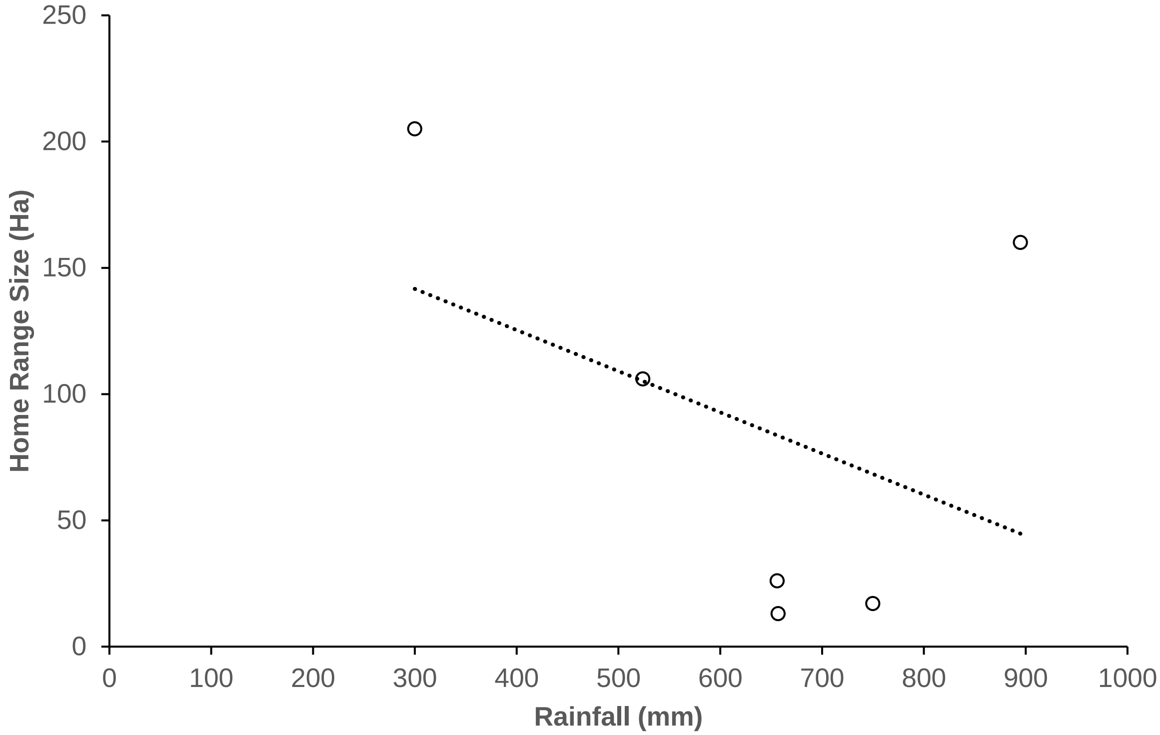

Figure 5.9. Relationship between rainfall and home range size based on the current and earlier studies. The correlation is statistically non-significant if the outlier (900 mm rainfall) is included.

5.3.4 Relationship between tortoise weight and home range size

The relationship between tortoise weight and home range size in this study suggests that larger tortoises tend to have bigger home range sizes than smaller tortoises do (Figure 5.10). The correlation between tortoise weight and home range size found in this study is not statistically significant (Regression: $r^2 = 0.02$; $P = 0.73$; $N = 7$). There was a weak positive relationship between home range size and tortoise weight.

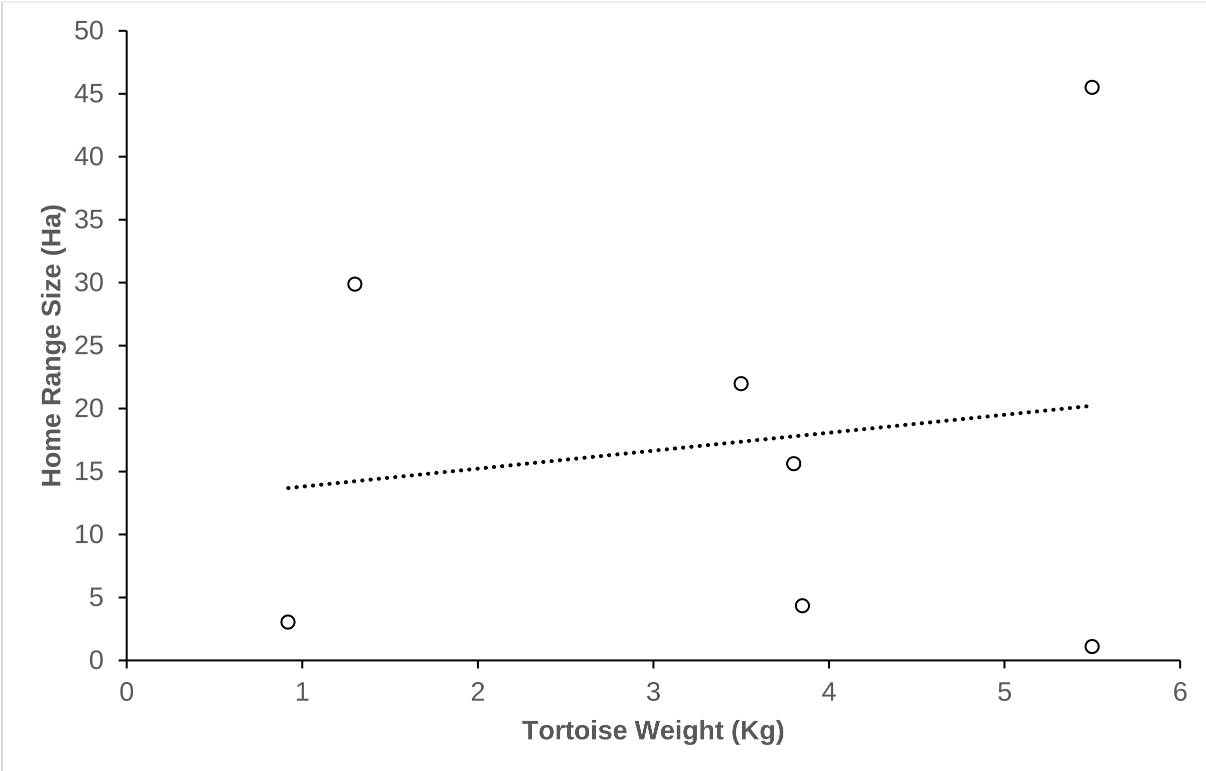

Figure 5.10. Relationship between tortoise weight and home range size suggesting no correlation and that as tortoise weight increases, so does home range size; however, the finding is not significant.

5.4 Discussion

5.4.1 Tortoise home range sizes and descriptions

Tortoises in this study were more active during the warm wet season compared to cold dry season and used larger portions of their home ranges during the warm wet season. This could be attributed to the tortoises not moving much during the colder dry season months when resources were limited and tortoises brumate. Tortoises reserve energy during the day when it is extremely hot or extremely cold, and during the cold dry season spend several days in the same location without moving, or moving very short distances when they do move, resulting in the study tortoises using smaller proportions of their home ranges.

5.4.2 Proportional home range utilization by the study tortoises

Tortoises 3159, 3160, 3154 and 3157 used between 3.45% and 57.94% of their overall home range during the dry season, and between 76.15% and 100% during the warm wet season (Table 5.1), which supports the suggestion that leopard tortoises move less during the cold dry season (Douglas & Rall 2006).

The male tortoise 3160 only used 3.45% of his home range in the dry season, compared to between 18.87% and 57.94% for the female tortoises (3159, 3154 and 3157). Possible reasons for this could be that the male has a home range with plants that contained more nutrients than the females home ranges did, or that the females require more food/nutrients than the male does during the dry season (Hailey 1989). During the warm wet season there was no noticeable differences between male and female home range utilization. For the three tortoises that had very little data, no differences were seen between male 3161 and females 3155 and 3158 during the dry season, but there was a difference in the warm wet season with the females using more of their home ranges than the male. Due to insufficient data, this is merely an observation.

5.4.3 Relationship between rainfall and home range size

The relationship between rainfall and home range size in our study indicated that home range size decreased with increasing rainfall (Figure 5.9). Availability of rain increases resource availability which reduces the need to travel further afield for resources. Poor rainfall encourages tortoises to move further in search of resources, while increased availability of resources in higher rainfall areas translates into smaller home range sizes (McMaster & Downs 2006). According to Loehr et al. (2011), in areas with higher rainfall the home ranges of *Chersobius signatus* are smaller in comparison to areas with lower rainfall. This is likely due to the increased availability of food, water, nesting sites and shelter (Loehr & Henen 2007; Loehr et al. 2011). The findings of our study, although done on a different species, support this notion.

5.4.4 Relationship between tortoise weight and home range size

The results from this study suggests a weak relationship between tortoise weight and home range size. The expectation is for smaller tortoises, by virtue of their size to move less than larger tortoises. Often the smaller and younger tortoises are not sexually mature and do not look for mates, which means that they travel less and have smaller home ranges. Younger and smaller tortoises also travel less to avoid the risk of predation and heat during the day (Personal. obs.). It is also possible that home ranges expand only when sexual maturity is reached. Yet the current study could show no significant correlation. We noted an exception to the aforementioned for tortoise 3160 that was a relatively small male who moved quite a bit and had a large home range for its size, compared to the larger females.

5.4.5 General discussion

Mean combined annual home range size for the seven telemetered tortoises was 17.34 ha. The mean home range size for the five females was 18.09 ha and for the two males was 15.48 ha. Female home range sizes were slightly larger than those of males and could be attributed to the females travelling further to search for suitable nesting sites, while males roam in the areas where there are resources. Studies in the Northern and Eastern Cape provinces suggest that female tortoises generally have larger home range sizes compared to males (Mason & Weatherby 1995; Mason et al. 2000; McMaster & Downs 2009). Our results indicate similar findings.

The mean home range size for the five females in the dry season was 6.08 ha and 0.99 ha for the two males. The warm wet season mean home range size for the five females was 45.60 ha and 45.76 ha for the two males. During the dry season the tortoises brumated and restricted themselves to the immediate vicinity of their shelters, travelling short distances when and if they did travel. Resources were scarce during the dry season and temperatures were low leading to reduced activity.

Home ranges of *S. pardalis* in various African countries and mean annual home ranges for all tortoises in the current study are shown in Table 5.2.

Table 5.2. Summarized home range results for *S. pardalis* from various regional studies for comparison to the current study.

Country	**Habitat type**	**Home Range Size (Ha)**	**Rainfall (mm)**	**References**
South Africa	Nama Karoo	205.4	300	McMaster & Downs (2009)
Tanzania	Grassland/Savanna	160.0	895	Bertram (1979)
South Africa	Valley thicket	106.4	524	Mason & Weatherby (1995)
Zimbabwe	Miombo/Mopane	26.0	656	Hailey & Coulson (1996)
Swaziland	Acacia Savanna	13.5	657	Monadjem et al. (2013)
South Africa	Kruger National Park Savanna	*17.3 **28.2	750	**Current study**

* Mean for all tortoises, ** Mean for the four tortoises that had at least four months of warm wet and cold dry season data

The cold dry season home ranges mostly overlap with the warm wet season home ranges for tortoises 159, 3160, 3154 and 3157. This indicates that in the study area, the surveyed animals do not necessarily have separate dry season home ranges and they brumate during the dry months within their warm wet season home ranges, moving very short distances. Data for the other tortoises are insufficient to investigate seasonal home range variations; however, we believe that if the data for all tortoises were complete for full warm wet and cold dry seasons, that we would see the same pattern as observed for the four tortoises that we investigated. Future research could investigate this to confirm our assumptions.

5.5 Conclusion

In this study we found noticeable variation in individual daily distances travelled, which resulted in different home range sizes for the tortoises we studied. Seasonality had an impact on home range sizes, with very little tortoise movement in the cold dry season when tortoises brumate due to reduced resources and low temperatures, which resulted in small home range sizes. During the warm wet season tortoises moved more and home range sizes were larger.

The relationship between rainfall and home range size indicated that home range size decreased with increasing rainfall. The relationship between tortoise weight and home range size in this study suggests that larger tortoises tend to have bigger home range sizes than smaller tortoises do and is likely related to larger tortoise being sexual mature and travelling further to find suitable mates and places to lay eggs.

The results from this study could assist KNP management with understanding *S. pardalis* in the southern section of the park where the study was carried out. Results provide useful information about tortoise home range sizes that could be used for conserving tortoises in general, and specifically in areas with similar vegetation, as it provides information about the effects of rainfall and tortoise size on seasonal home range size and utilization.

Challenges encountered during this study included faulty transmitters that were supplied and that stopped working shortly after being deployed. Some tortoises could not be followed or located due to the high risk of poaching that occurred in some areas after the study started, and the resultant restrictions on movement in such high-risk areas. We recommend that further research be carried out on tortoise daily activity patterns to investigate seasonal differences in activity budgets and diets. It would also be interesting to see if the cold dry season home ranges are core areas within warm wet season home ranges in terms of having the best available resources in their home ranges, as the tortoises' used portions of their warm wet season home ranges during periods of reduced activity.

CHAPTER 6

SEASONAL AND DAILY MOVEMENT PATTERNS AND THERMOREGULATORY BEHAVIOUR

6.1 Introduction

Reptiles are ectothermic, their body temperatures rely on external heat and their activities are dependent on suitable environmental conditions to support their metabolism (Porter et al. 1973; Drabik-Hamshare 2016). Reptiles therefore tend to become more active when temperatures rise, but avoid excessive heat (Avery, Bedford & Newcombe 1982). According to Brown & Sexton (1973), humidity is an important environmental determinant of activity patterns e.g. it influences breeding. Sufficient resource availability (food, water, nesting sites and shelter from predation and extreme weather conditions) is a requirement for survival and procreation (Auffenberg & Weaver 1969; Nagy & Medica 1986; Henen 1997; Downes & Shine 1998).

The habitat that reptiles occur in plays a vital role in their daily movement patterns, dictating the distances that they travel (Pough 1980; Grant & Dunham 1988; Huey 1991). In addition to habitat, body size also plays a role in heat acquisition which affects tortoise movement patterns (Stevenson 1985). Movement patterns and distances travelled are also influenced by the availability of resources (Boyce & McDonald 1999).

In the dry season *S. pardalis* have difficulties regulating their body temperature due to cold weather, especially during the early morning period, whereas in the warm wet season they are readily able to regulate their body temperature due to warmer ambient temperatures (McMaster 2007). Extreme temperatures negatively affect tortoise movement patterns and behaviour, particularly food acquisition and mating (Swingland & Frazer 1979; Hailey & Coulson 1996).

In the Kruger National Park where this study was conducted, two species of tortoises occur within the study area (*Kinixys spekii* and *S. pardalis*). Both these species are often seen basking on tar roads to obtain heat from the road surface – this is especially noticeable early in the mornings. Reptiles and amphibians commonly move along road surfaces as there are less obstructions to hinder them (Kabugumila 2001, Vijayakumar et al. 2001, Andrews et al. 2008, Kambourova-Ivanova et al. 2012, Joachimsen et al. 2013). Both species were observed using the roads regularly, particularly after rain had occurred when they would be seen drinking water from small pools on tar roads. Due to their body shape and size, tortoises are unable to move very quickly when crossing roads and are at risk of being killed by vehicles that use the roads (Sullivan 1981; White & Burgin 2004; Meek 2009; Nafus et al. 2013).

This study investigated the seasonal and daily movement patterns of seven leopard tortoises across three daily periods (morning, afternoon and night) in the southern Kruger National Park. The effects that the hottest and coldest hours in a 24-hour period have on the study tortoise's movement patterns is also examined.

6.2 Methods

6.2.1 Combined and seasonal movement patterns

Annual (warm wet and cold dry season combined) and seasonal movement patterns were determined using daily GPS location points collected for all telemetered tortoises. Combined movements include all GPS locations collected across both the warm wet (1 November to 30 April) and the cold dry season (1 May to 31 October). All points for combined, warm wet and cold dry seasons were sorted by date/time and extracted for each day in these seasons. A day was defined as the 24-hour period starting at 00:00 on a particular date and ending after 23:59 on the same date. GPS locations for a particular day were joined into arcs to form a route for the day.

Distances in meters were calculated for comparison across days and seasons. Movement All maps were generated using ARCMAP 10.2 (Khan & Mohiuddin 2018). Daily movement vector maps were created to a 0.8 km scale for visual comparison and to prevent potential perceptual distortions.

6.2.2 Daily movement patterns

We calculated the daily distance travelled for all the tortoises during the warm wet and cold dry seasons to obtain the mean distances travelled.

Daily movement patterns were determined using the GPS locations that were collected. A day was defined as the 24-hour period starting at 00:00 on a particular date and ending after 23:59 on the same date.

To compare movements and distances travelled in a particular day, each day was split into the following time periods:

- Night From 00:00 to 05:59 and from 18:00 to 23:59
- Morning From 06:00 to 11:59

- Afternoon   From 12:00 to 17:59.

For thermoregulatory related movements and distances travelled, each day was split into the hottest and coldest periods using daily recorded temperature data to determine the periods that were the coldest and the hottest for the study area (Figure 3.6):

- Cold   From 02:00 to 06:00
- Hot   From 12:00 to 16:00

Since GPS locations were collected at five hourly intervals (on the hour) that incremented daily i.e., each day the times incremented by one hour due to the odd (five) hourly data download protocol used, data was collected spanning all hours of a day.

Chronological GPS locations/points for a particular day were joined together into ‘route’ segments/arcs that were collectively combined into a day range for that day. The route segments for a day were added into the various periods provided above if more than 3 hours of a 5-hour route fell into a particular time period.

6.2.3 Statistical analysis

We calculated the mean distance travelled and standard deviation for all the tortoises in the cold dry season and warm wet season. Using Z-tests, we tested for seasonal and daily differences in distances travelled for three periods, morning, afternoon and night. We log-transformed daily route segments to conform with normality requirements and to improve the validity of our analyses. Mean ($\bar{x}$), Standard Deviation (SD) and Standard Error (SE) of distances travelled were calculated for each tortoise’s daily route segments for the cold dry and warm wet seasons.

Histograms were created to compare study tortoise movement patterns across seasons and for the various daily periods. Frequency distributions were produced of combined, warm wet, and cold dry season distances travelled.

6.3 Results

Only results for the four tortoises that had sufficient data for meaningful analyses (tortoises 3159, 3160, 3154 and 3157) are presented here. Information about the movement patterns for the remaining three tortoises is presented in Appendix F to prevent confusion.

6.3.1 Annual and seasonal daily movement patterns

6.3.1.1 Tortoise 3159

Combined warm wet and cold dry season daily movements for tortoise 3159 are shown in Figure 6.1. The mean daily distance travelled was 31.34 m, minimum daily distance was 0 m, and the maximum was 600.17 m.

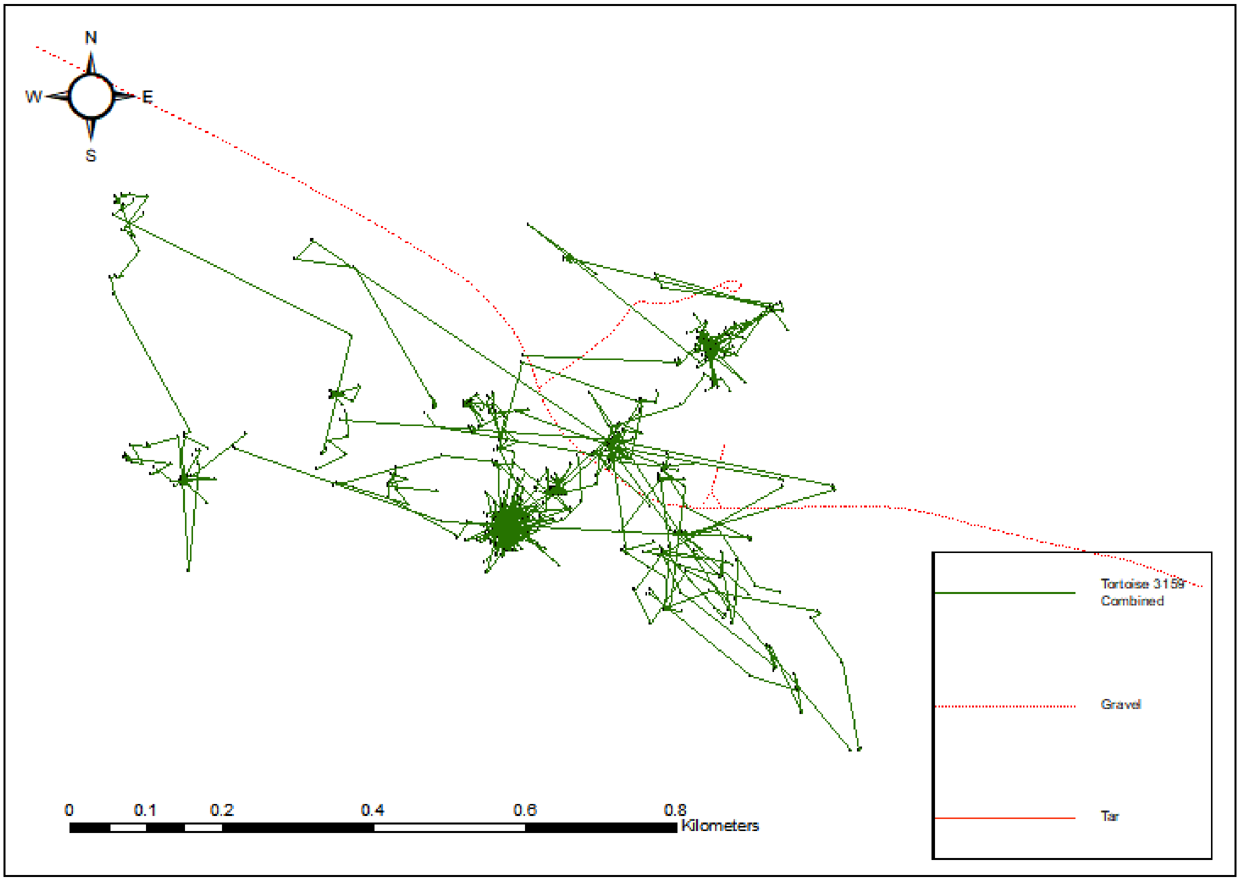

Figure 6.1. Combined warm wet and cold dry season daily movements for tortoise 3159.

The daily movements for tortoise 3159 in the warm wet season are shown in Figure 6.2. The mean daily distance travelled in this season was 55.73 m, the minimum daily distance was 0 m, and the maximum was 600.17 m.

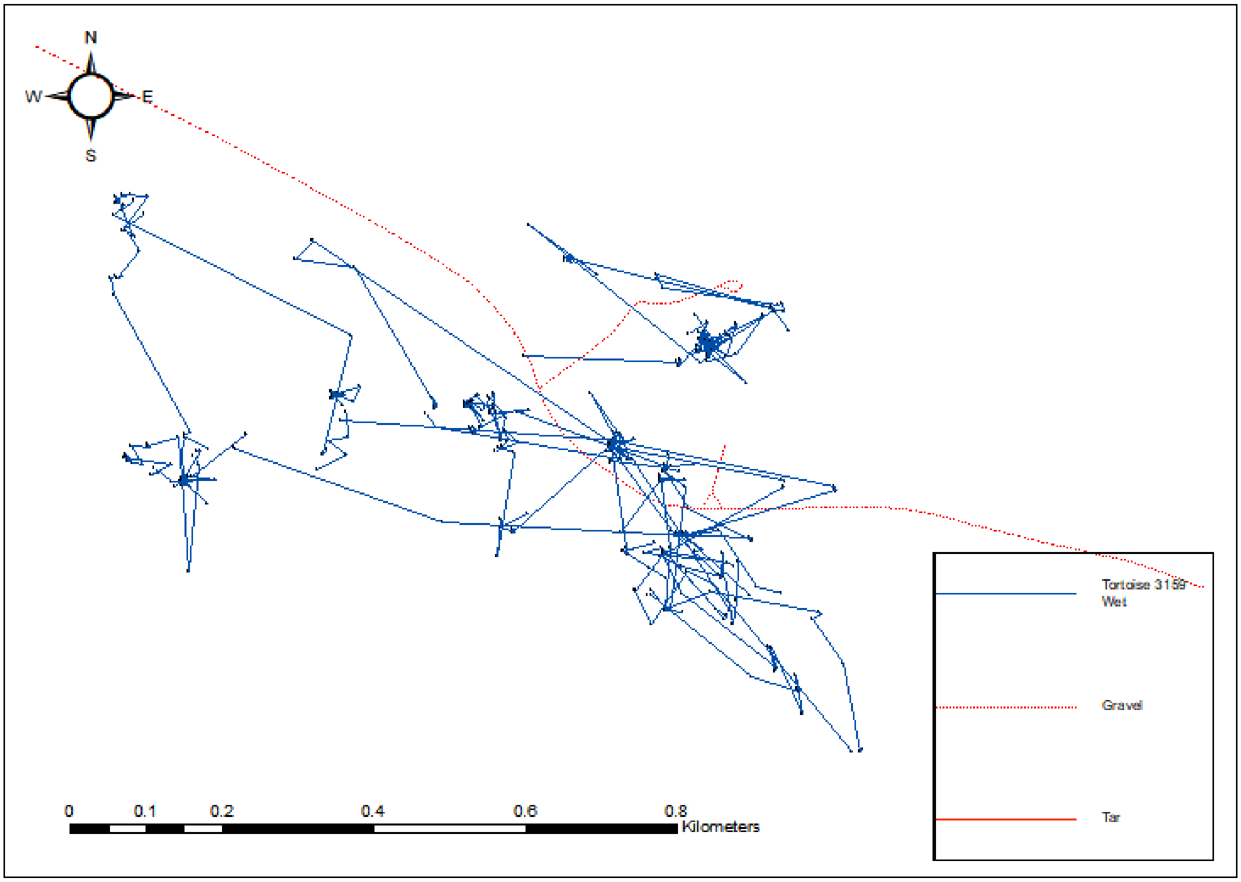

Figure 6.2. Warm wet season daily movements for tortoise 3159.

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The daily movements for tortoise 3159 in the dry season are shown in Figure 6.3. Mean daily distance travelled in the dry season was 19.17 m, the minimum daily distance was 0 m, and the maximum was 187.52 m.

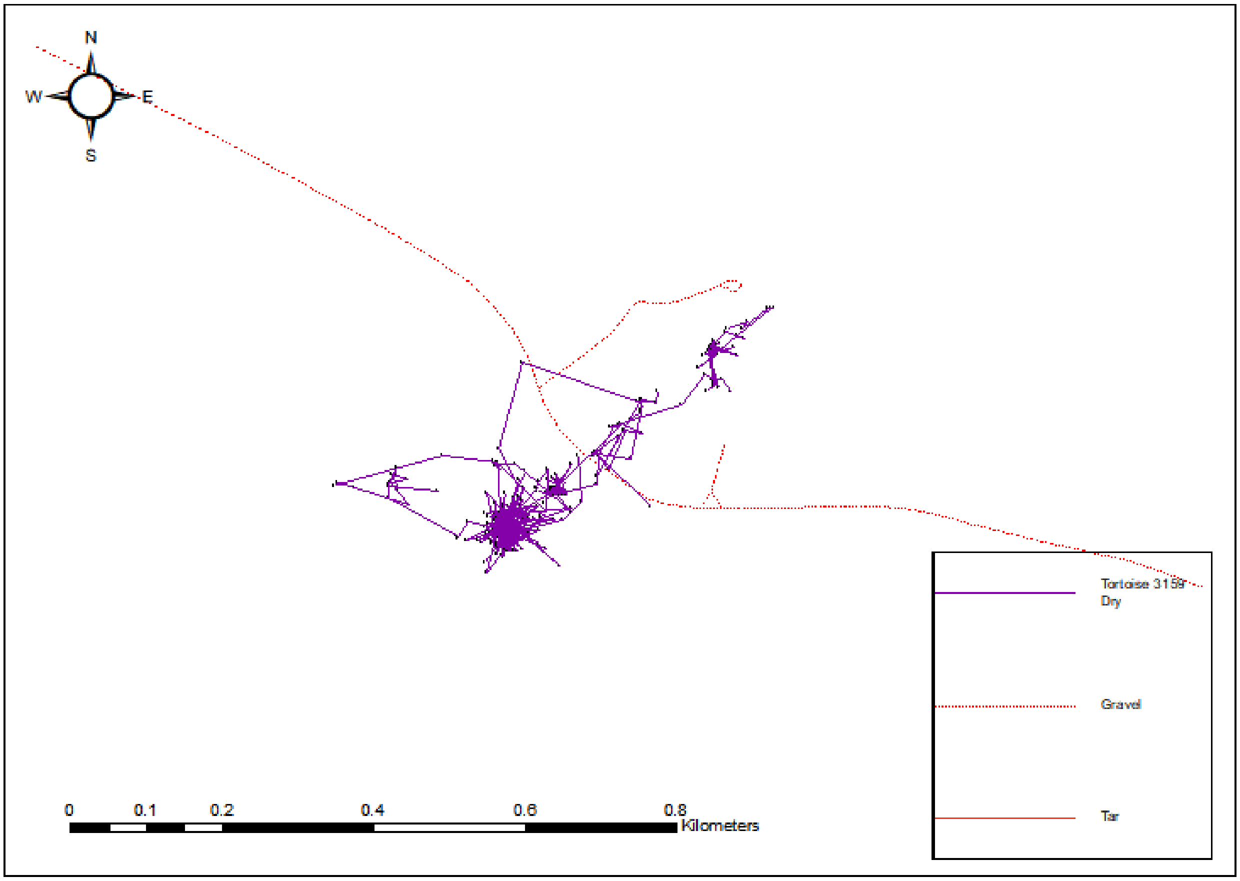

Figure 6.3. Dry season daily movements for tortoise 3159.

6.3.1.2 Tortoise 3160

The combined warm wet and cold dry season daily movements for tortoise 3160 are depicted in Figure 6.4. The mean daily distance travelled was 26.08 m, the minimum daily distance was 0 m, and the maximum was 395.79 m.

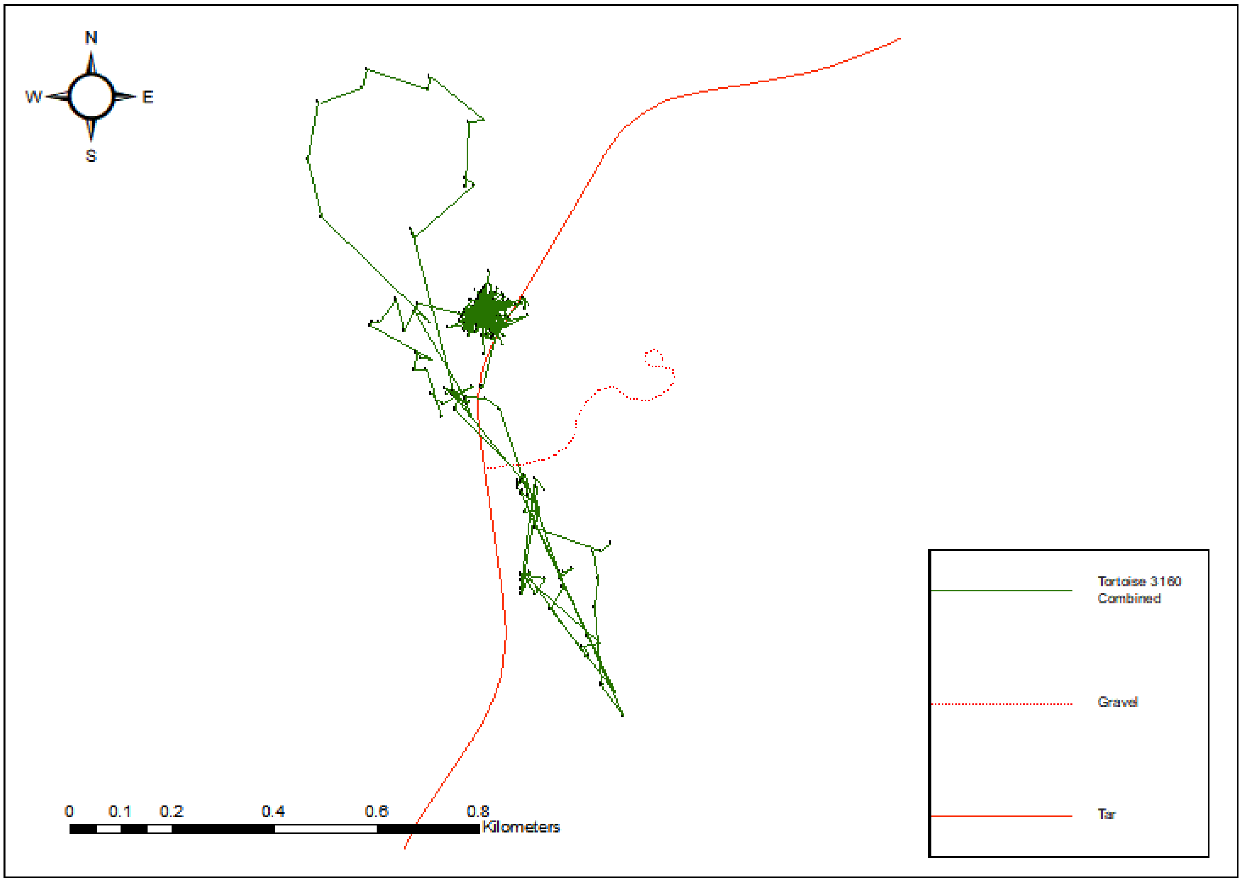

Figure 6.4. Combined warm wet and cold dry season daily movements for tortoise 3160.

The daily movements for tortoise 3160 in the warm wet season are shown in Figure 6.5. The mean daily distance travelled in the warm wet season was 58.87 m, the minimum daily distance was 2.00 m, and the maximum was 395.79 m.

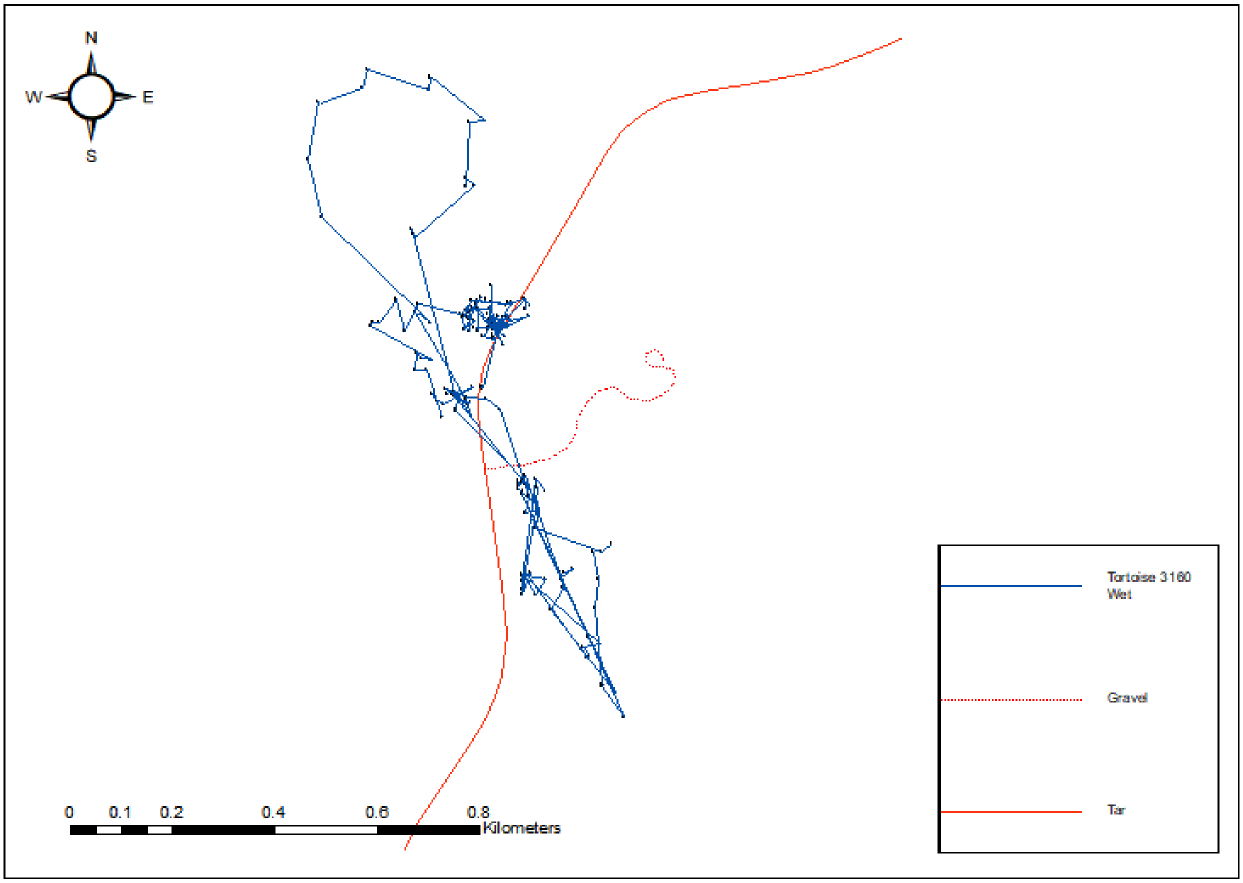

Figure 6.5. Warm wet season daily movements for tortoise 3160.

The daily dry season movements for tortoise 3160 is shown in Figure 6.6. Mean daily distance travelled in the dry season was 15.52 m, minimum daily distance was 0 m and maximum were 94.53 m.

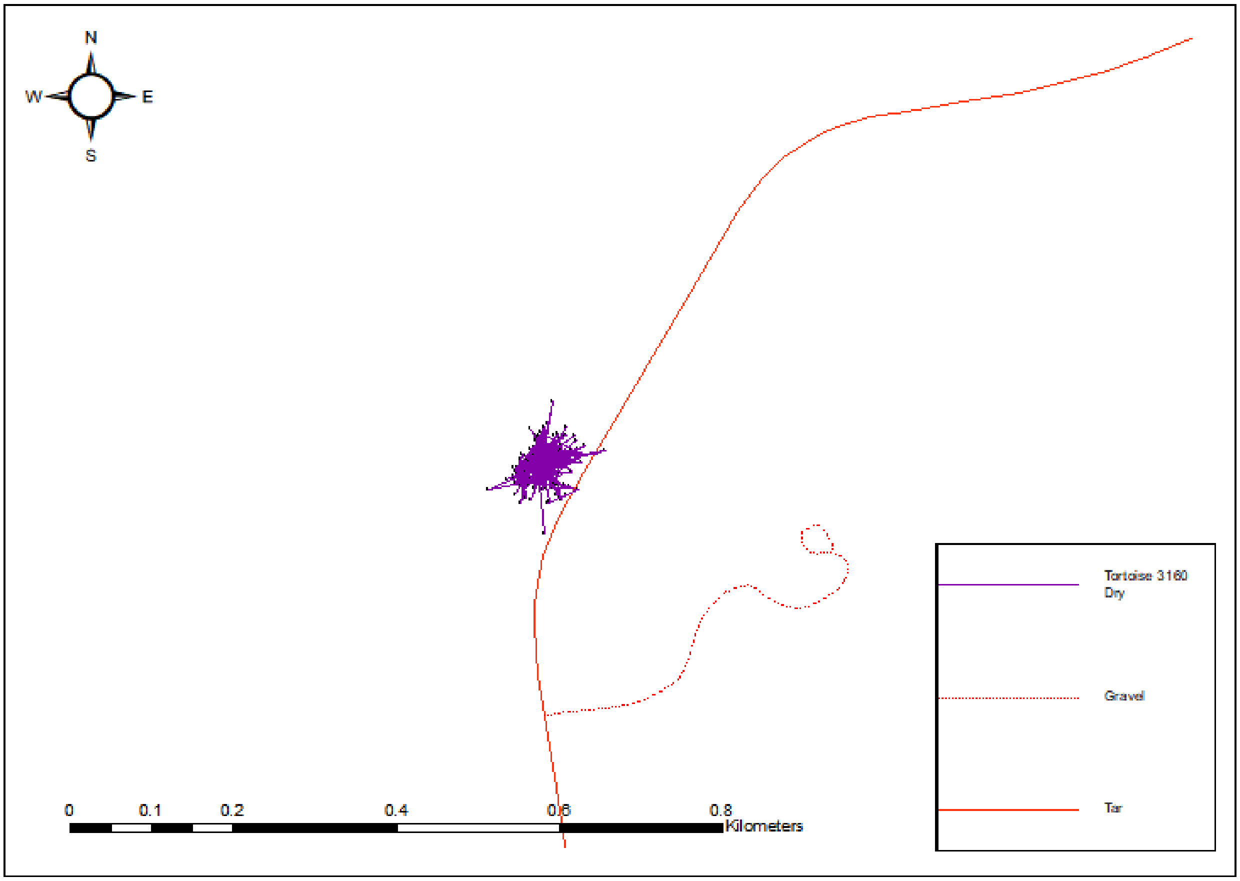

Figure 6.6. Dry season daily movements for tortoise 3160.

6.3.1.3 Tortoise 3154

Combined warm wet and cold dry season daily movements for tortoise 3154 are shown in Figure 6.7. Mean daily distance travelled was 21.40 m, minimum daily distance was 0 m and maximum were 314.34 m.

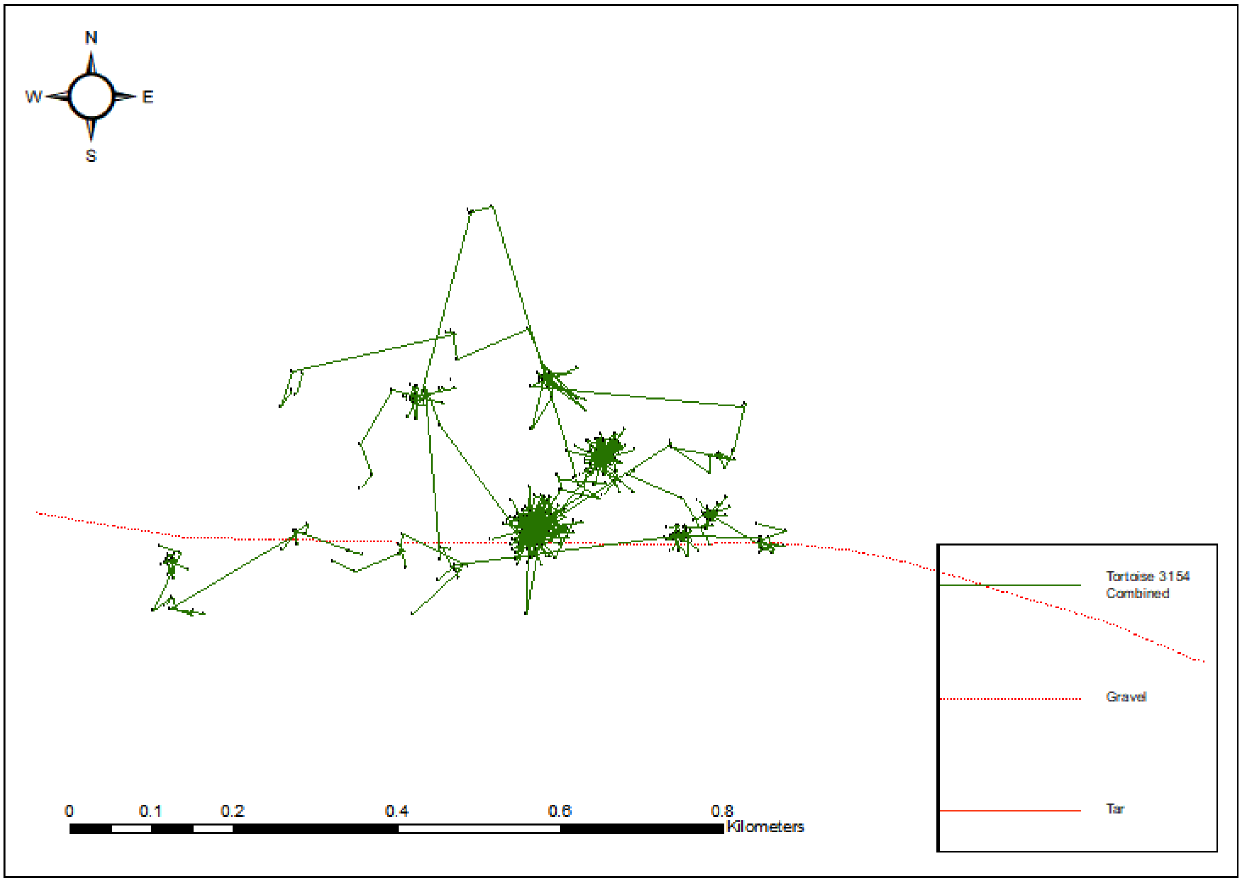

Figure 6.7. Combined warm wet and cold dry season daily movements for tortoise 3154.

The warm wet season daily movements for tortoise 3154 are shown in Figure 6.8. The mean daily distance travelled in the warm wet season was 31.54 m, minimum daily distance was 1.00 m and maximum were 282.82 m.

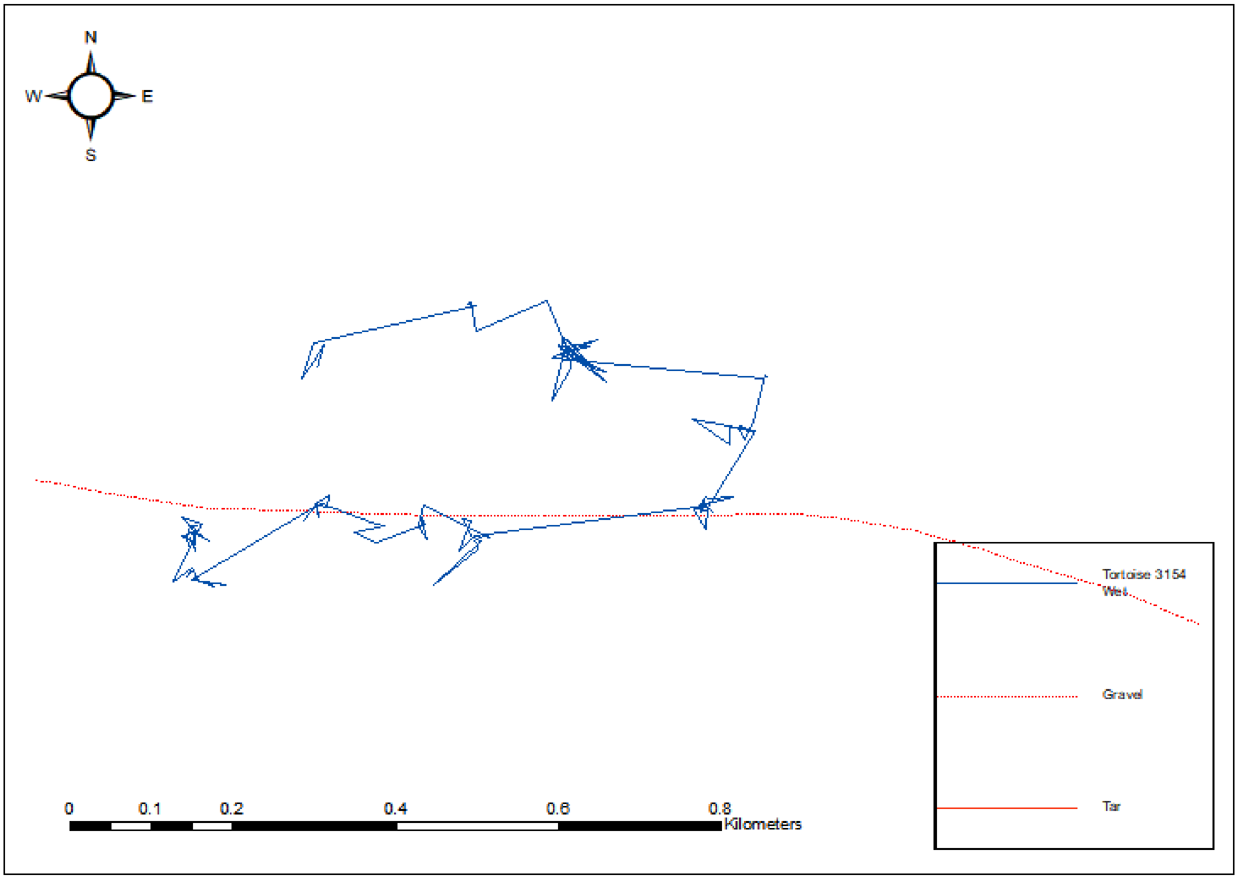

Figure 6.8. Warm wet season daily movements for tortoise 3154.

Dry season daily movements for tortoise 3154 are shown in Figure 6.9. Mean daily distance travelled in the dry season was 19.60 m, minimum daily distance was 0 m and maximum were 314.34 m.

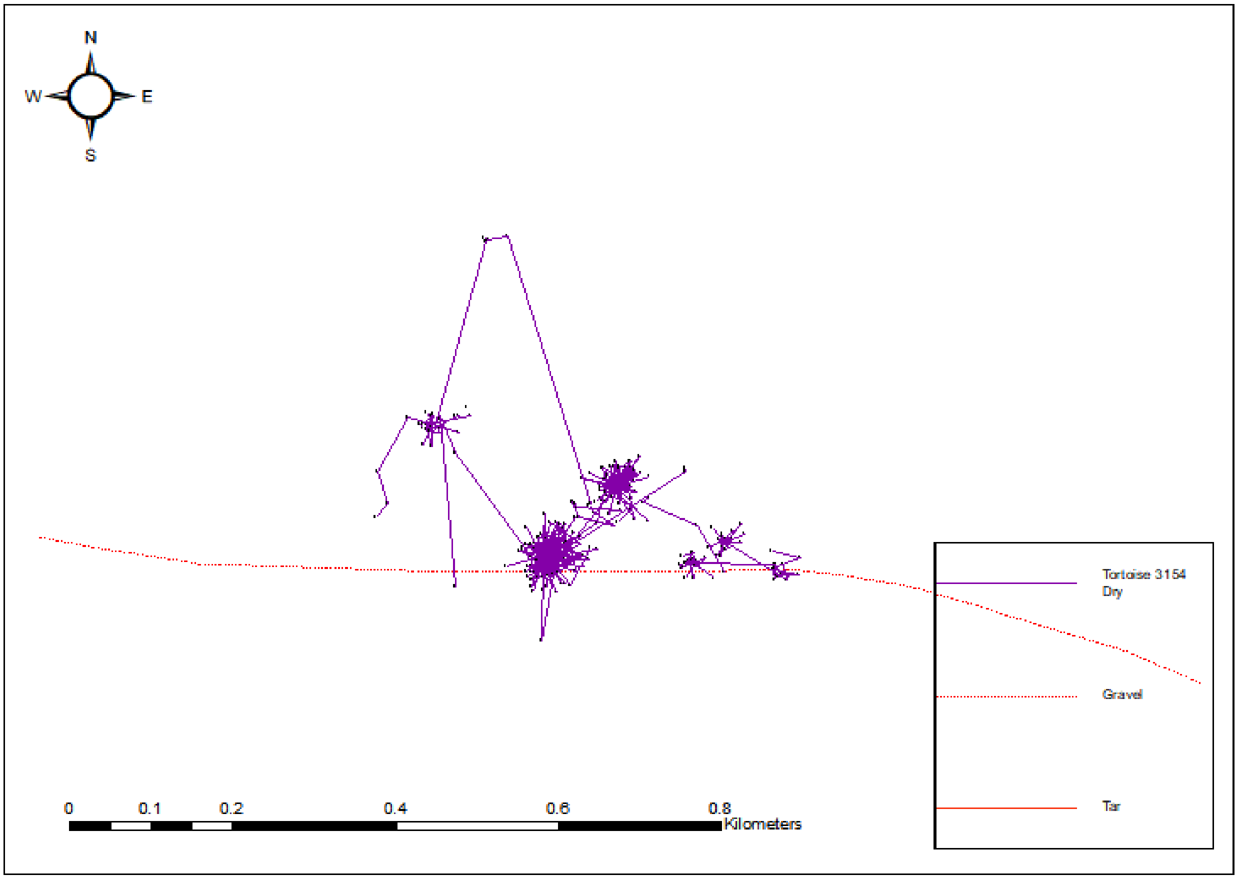

Figure 6.9. Dry season daily movements for tortoise 3154.

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6.3.1.4 Tortoise 3157

The combined warm wet and cold dry season daily movements for tortoise 3157 are depicted in Figure 6.10. The mean daily distance travelled was 24.04 m, minimum daily distance was 0 m and maximum was 280.59 m.

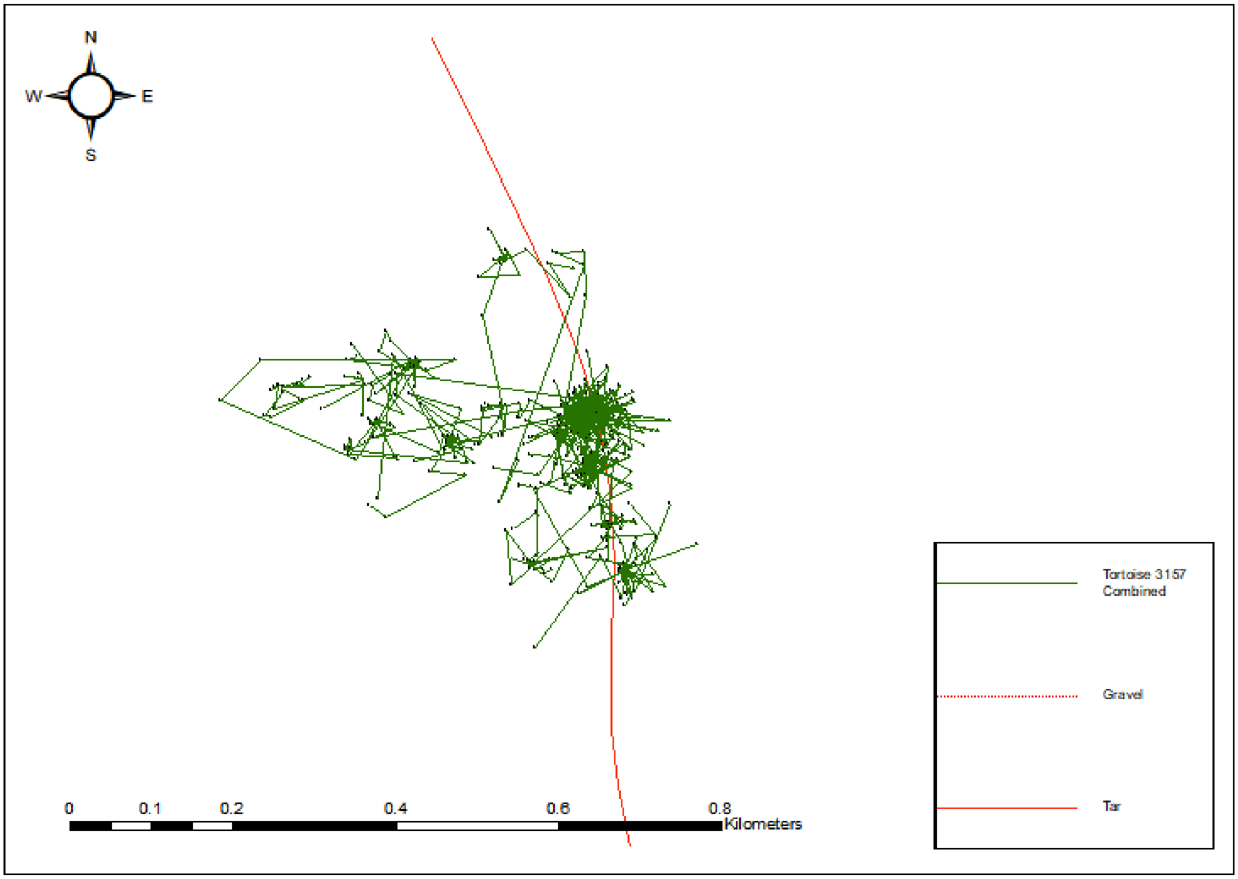

Figure 6.10. Combined warm wet and cold dry season daily movements for tortoise 3157.

The warm wet season daily movements for tortoise 3157 are shown in Figure 6.11. Mean daily distance travelled in the warm wet season was 36.36 m, minimum daily distance was 1.00 m and maximum were 280.59 m.

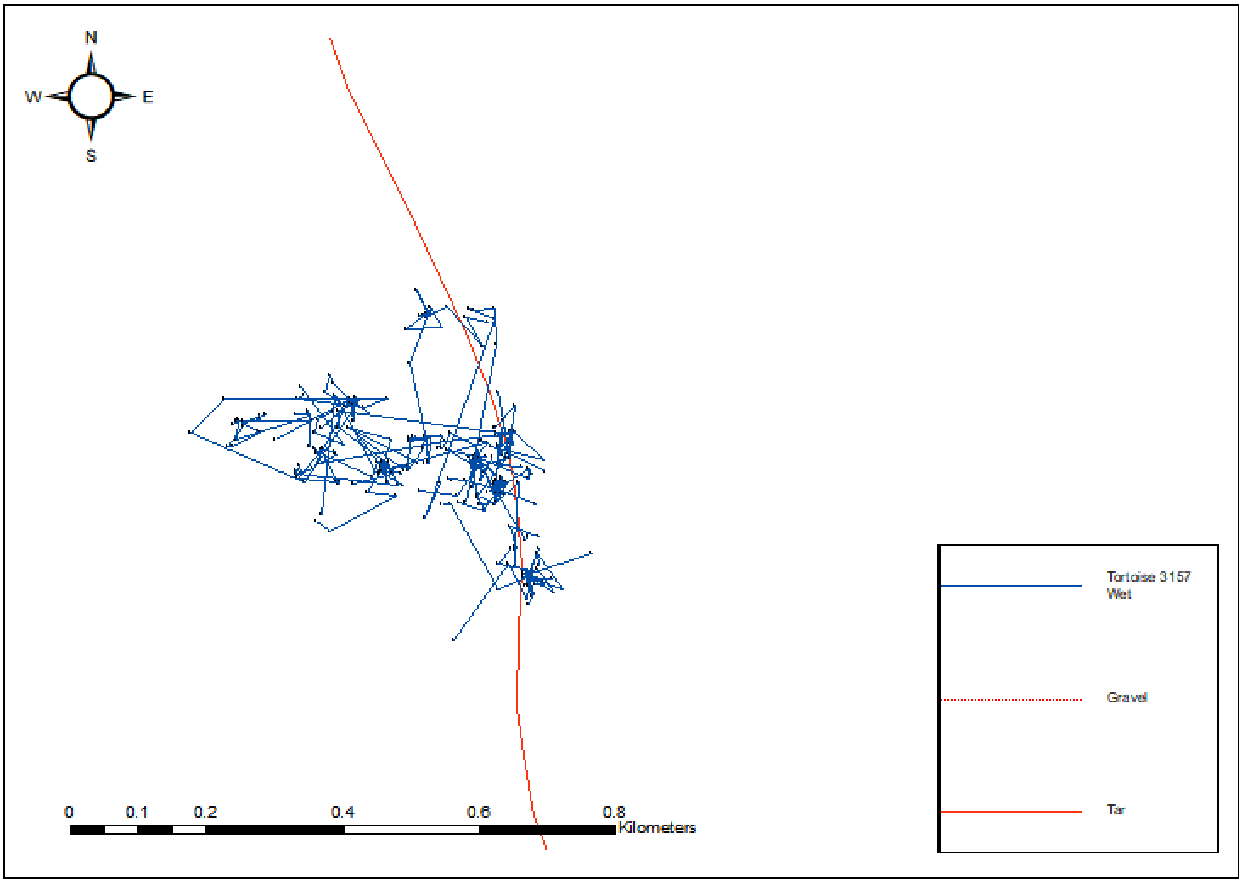

Figure 6.11. The warm wet season daily movements for tortoise 3157.

The cold dry season movements for tortoise 3157 is shown in Figure 6.12. The mean daily distance travelled in the dry season was 17.86 m, the minimum daily distance was 0 m and the maximum were 123.32 m.

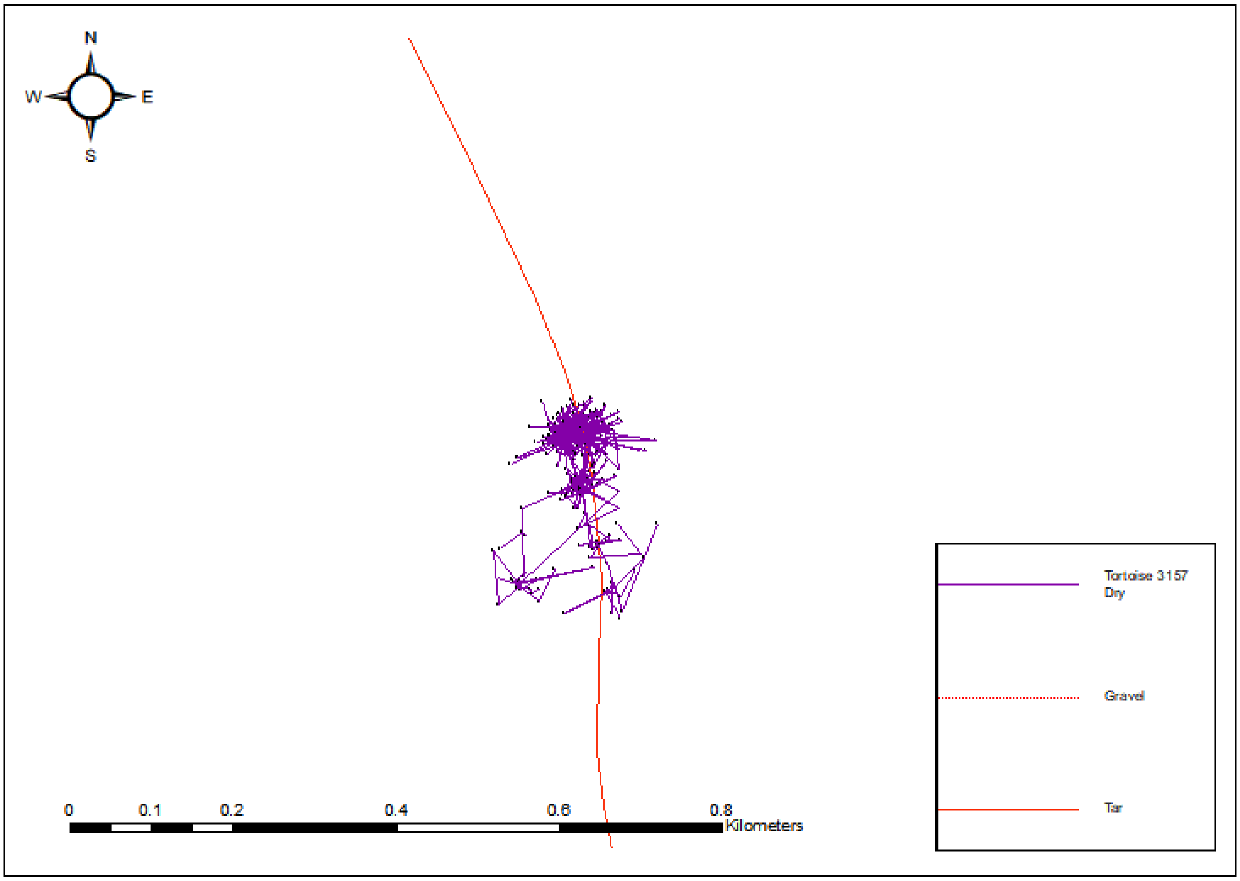

Figure 6.12. Dry season daily movements for tortoise 3157.

6.3.2 Summary of daily period (morning, afternoon, night, hot and cold) movement patterns

Table 6.1 below summarizes the mean daily distances travelled by the four transmittered tortoises that had sufficient data, for the study period (1 March 2019 to 31 March 2020) within each daily period.

Table 6.1. Mean daily distances travelled, SD, SE and log transformed mean daily distances, SD and SE for the four tortoises with sufficient data across the different daily periods in the study for the warm wet and cold dry seasons.

	Wet Daily Periods					**Dry Daily Periods**				
	M	**A**	**N**	**H**	**C**	**M**	**A**	**N**	**H**	**C**
$\bar{x}$	53.27	41.67	50.61	49.43	21.65	16.53	17.82	18.43	18.48	15.34
SD	80.36	62.04	75.52	71.50	23.33	32.24	18.45	23.67	20.40	16.81
SE	10.84	3.75	4.15	5.57	2.23	2.66	0.68	0.80	0.99	0.99
Log10 $\bar{x}$	1.41	1.24	1.32	1.32	1.07	0.87	1.05	1.00	1.06	0.96
Log10 SD	0.52	0.58	0.61	0.59	0.52	0.53	0.45	0.49	0.45	0.47
Log10 SE	0.07	0.04	0.03	0.05	0.05	0.04	0.02	0.02	0.02	0.03

M=morning, A=afternoon, N=night, H=hot, C=cold

We compared the within period $\log_{10}$ transformed daily distance travelled values for the cold dry and warm wet seasons (Table 6.1). For the morning (Z-test: z = 6.63; F= 1.01; P = 0.01), afternoon (Z-test z = 4.90; F= 1.72; P = 0.01) and night (Simple correlation: z = 8.39; F = 1.55; P = 0.01) periods, warm wet season mean distances travelled were significantly longer than dry season distances travelled.

Tortoise activity peaked during the warm wet season 'hot period' (Table 6.1), while mean distances travelled during the warm wet season 'cold period', dry season 'hot period' and dry season 'cold period' were similar.

Morning period mean daily distances travelled by individual tortoises for the combined, wet, and dry seasons are shown in Figure 6.13. Warm wet season mean daily distances for the morning period are longer than for the dry season.

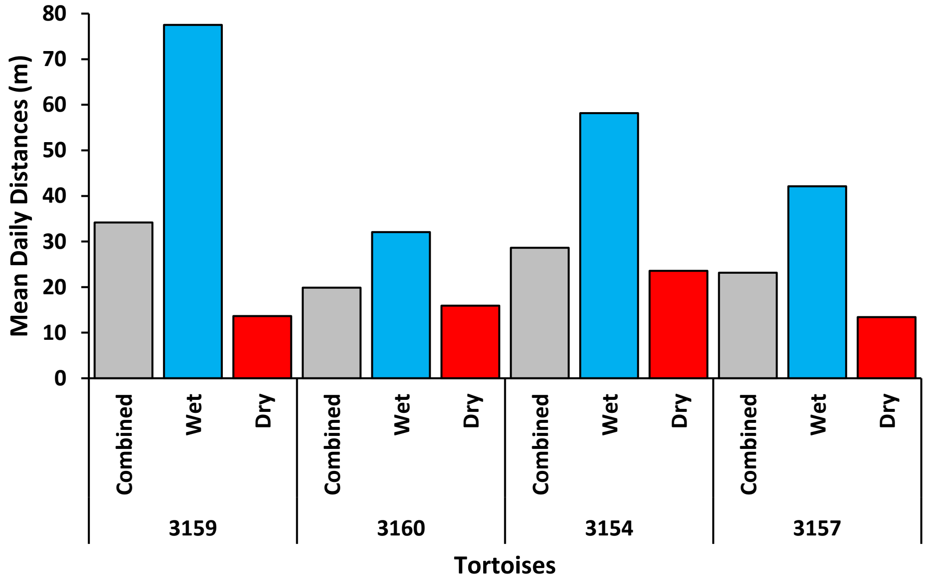

Figure 6.13 Mean daily distances travelled by individual tortoises during the morning period for the warm wet, cold dry and combined seasons.

Afternoon period mean daily distances travelled by individual tortoises for the combined, warm wet, and cold dry seasons are shown in Figure 6.14. Warm wet season mean daily distances for the afternoon period are longer than for the cold dry season.

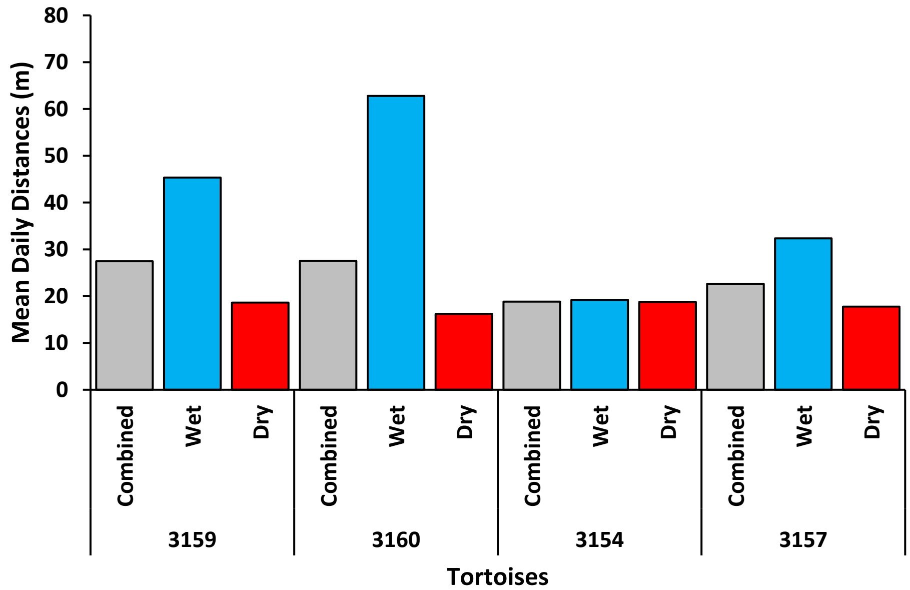

Figure 6.14. Mean daily distances travelled by individual tortoises during the afternoon period for the warm wet, cold dry and combined seasons.

Night period mean daily distances travelled by individual tortoises for the combined, wet, and dry seasons are shown in Figure 6.15. Warm wet season mean daily distances for the night period are longer than for the cold dry season.

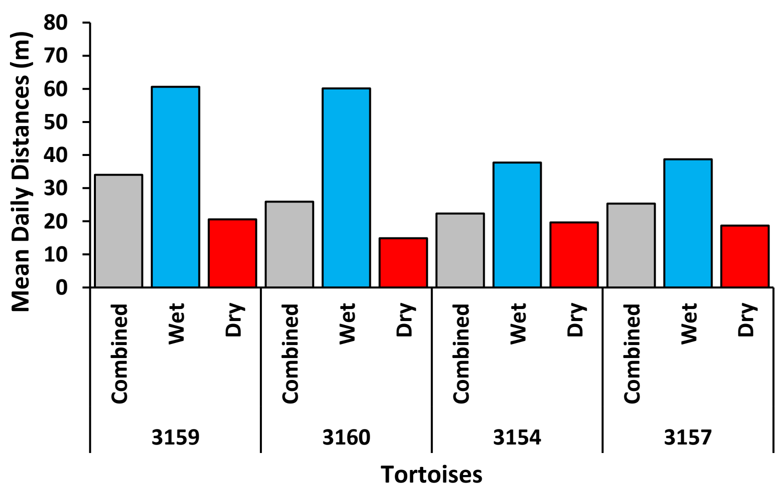

Figure 6.15. Mean daily distances travelled by individual tortoises during the night period for the warm wet, cold dry and combined seasons.

Hot period mean daily distances travelled by individual tortoises for the combined, wet, and dry seasons are shown in Figure 6.16. Warm wet season mean daily distances for the hot period are longer than for the cold dry season.

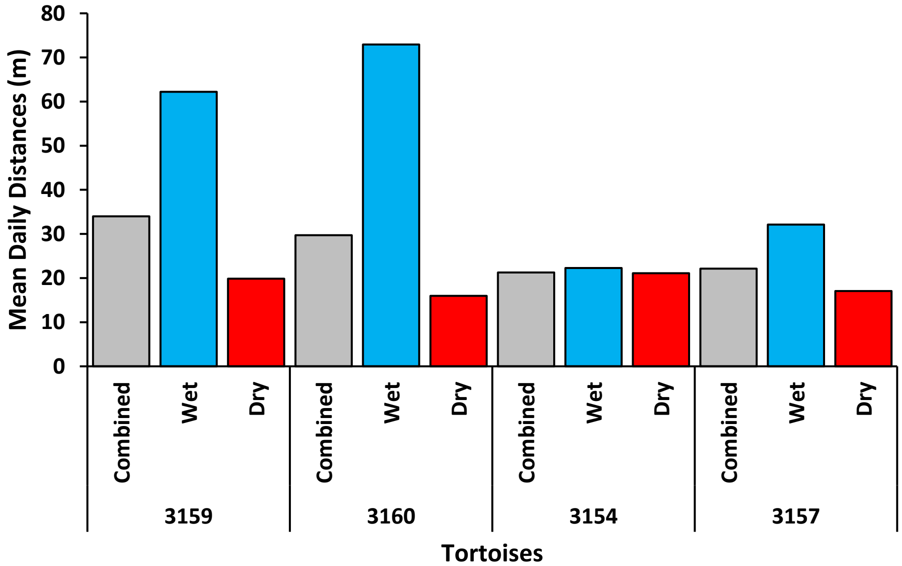

Figure 6.16. Mean daily distances travelled by individual tortoises during the hot period for the warm wet, cold dry and combined seasons.

Cold period mean daily distances travelled by individual tortoises for the combined, wet, and dry seasons are shown in Figure 6.17. Warm wet season mean daily distances for the cold period are longer than for the cold dry season.

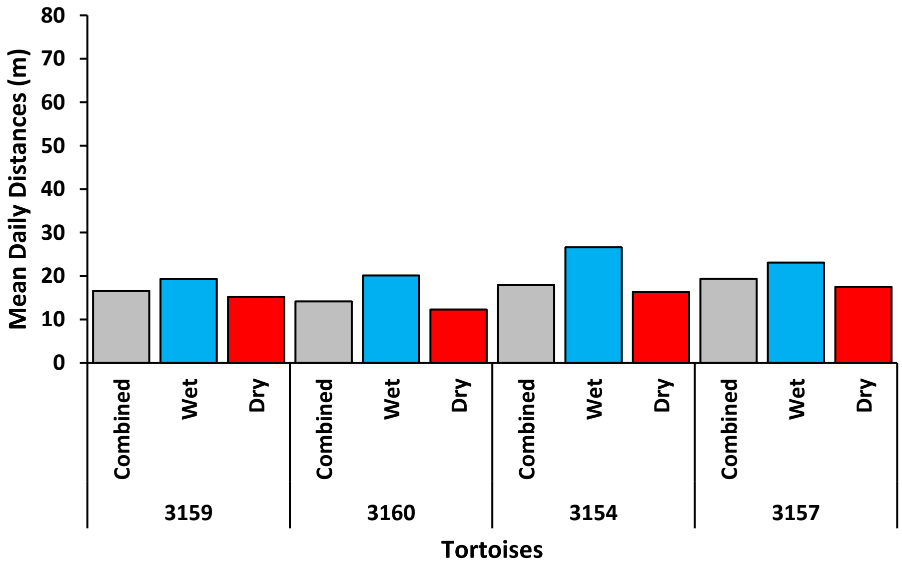

Figure 6.17. Mean daily distances travelled by individual tortoises during the cold period for the warm wet, cold dry and combined seasons.

6.3.3 Summary of total distances travelled by tortoises in the study area

A frequency distribution of total daily distance travelled for the four tortoises with sufficient data (n = 4) for the combined warm wet and cold dry seasons is shown in Figure 6.18.

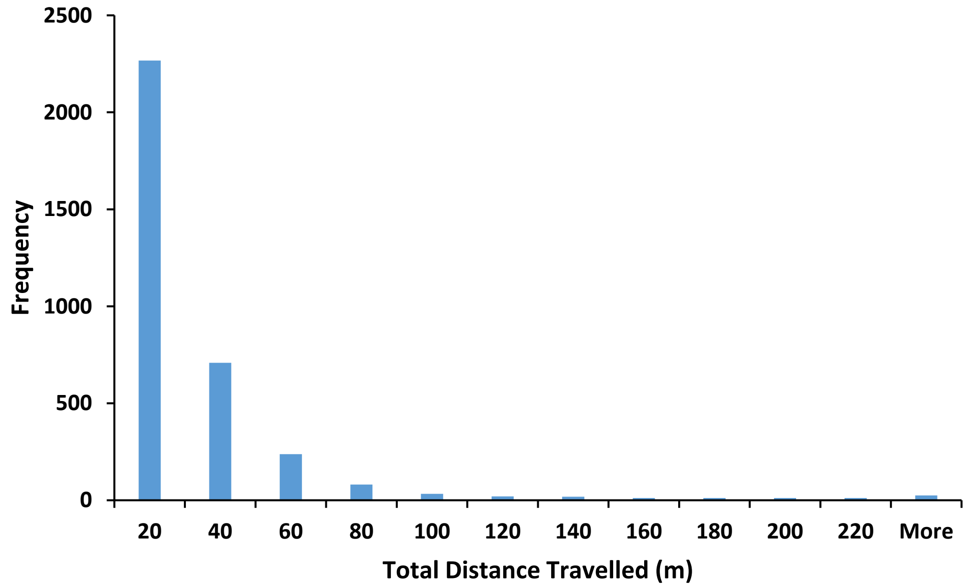

Figure 6.18. Frequency distribution illustrating daily distances travelled for the combined warm wet and cold dry seasons.

Tortoises travelled daily distances between 20 and 80 m but rarely further than 100 m (Figure 6.18).

Total daily distance travelled for all tortoises with sufficient data (n = 4) in the dry season are summarized in Figure 6.19.

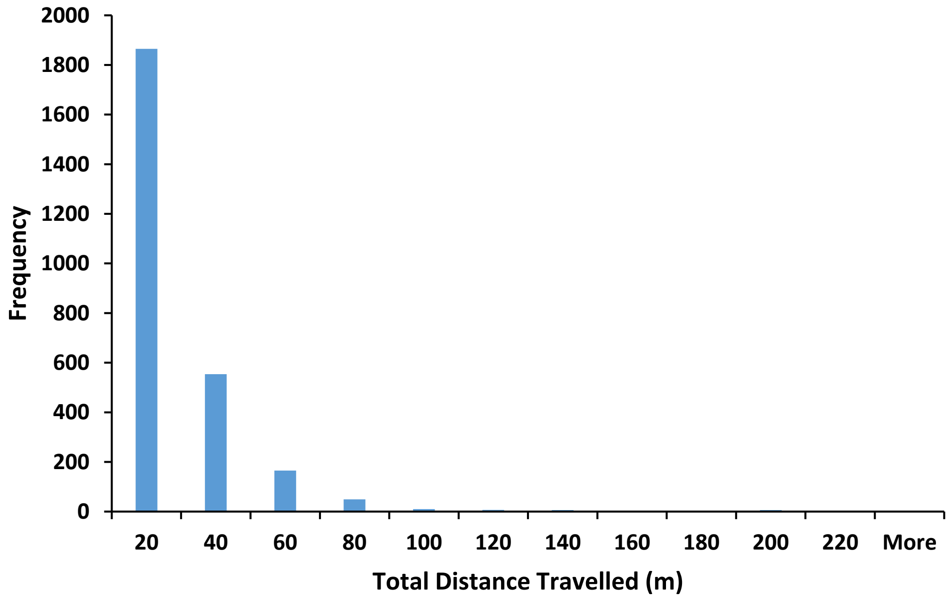

Figure 6.19. Frequency distribution showing daily distances travelled during the dry season.

Daily distances travelled during the dry season were rarely further than 80 m and were mostly within the 20 to 80 m range.

Total distance travelled for all tortoises with sufficient data (n = 4) during the warm wet season are summarized below in Figure 6.20.

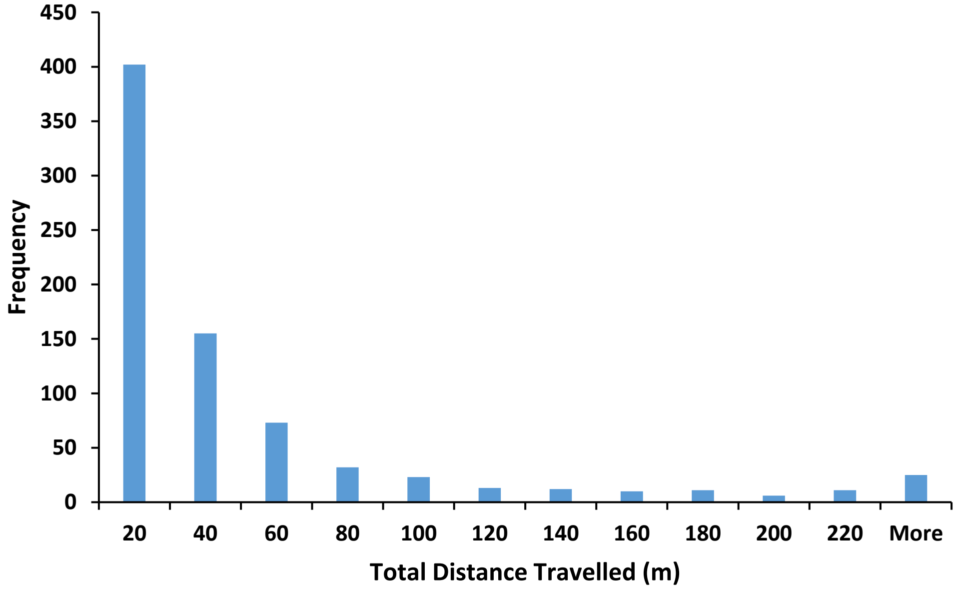

Figure 6.20. Frequency distribution showing daily distances travelled during the warm wet season.

The warm wet season daily distances covered a broad spectrum of distances, sometimes further than 220 meters, but the highest frequency was within the 20 to 60 m range.

6.4 Discussion

The objectives for this chapter included determining seasonal and daily movement patterns for the study tortoises across three daily periods (morning, afternoon and night) and investigating the effects of the hottest and coldest hours in a 24-hour period on tortoise distances travelled.

The tortoises investigated in this study were more active during the warm wet season compared to the dry season. This was due to the warm wet season having an abundance of resources, including surface water that was available on road surfaces directly after rain had fallen, that facilitated foraging and breeding in this season. Temperature was also a factor, with tortoises moving less during the cold dry season when temperatures were lower, than during the warm wet season. We also found that tortoises move less when temperatures are too hot or too cold during the hottest and coldest periods of a 24-hour cycle.

During the warm wet season, daily distances travelled increased as the tortoises utilized a variety of resources available to them, and which were not available during the cold dry season. Several explanations could potentially explain the increased activity during the warm wet season. For example, increased warm wet season daily distances travelled could be due to mating behavior and assumed higher energy levels due to increased abundance of better-quality food. Yet, according to Hailey & Coulson (1996), longer travel distances can also be recorded when food is of a lower quality and tortoises need to travel further to meet their daily metabolic needs. The current study does not support this possibility. Finally, female tortoises also search for secure nesting sites to lay their eggs during the warm wet season, which could contribute towards them moving further during this season.

The study animal's movements for the three daily periods (morning, afternoon and night) were less during the dry season than for the warm wet season. This is likely attributed to colder daily temperatures during the dry season, and the tortoises brumating during the colder months (Joshua et al. 2005). Increased morning movements during the warm wet season could be attributed to the tortoises moving around more to find food and mates during the cooler morning hours, before midday when temperatures increase, and it becomes too hot. Similarly, during the warm wet season afternoons, tortoises become active again and move more after the hot midday period when the heat has subsided. During warm nights, the study tortoises also moved around, but travel distances decreased during the cold period when temperatures were at their lowest. Nocturnal activities for tortoises were observed on Farmland in the semi-arid Karoo of South Africa during the warm wet season when tortoises were breeding, and the researchers recorded decreased movements during the winter months. The findings from the present study corresponds with those of Drabik-Hamshare (2016).

During out study, daily distances where tortoises travelled further than 120 m were rarely recorded. Daily distances of between 20 and 80 m were the norm for the dry season, and distances of between 20 and 120 m for the warm wet season. The relatively short daily distances travelled for both the warm wet and dry seasons are indicative of an environment that has sufficient resources for the tortoises living in it and shows that the study area in the southwestern region of KNP meets the requirements of the study tortoises and likely the *S. pardalis* population living there.

6.3 Conclusion

This study shed further light on the spatial requirements of the leopard tortoise across various temporal scales. Daily distances travelled were investigated for the warm wet, cold dry and combined seasons for three daily periods (morning, afternoon, night), and the hottest and coldest periods in a 24-hour cycle.

Findings indicate that the study tortoises travel longer distances in the early morning and late afternoon periods when ambient temperatures are not too hot or too cold. Although the study tortoises moved around on warm nights, their distances travelled decreased during the cold period when temperatures were at their lowest. Daily distances travelled are further during the warm wet season for all daily periods and could be attributed to increases in daily temperatures and rainfall, which results in tortoises no longer brumating and becoming active after the cold, resource scarce dry season.

Tortoises play a vital role in ecosystems where they provide food for various predators, play a role in seed dispersal and are indicators of ecosystem health and functioning (Jerozolimski et al. 2009, Blake et al. 2012, Falcon & Hansen 2014).

CHAPTER 7

CONCLUSION

Home range utilization and movement patterns of *S. pardalis* has been studied in several regions of southern Africa, but not yet in the KNP (Bertram 1979, Mason & Weatherby 1995, Hailey & Coulson 1996, McMaster & Downs 2009, Drabik-Hamshare 2016). In the Karoo, home range sizes differed seasonally, with tortoises having larger home ranges in the warm wet months compared to the cooler dry months; tortoises also moved longer distances during the warm wet months compared to the cool dry months (McMaster & Downs 2009). This study supports earlier findings from the Karoo, where daily distances travelled were longer and home range sizes were larger in the warm wet months compared to the cool dry months.

Mean annual home range size for tortoises in the Karoo study was 205 ha (McMaster & Downs 2009). Another study in the semi-arid Karoo using GPS technology to record movements of *S. pardalis* over a 12-month period showed that home ranges were between 40.5 and 258.5 ha in size (Drabik-Hamshare 2016). A short-term home range study of *S. pardalis* in open Savanna woodland at the Sengwa Wildlife Research in Zimbabwe produced a mean home range size of 26 ha (Hailey & Coulson 1996). Apart from the Sengwa Wildlife Research Area study being over a short period of time, the tortoises in the study also had a smaller body size than in the Karoo studies, both factors of which might have had an influence on home range size. In our study, mean home range size was 28.2 ha, which corresponds with the study at Sengwa in Zimbabwe. The similar sized home ranges at Sengwa and KNP could be related to both areas having comparable environments, vegetation and rainfall.

Resource abundance in areas where tortoises occur influences the size of their seasonal home ranges, with areas that have a scarcity of resources generally having larger home range sizes (McMaster & Downs 2006). Predation risk can also influence home range size. For example, small mammal home range sizes decrease in areas where predator numbers are high (Hailey & Coulson 1995). For reptiles, similar information could not be found in literature but they are risk sensitive and alter their activity patterns to avoid predation (Martin & Lopez, 1999). The impact of predation on home range size was not investigated in the current study, although evidence was found of predation on a telemetered tortoise who had been killed by African Southern Ground Hornbill. An incident where buffalo trampled and killed a tortoise was also observed during the current study, suggesting survival probability is shaped by factors additional to predation.

In vegetated areas tortoises cover shorter distances because the resources they require (shade, shelter, water, and food) are relatively abundant and they do not need to travel long distances. Thickets in densely vegetated areas like the Kruger, provide hiding places for tortoises, which could assist with predator avoidance, compared to open arid areas like the Karoo that have sparse vegetation. In the present study the home range sizes of the leopard tortoises were much smaller in comparison to tortoises living in arid environments like the Karroo (McMaster & Downs 2009), most likely a consequence of lower availability of resources in the Karroo study.

This study provided valuable information about tortoise seasonal home range utilization and daily movement patterns within the study area. Findings indicated seasonal shifts in home range utilization and daily distances travelled. These findings align with what researchers found for leopard tortoises in the Karoo (McMaster & Downs 2006). The Karoo study also showed that leopard tortoise home ranges were restricted during the cool dry season when food became scarce, and the tortoises went into brumation (McMaster & Downs 2006).

For conservation planning, it is important to understand how animals utilize their habitat and available resources. Furthermore, it is important to understand possible competition for food and other resources. Large parts of northeastern South Africa are threatened by habitat destruction and the well-being of species in protected areas, such as the KNP, is of great importance. Consequently, this research on the spatial movement ecology of leopard tortoises in the KNP could be used to inform management plans about how these animals and their habitats need to be protected and what future research is required to get a better understanding about their activity budgets and diets. The role of tortoises in ecosystems could be used for public awareness campaigns, highlighting the importance of conserving them.

Recommendations for future investigations include a detailed dietary analysis for *S. pardalis* to determine their daily diets and the nutritional breakdown of food items they consume, as these likely influence their behavior, home range sizes and distances travelled. Generally, if an animal does not need to travel great distances to meet its metabolic requirements, then it won't (Wilson et al. 2015). We also recommend that future research be conducted to investigate tortoise daily activity patterns and behavior.

Challenges encountered during this study include faulty transmitters that resulted in some tortoises not being located relatively soon after the study started, and limited access to some of the areas where the tortoises lived due to potential poacher encounters.

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APPENDICES

Appendix A

Datasheet for morphometric measurements at first capture of *Stigmochelys pardalis*, and when recapturing a non-telemetered tortoise. VHF and AWT numbers are to link the tortoise ID to the transmitter frequency and the GPS units.

Date	Time	Species	ID	VHF (freq)	AWT (no)	Cohort	Mass (g)	SCL (mm)	SW (mm)	SH (mm)	PL (mm)	CCL (cm)	Latitude (=South)	Longitude (=East)	Photos	Remarks

Species: **Sp**=*Stigmochelys pardalis* (leopard tortoise)

Cohort: **M**=Male; **F**=Female; **J**=Juvenile

SCL=Straight carapace length; **SW**=Shell width; **SH**=Shell height; **PL**=Plastron length; **CCL**=Curved carapace length

Appendix B

Datasheet to record activity and habitat information for tortoises with and without transmitters.

											Habitat in a 5 m radius around tortoise					
Date	Time	Species	ID	Cohort	Weather	Resting / active	Refuge	Active behaviour	Food type	Food species	Dominant vegetation	% Vegetation cover	Average vegetation height	% Rocky cover	Latitude (=South)	Longitude (=East)
REMARKS																

Species: **Sp**=*Stigmochelys pardalis* (leopard tortoise)

Cohort: **M**=Male; **F**=Female; **J**=Juvenile

Weather: **Sun**; **Cloud cover** in 10% increments; **Rain**

Resting/Active: **R**=resting in a refuge; **Asun**=active in sun; **Ashade**=active in shade

Refuge: When resting record the refuge, e.g., **G**=in grasss; **Sh**=under shrub; **Cr**=in rocky crevice; **Bu**=in burrow

Active behaviour: **B**=basking; **W**=walking; **F**=feeding; **Fi**=fighting males; **C**=courtship (male persuing or mounting female); **N**=nesting

Food type (when feeding): **G**=grass; **Sh**=shrub; **H**=herb; **Fu**=fungus; **M**=moss; **I**=insect; **B**=bone; **F**=faeces; **S**=soil

Food species: when possible, record the plant or insect name of the food species

Dominant vegetation: **G**=grasses; **Sh**=shrubs; **H**=herbs; **T**=trees

% Vegetation cover: record cover where no ground is visible in 10% increments

Mean vegetation height: record mean height of vegetation to distinguish between low (<30 cm), medium (30-100 cm), and high (>100 cm)

% Rocky cover: scan the surroundings for rocky outcrops to indicate its presence in the habitat

Appendix C

Data and records for the tortoises encountered without transmitters in the study area.

Tortoise ID	Sex (M/F)	Mass (g)	Straight Carapace Length (mm)	Shell Width (mm)	Shell Height (mm)	Plastron Length (mm)	Curved Carapace Length (mm)
A1	M	584.0	150.0	126.0	98.0	140.0	266.0
A2	M	961	168.4	120.0	93.5	166.0	258.0
A3	M	856.0	153.3	106.7	90.4	133.3	254.0
A4	F	1200.0	246.6	169.5	136.0	208.0	264.0
A5	M	915.0	170.0	115.0	92.0	142.0	256.0
A6	M	918.0	184.0	118.0	96.0	145.0	268.0
A7	F	917.0	172.0	120.0	94.6	144.0	234.0
A8	M	914.0	168.0	116.0	93.0	143.0	248.0
A9	F	1300.0	186.1	128.0	92.2	160.0	264.0

Appendix D

The Honegger system (Honegger 1979) of filing marginal scutes of tortoises to give them individual numbers.

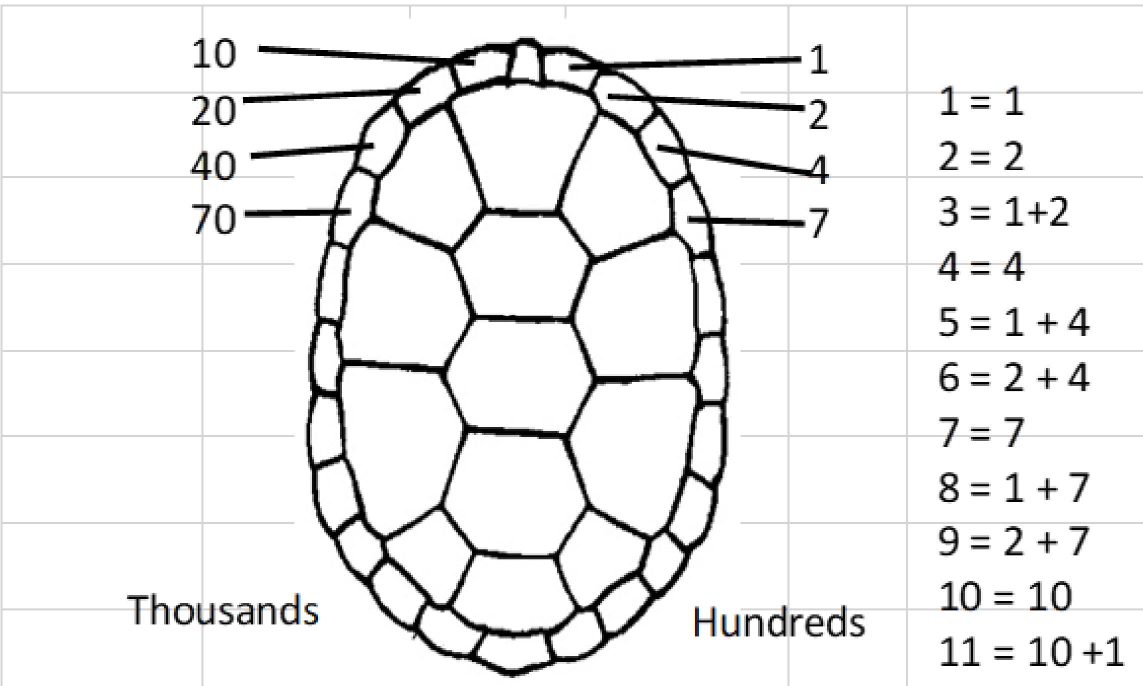

Figure D1. Hongger system for filing of tortoise scutes to provide unique identification numbers.

Appendix E

This appendix contains home range information for the three tortoises (3155, 3161, 3158) that did not have sufficient data for meaningful analyses.

Tortoise 3155

Tortoise 3155 lived along the H3 tar road between Skukuza and Afsaal, approximately midway down the road from Skukuza to Afsaal. The combined home range size for this tortoise was 4.33 ha and spanned across the road to both the east and west of the road, with the bulk of the home range being to the west of the road (Figure E1).

The mean vegetation cover in the home range was 83%. The mean height of the shrub and grass layer was 240 cm. There were no rocks or rocky outcrops in the home range.

The dominant woody plant species occurring in the home range were *Combretum apiculatum*, *Combretum hereroense* and *Euclea divinorum*. Common grass species included *Themeda triandra*, *Panicum maximum*, *Digitaria eriantha, Schmidtia pappophoroides, Eragrostis rigidior* and *Heteropogon contortus*.

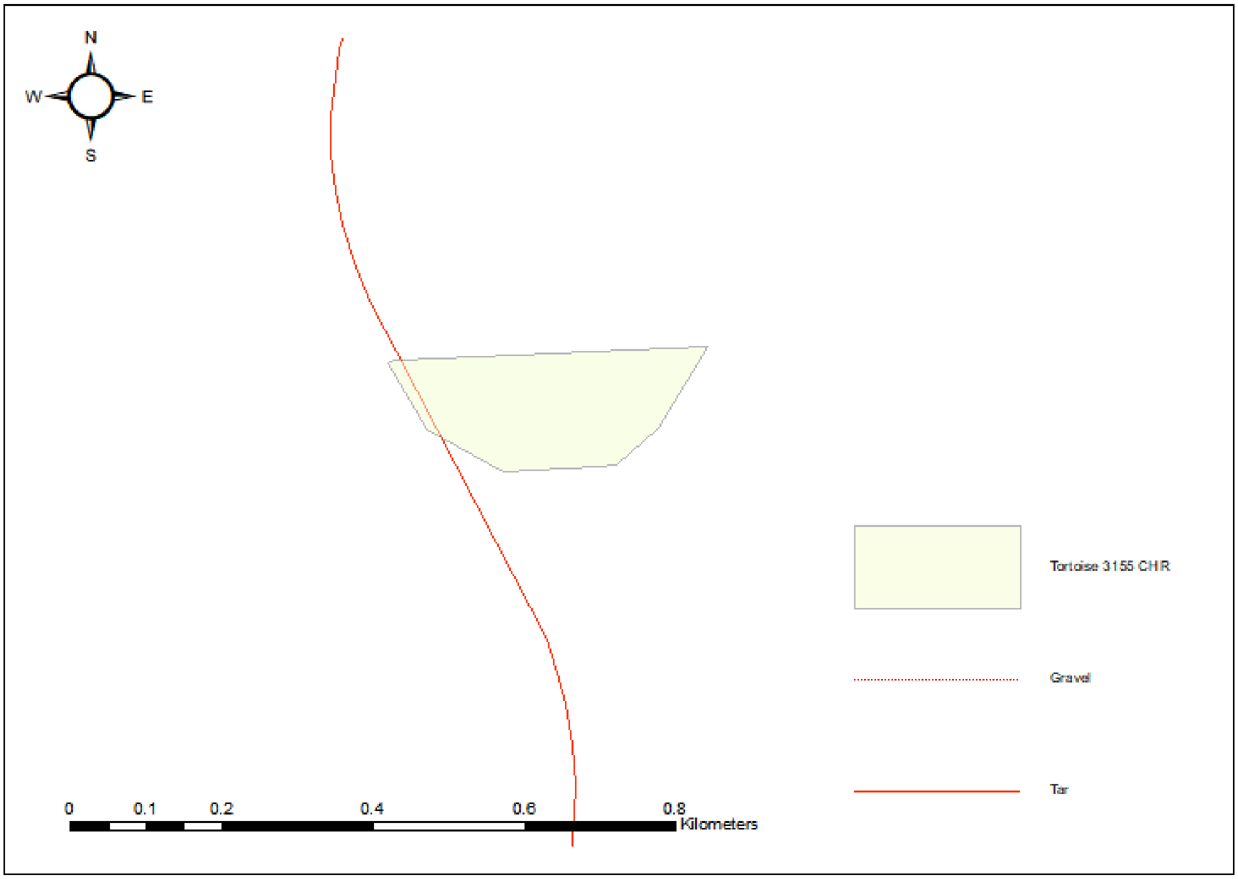

Figure E1. Combined home range for tortoise 3155. Home range size was 4.33 ha.

Seasonal home ranges for tortoise 3155 are depicted in Figure E2. The warm wet season home range was 2.63 ha in size and the cold dry season home range was 3.07 ha. For this tortoise the dry season home range was larger than the warm wet season home range and was 85.67% of the size of the dry season home range. This was likely due to the limited size of the dataset collected for this tortoise as a result of either transmitter failure, the tortoise being killed by a predator, or the tortoise moving a great distance – the tortoise could not be located after September 2019.

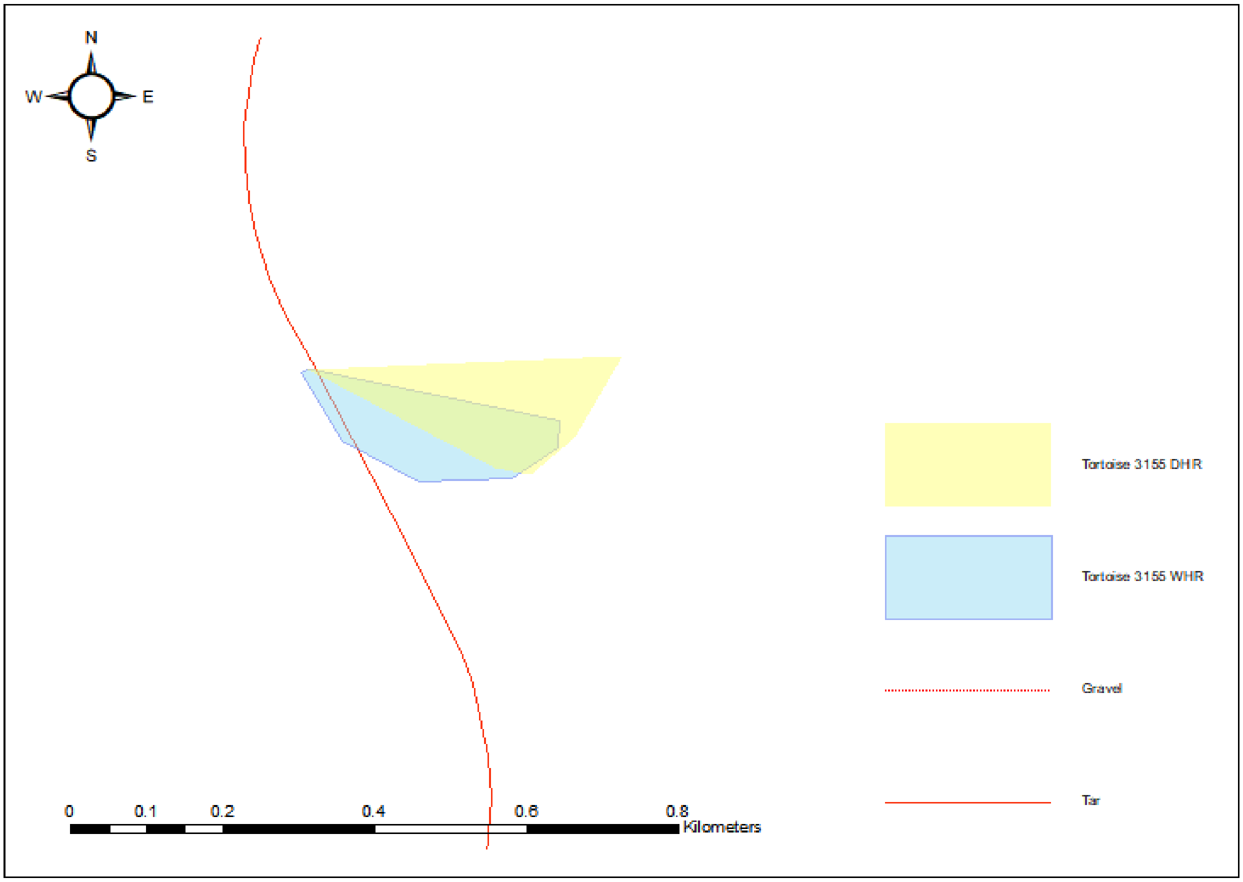

Figure E2. Warm wet and cold dry season home ranges for tortoise 3156. Warm wet season home range size was 2.63 ha and the cold dry season home range size was 3.07 ha.

Tortoise 3161

Tortoise 3161 lived along the H1-1 tar road between Skukuza and the H3 junction to Afsaal. The combined home range size for this tortoise was 1.09 ha and was situated to northwest of the road (Figure E3).

The mean vegetation cover in the home range was 73%. The mean height of the shrub and grass layer was 117 cm. There were no rocks or rocky outcrops in the home range.

The dominant woody plant species occurring in the home range were *Combretum apiculatum*, *Sclerocarya birrea* and *Terminalia sericea*. Common grass species included *Digitaria erianthra*, *Panicum maximum* and *Heteropogon contortus*.

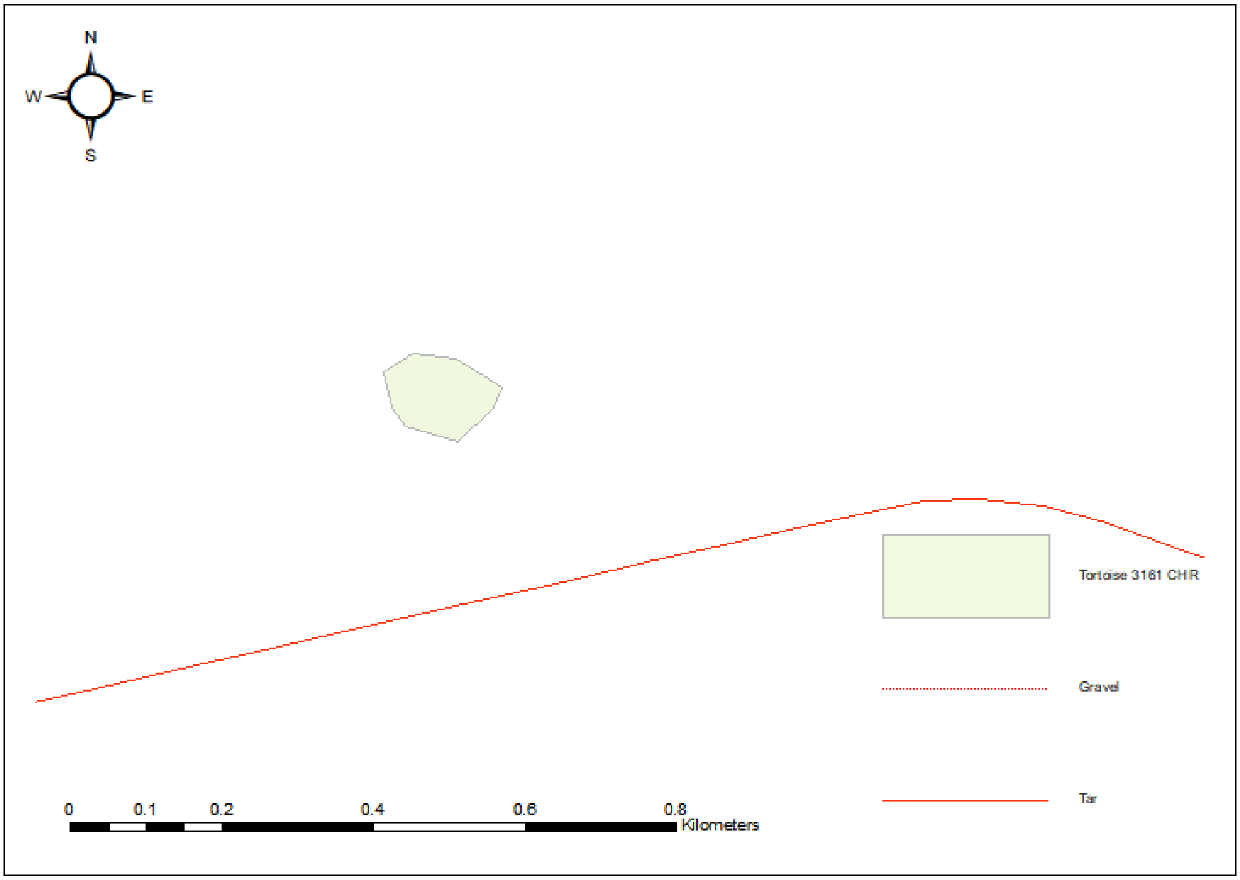

Figure E3. Combined home range for tortoise 3161. Home range size was 1.09 ha.

Seasonal home ranges for tortoise 3161 are depicted in Figure E4. The warm wet season home range was 0.23 ha in size and the cold dry season home range was 0.96 ha. As for tortoise 3155, the cold dry season home range was larger than the warm wet season home range, which was 23.96% the size of the cold dry season home range. This was likely due to the limited size of the dataset collected for this tortoise, which was as a result of either transmitter failure, the tortoise being killed by a predator, or the tortoise moving a great distance – the tortoise could not be located after July 2019.

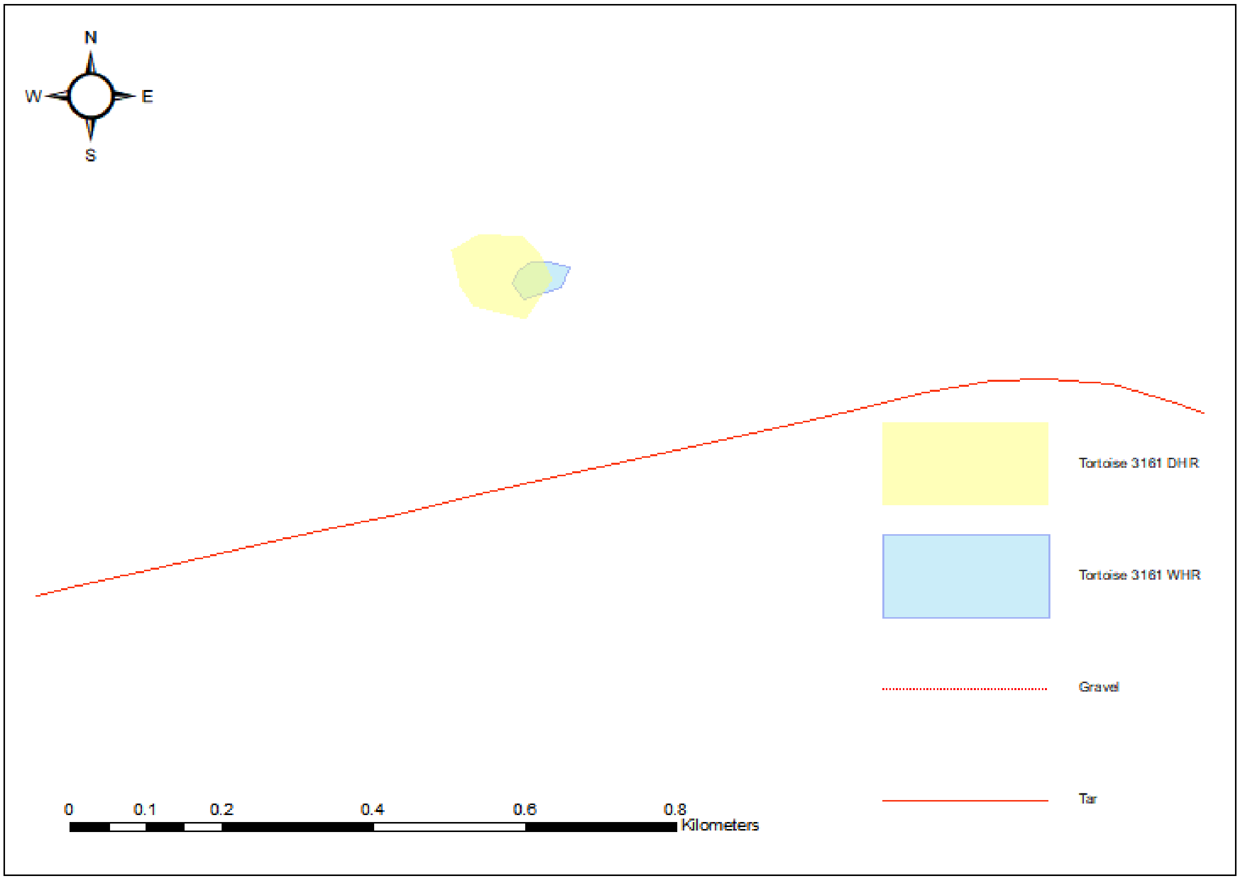

Figure E4. Warm wet season and cold dry season home ranges for tortoise 3161. Warm wet season home range size was 0.23 ha and cold dry season home range size was 0.96 ha.

Tortoise 3158

Tortoise 3158 lived along the H1-1 tar road between Skukuza and the H3 junction to Afsaal. The combined home range size for this tortoise was 3.03 ha and spanned across the road to both the north and south of the road, with the bulk of the home range being to the south of the road (Figure E5).

The mean vegetation cover in the home range was 68%. The mean height of the shrub and grass layer was 176 cm. There were no rocks or rocky outcrops in the home range.

The dominant woody plant species occurring in the home range were *Terminalia sericea Combretum heroroense* and *Dichrostachys cinerea*. Common grass species included *Digitaria erianthra*, *Bothriochloa radicans*, *Eragrostis superba*, *Brachiaria decumbens* and *Themeda triandra*.

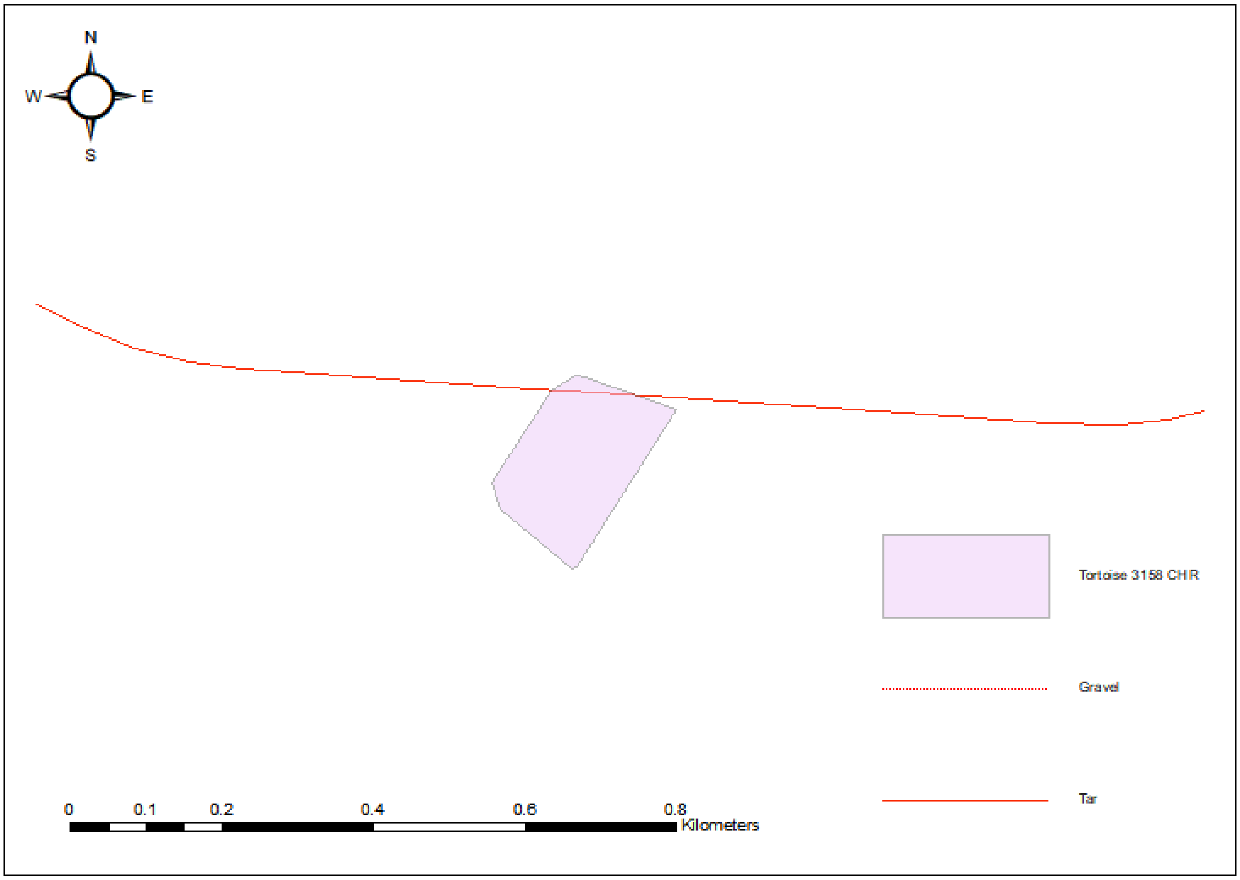

Figure E5. Combined home range for tortoise 3158. The home range size was 3.03 ha.

Seasonal home ranges for tortoise 3158 are depicted in Figure E6. Warm wet season home range was 1.86 ha in size and cold dry season home range was 1.64 ha. The cold dry season home range was 88.17% of the warm wet season home range size.

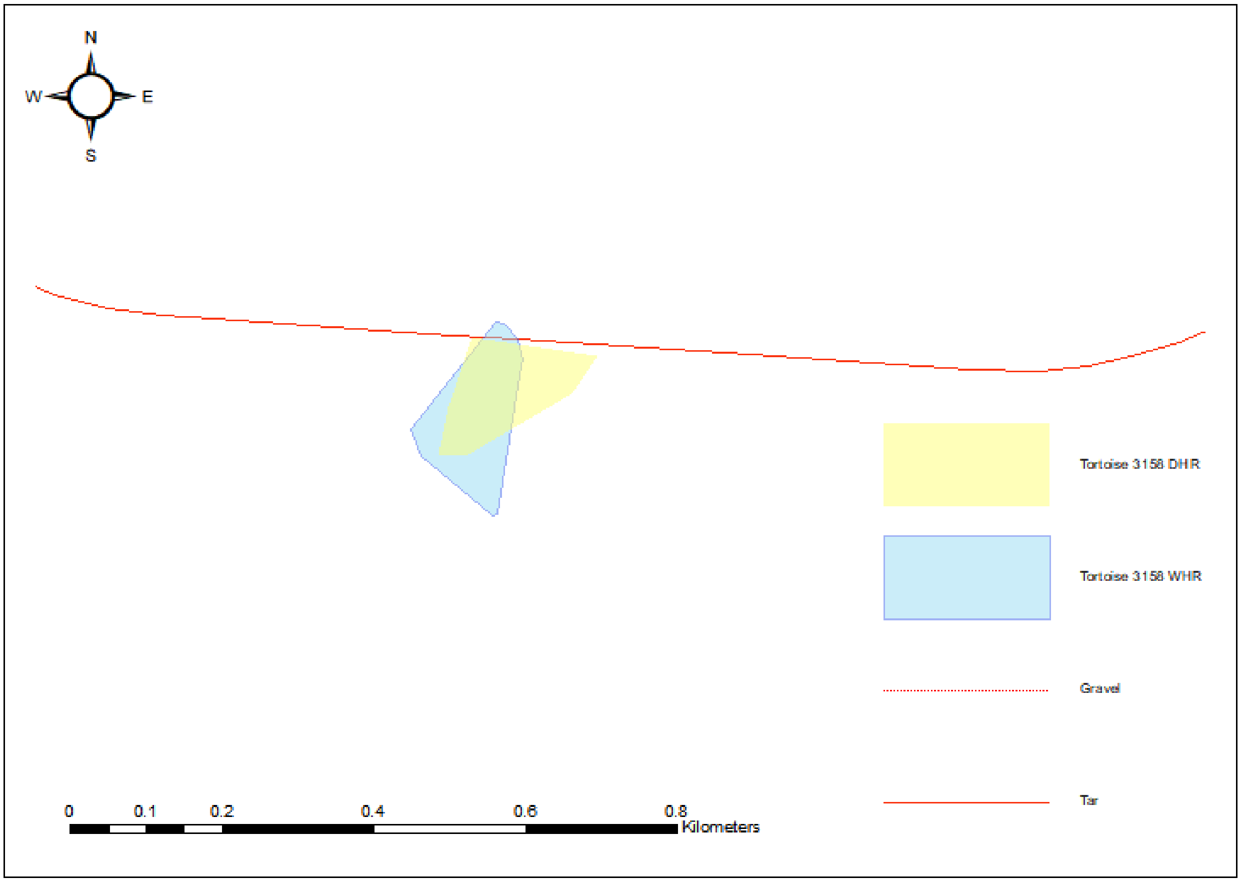

Figure E6. Warm wet season and cold dry season home ranges for tortoise 3158. Warm wet season home range size is 1.86 ha and cold dry season home range size is 1.64 ha.

Appendix F

This appendix contains movement information for the three tortoises (3155, 3161, 3158) that did not have sufficient data for meaningful analyses.

Annual and seasonal daily movement patterns

Tortoise 3155

Combined warm wet season and cold dry season daily movements for tortoise 3157 are shown in Figure F1. Mean daily distance travelled was 16.10 m, minimum daily distance was 1.00 m and maximum was 165.86 m.

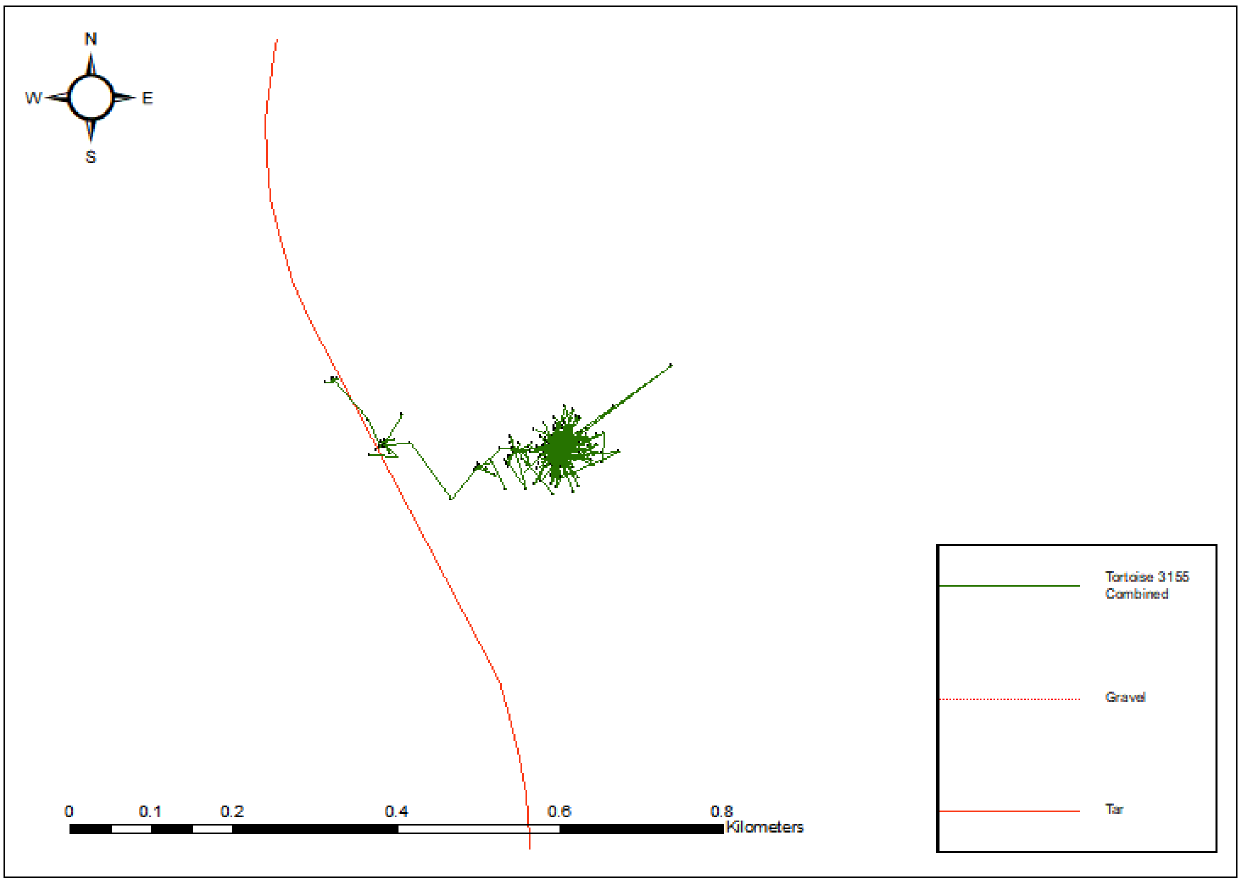

Figure F1. Combined warm wet season and cold dry season daily movements for tortoise 3155.

Warm wet season daily movements for tortoise 3155 are shown in Figure F2. Mean daily distance travelled in the warm wet season was 21.18 m, minimum daily distance was 1 m and maximum were 98.03 m.

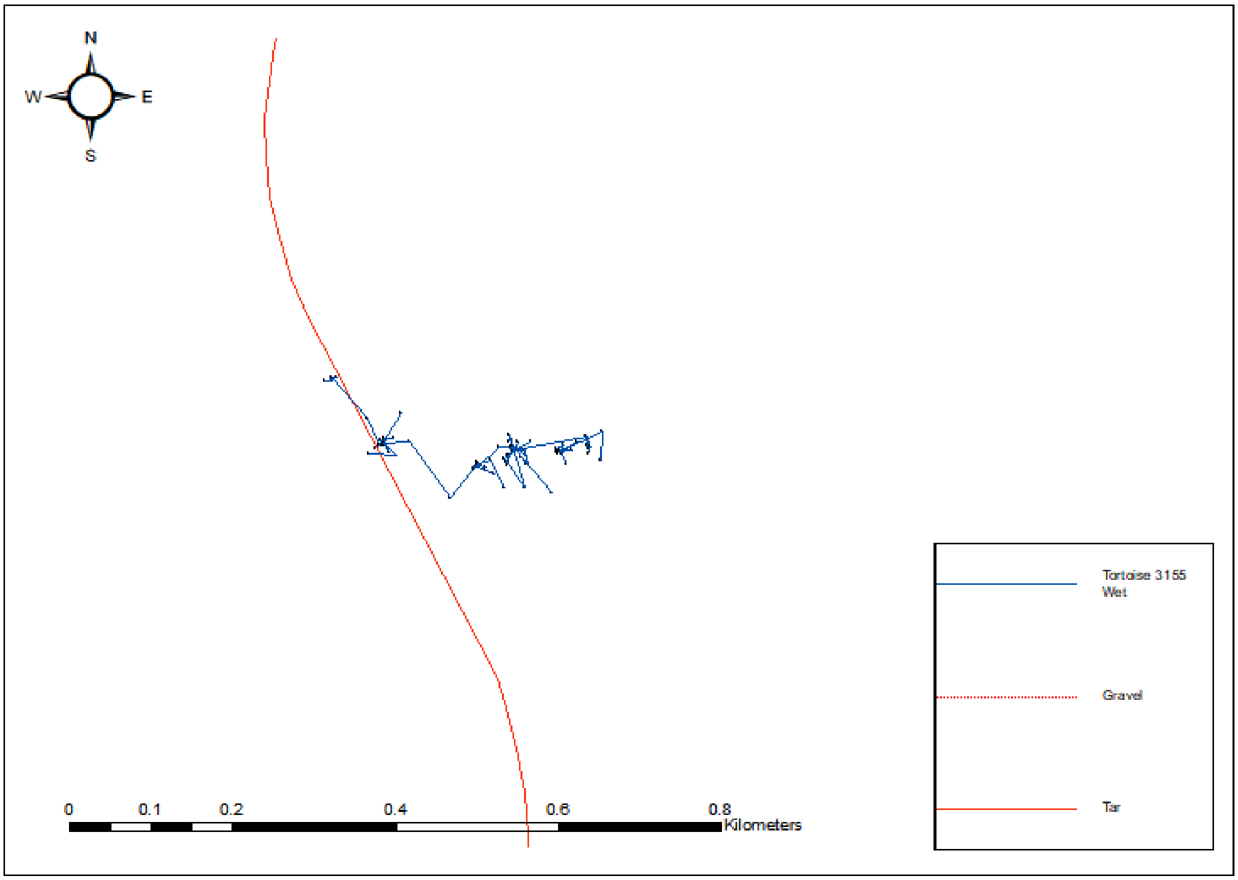

Figure F2. Warm wet season daily movements for tortoise 3155.

Dry season daily movements for tortoise 3155 are shown in Figure F3. The mean daily distance travelled in the dry season was 15.43 m, minimum daily distance was 1.00 m and maximum was 165.86 m.

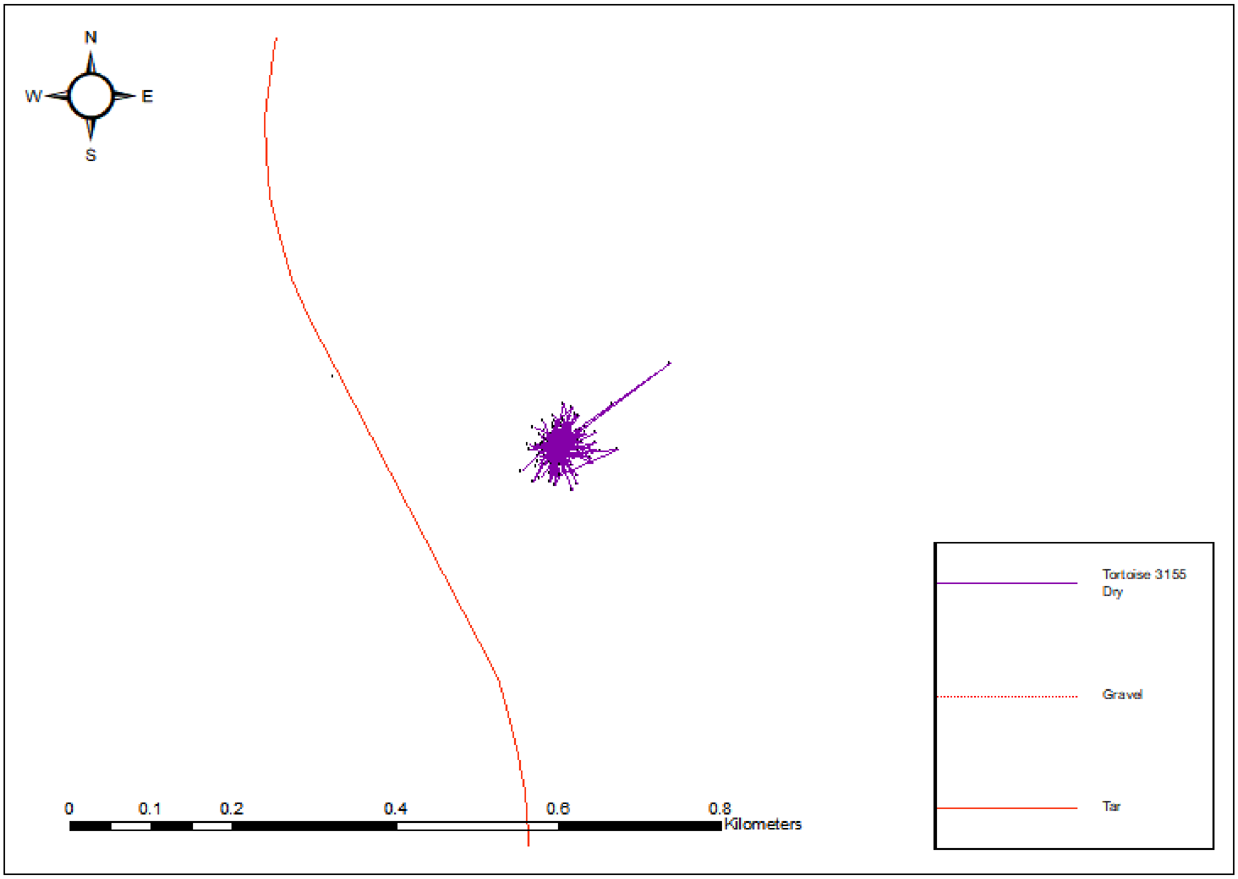

Figure F3. Dry season daily movements for tortoise 3155.

Tortoise 3161

The combined warm wet and cold dry season daily movements for tortoise 3161 are depicted in Figure F4. Mean daily distance travelled was 15.24 m, minimum daily distance was 0 m and maximum were 72.80 m**.**

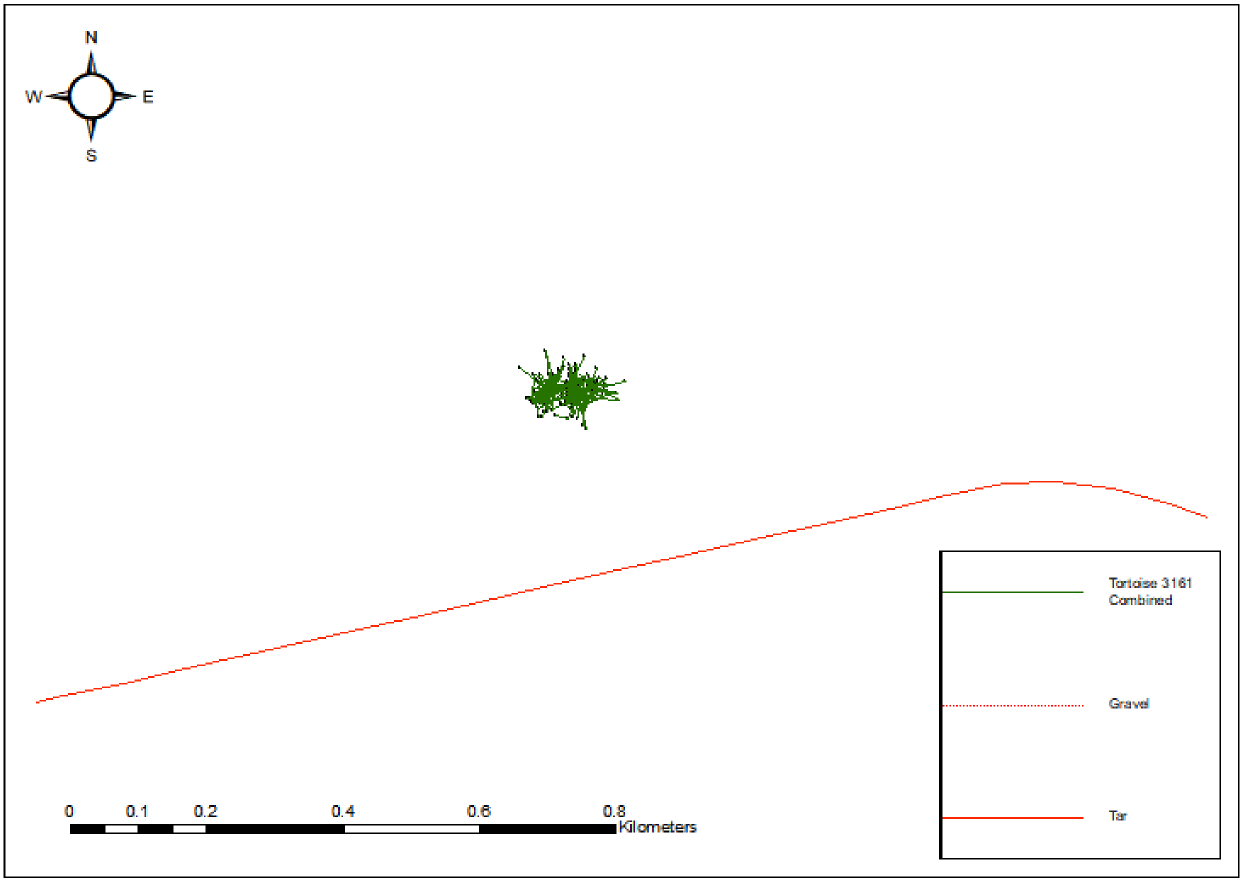

Figure F4. Combined warm wet and cold dry season daily movements for tortoise 3161.

The warm wet season daily movements for tortoise 3161 is shown in Figure F5. Mean daily distance travelled in the warm wet season was 13.34 m, minimum daily distance was 2.00 m and maximum were 40.02 m.

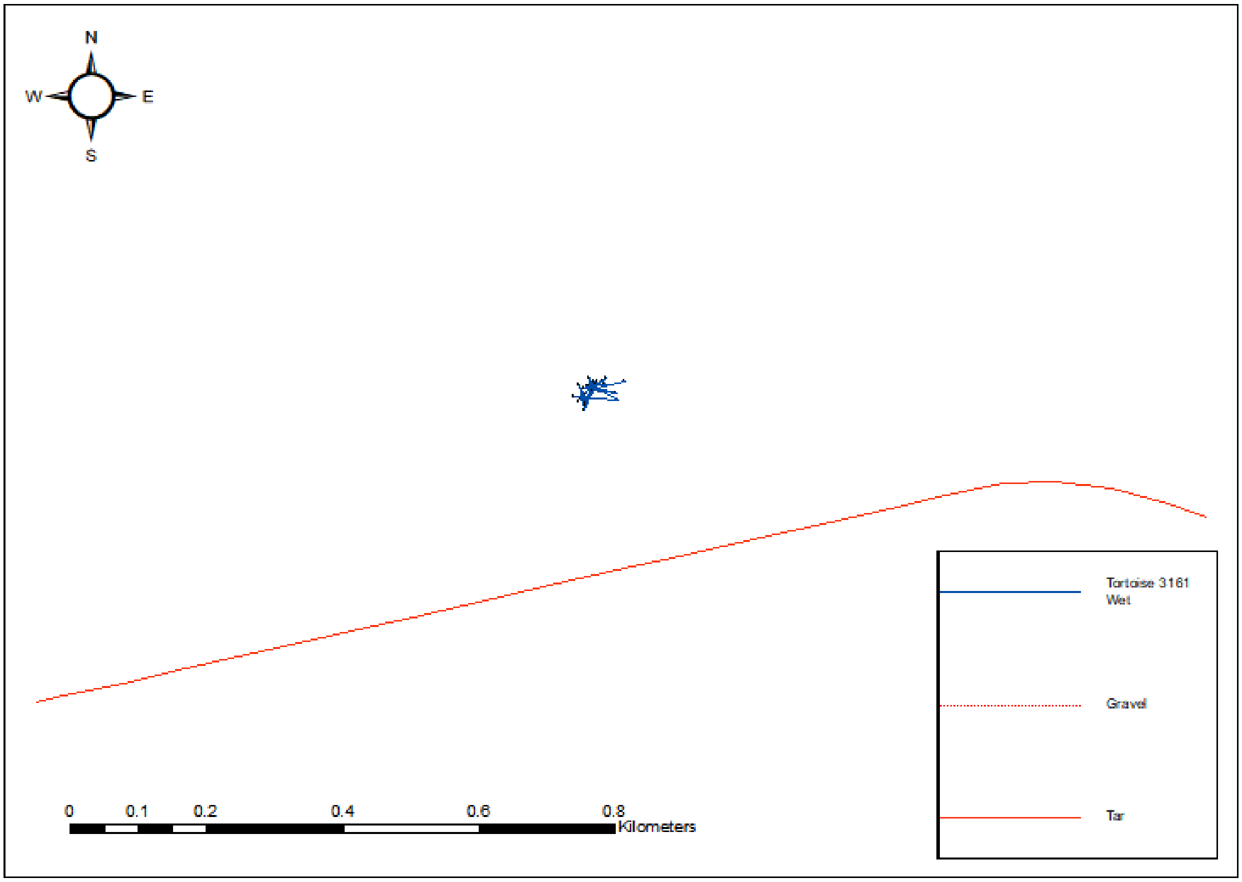

Figure F5. Warm wet season daily movements for tortoise 3161.

Daily cold dry season movements for tortoise 3161 is shown in Figure F6. The mean daily distance travelled was 15.51 m, the minimum daily distance was 0 m and the maximum were 72.80 m.

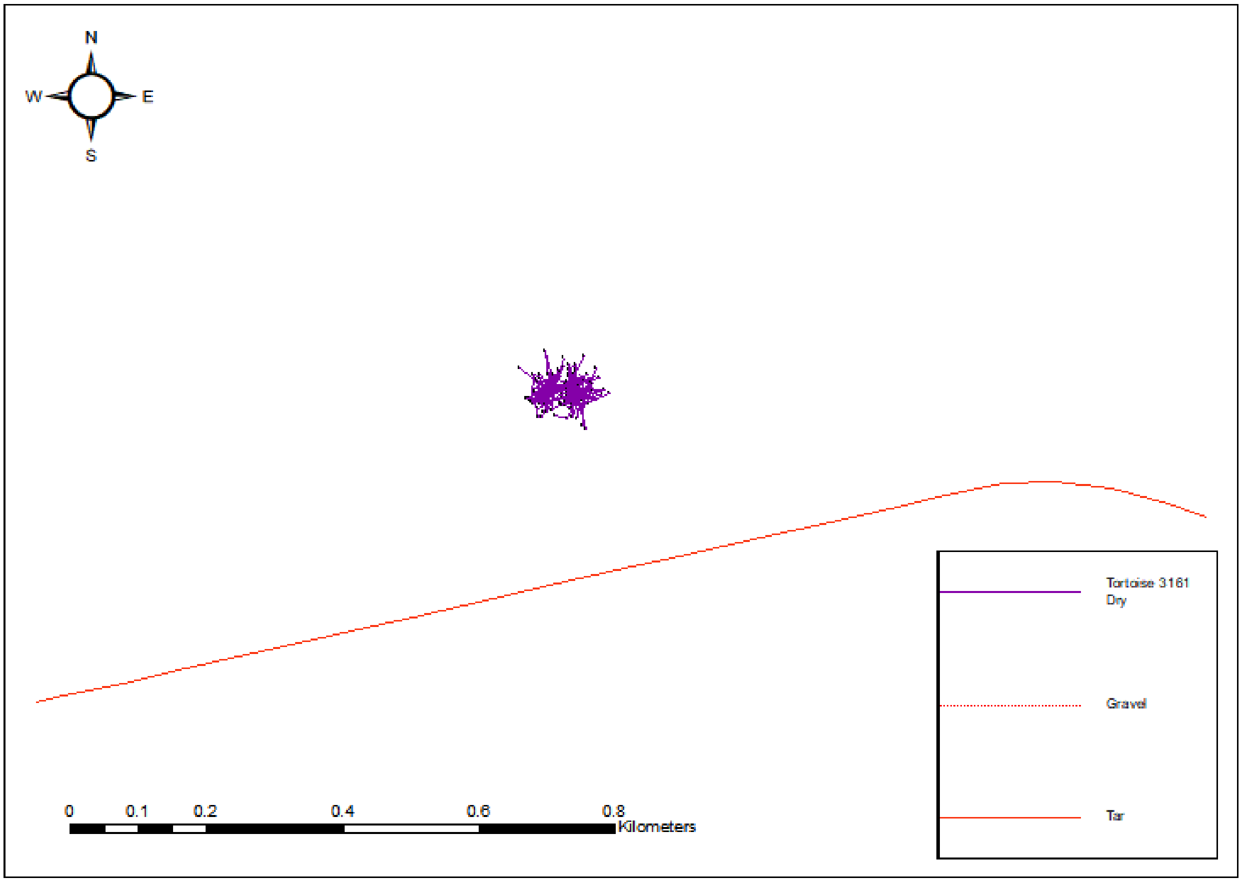

Figure F6. Dry season daily movements for tortoise 3161.

Tortoise 3158

The combined warm wet and cold dry season daily movements for tortoise 3158 are depicted in Figure F7. Mean daily distance travelled was 15.91 m, minimum daily distance was 0 m and maximum were 144.94 m.

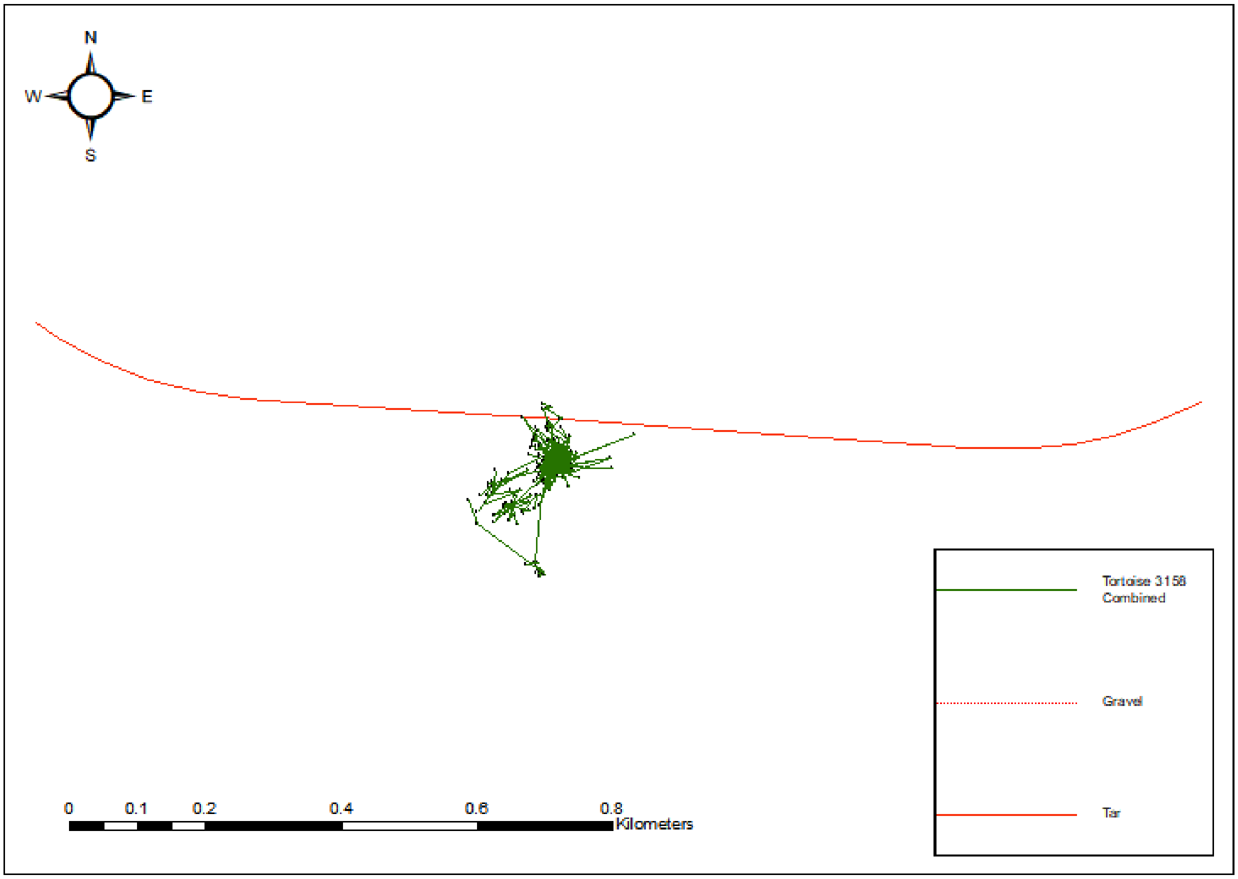

Figure F7. Combined warm wet and cold dry season daily movements for tortoise 3158.

The warm wet season daily movements for tortoise 3158 are shown in Figure F8. Mean daily distance travelled in the warm wet season was 18.74 m, minimum daily distance was 1.00 m and maximum were 92.66 m.

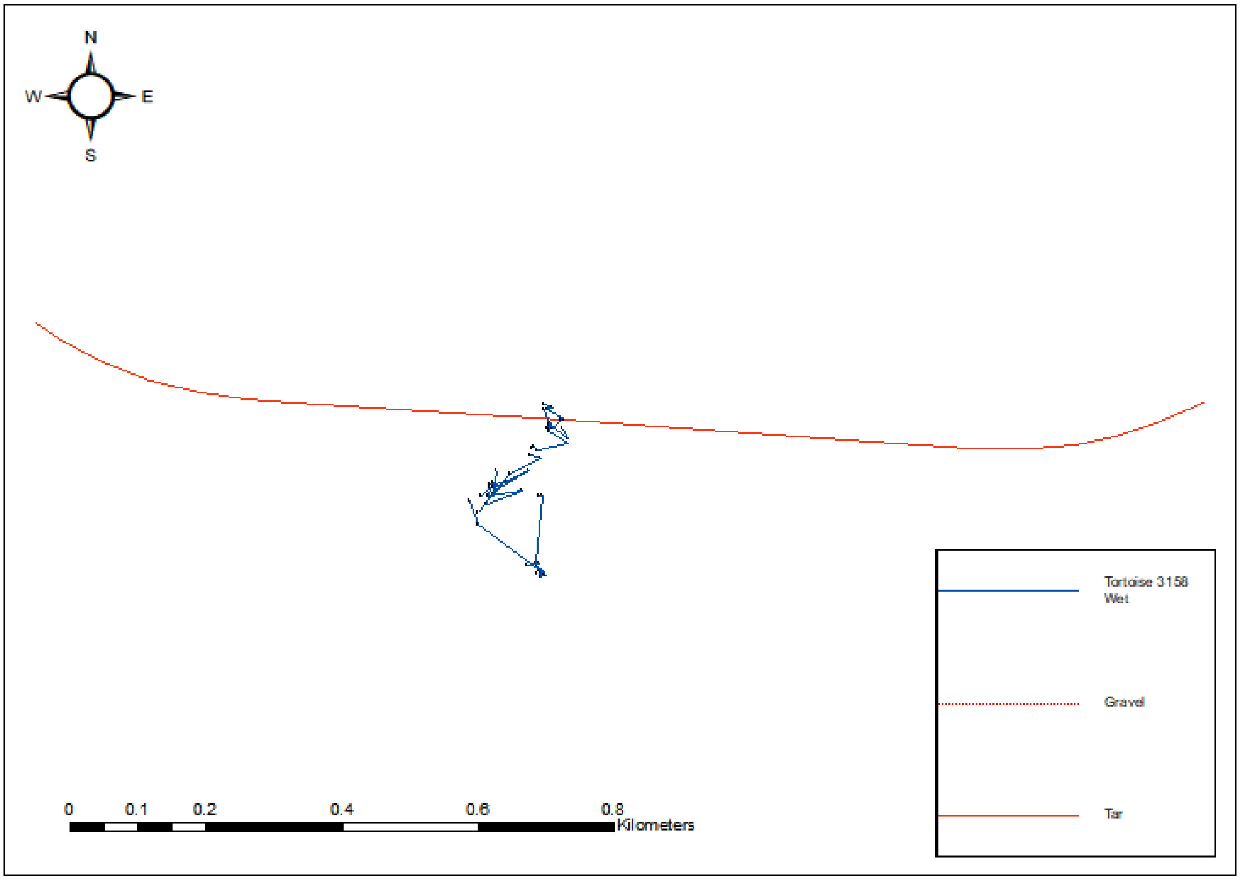

Figure F8. Warm wet season daily movements for tortoise 3158.

The cold dry season daily movements for tortoise 3158 is shown in Figure F9. The mean daily distance travelled in the cold dry season was 15.62 m, the minimum daily distance was 0 m and the maximum were 144.94 m.

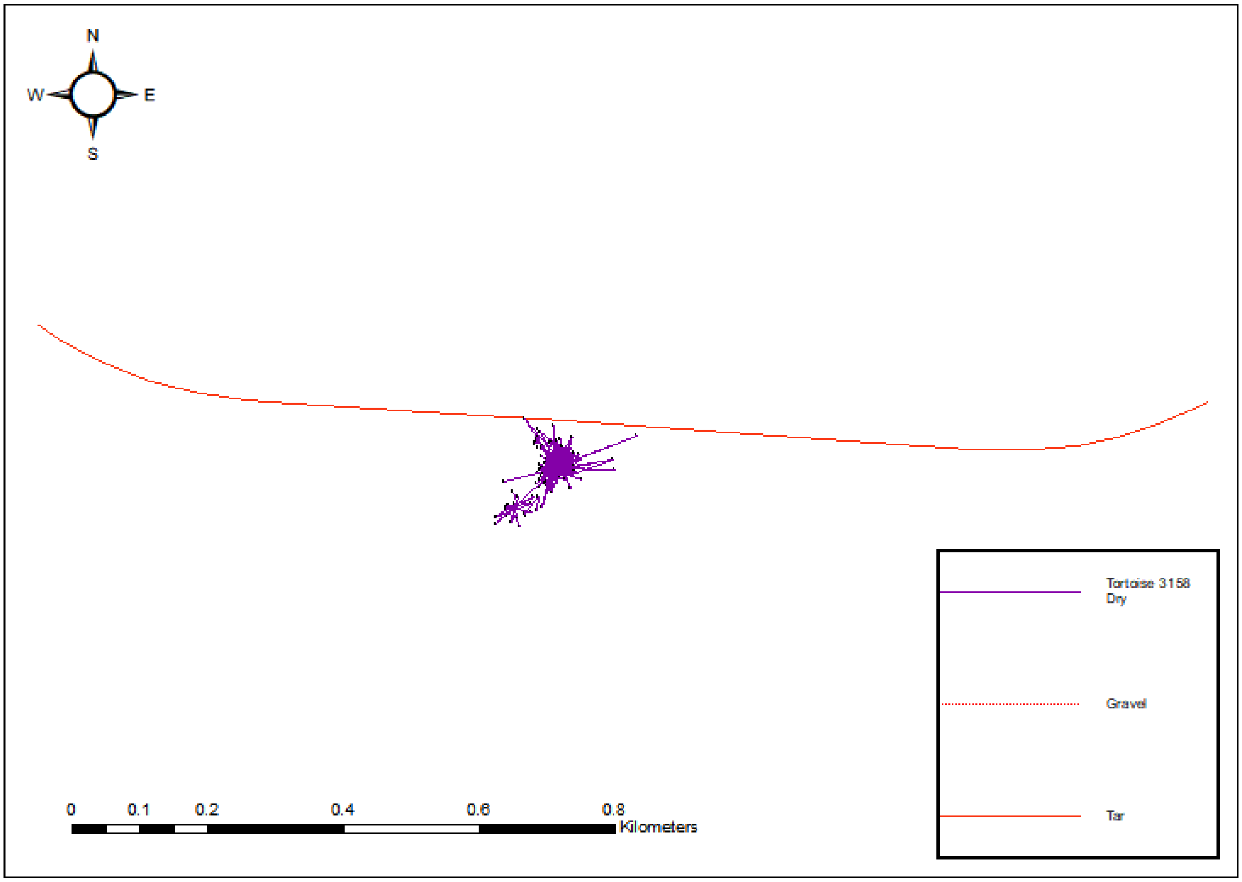

Figure F9. Dry season daily movements for tortoise 3158.