ECOLOGY OF RESIDENT TEMMINCK'S PANGOLIN (*SMUTSIA TEMMINCKII)* IN CENTRAL NAMIBIA

Kelsey Anne Prediger

Thesis presented in partial fulfilment of the requirements for the degree of **Master of Natural Resources Management** at the **Namibia University of Science and Technology.**

Supervisor: Dr. Morgan Hauptfleisch

Namibia University of Science and Technology

Co-supervisor: Dr. Monique MacKenzie

University of St. Andrews

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DECLARATION

I, Kelsey Anne Pediger, hereby declare that the work contained in the thesis entitled: Ecology of resident Temminck's pangolin (*Smutsia temminckii*) in central Namibia**,** is my own original work and that I have not previously in its entirety or in part submitted it at any university or higher education institution for the award of a degree.

Signature:..... Date: 3 October 2021

RETENTION AND USE OF THESIS

I, Kelsey A. Prediger, being a candidate for the degree of Master of Natural Resources Management accept the requirements of the Namibia University of Science and Technology relating to the retention and use of theses deposited in the Library and Information Services.

In terms of these conditions, I agree that the original of my thesis deposited in the Library and Information Services will be accessible for purposes of study and research, in accordance with the normal conditions established by the Librarian for the care, loan or reproduction of theses.

Signature:..... Date: 3 October 2021.....

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DEDICATION

I would like to dedicate this thesis to my father who suddenly passed away during its' completion in November 2019. I am eternally grateful for the sense of humor and adventurous spirit he has instilled in me for I would not have survived this thesis without them.

ABSTRACT

Pangolins are the most trafficked mammals worldwide and as Asian species' numbers have drastically declined, African pangolin species have been increasingly targeted for the illegal wildlife trade. Due to their nocturnal and elusive behaviour, many pangolin species, especially Southern Africa's Temminck's pangolin (*Smutsia temmicnkii*), are understudied and poorly understood. Previous research predominantly stems from the 1990's and demonstrates highly variable results in pangolin ecology and behaviour. This study represents the first detailed research within Namibia, focusing on the ecology of Temminck's pangolin in the central shrub savannah habitat on a fenced private nature reserve. The overall objective of this study was to contribute to knowledge of the basic ecology of Temminck's pangolin to help inform conservation strategies for pangolins through understanding home range sizes and overlaps between individuals, prey preference, and burrow selection. The study was conducted from September 2018 to March 2020 utilizing VHF telemetry, GPS tracking, and field observations. A total of 46 resident individuals were identified on the 22,000 hectare private reserve and 36 were tagged. Home range sizes were calculated for the entire tagging period utilizing MCP and 95% and 50% Kernel density models. Home range and core area during the growing and non-growing seasons for male and female individuals were calculated using 95% and 50 % Kernel Density models and Complex Region Spatial Smoother (CReSS) analysis. Home range sizes on average were 6.32 km2 – 23.97 km^2 for males and between 5.10 km^2 – 11.11 km^2 for females. Core area sizes on average ranged from 1.81 km^2 – 7.03 km^2 for males and between 1.75 km^2 – 2.17 km^2 for females. Male home ranges overlapped with four or more female home ranges, showing a polygamous mating system. During the growing season there were 53 instances of home range overlap and 23 instances of core area overlap. During the non-growing season there were 25 instances of home range overlap and 7 instances of core area overlap. Pangolins mostly fed by excavating nests, showed clear preference for 6 species of ants and termites, and fed almost exclusively on *Anoplolepis* spp. during the growing season although this species was not the most abundant in the area. The study animals preferred burrows of at least one meter deep located at the base

of termite mounds in dense thornshrub of mostly *Senegalia mellifera*. Home range and social dynamics were comparable to those found by Heath & Coulson in Zimbabwe and the preference for *Anoplolepis* sp. and burrows under termite mounds is comparable to studies done in South Africa. The study assists in determining likely densities of pangolins in Namibia's thornbush savanna and provides prey and burrow preference variables which can be used to determine suitable release sites for confiscated live trafficked pangolins.

Chapter 1: Introduction

1.1 Biodiversity loss

Biodiversity across the world is increasingly under threat and facing diminishment as habitat loss, climate change, poaching and wildlife trafficking, and pollution are ever growing threats (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, 2019). Approximately 75% of all terrestrial habitat has been severely altered by humans and over 290 million hectares of native forest cover was lost from 1990-2015 (Intergovernmental Science Policy Platform on Biodiversity and Ecosystem Services, 2019). The average global temperature is increasing by 1 degree Celsius per decade, 10 times higher than pre-industrial rates (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, 2019).

Some research suggests we have entered the sixth mass extinction at the start of the late Pleistocene Age and since then over 351 known mammal species have gone extinct (Andermann et al., 2020). Over a million plant and animal species are threatened with extinction in the next few decades (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, 2019). Loss of species can have a negative impact on the structure and productivity of entire ecosystems (Cardinale et al., 2012). It is important, now more than ever, to better understand the current populations and ecological statuses of vulnerable, keystone species to help determine conservation management practices and methods to be implemented to secure a future on Earth for these species.

1.2 Pangolin species, status, and distribution

1.2.1 General information

Pangolins, also known as scaly anteaters, are solitary, predominantly nocturnal, and myrmecophagous. There are eight species found in a range of habitats including tropical and sub-tropical forests, dry woodland, and savannas. They are covered in scales made of keratin which provide protection from carnivores while they are outside the safety of their burrows (Wang et al., 2016). Pangolins leave their burrows to forage for termites and ants using their exceptional sense of smell to sniff out nests, then their long sticky tongue navigates nest tunnels.

Their vision and hearing are considered to be poor and despite their dinosaur or reptilian-like appearance, they are mammals (Pietersen et al., 2020; Skinner & Chimimba, 2005).

The keratinous scales, which have provided protection for the species for over 66 million years, are also now leading to their demise (Gaudin, Emry, & Wible, 2009).Traditionally in Africa, pangolins and their scales were moderately used for bushmeat and muti, which is traditional African medicine (Ingram et al., 2017), but now there is a rising demand for African pangolin meat and scales from Asian markets due to the overexploitation of the Asian species which is putting increased pressure on the African species (Challender, Waterman, & Baillie, 2014; Pietersen, McKechnie, & Jansen 2014a; Pietersen et al., 2016, Ingram et al., 2017). Pangolin scales are used similarly to rhino horn, since both are comprised of keratin.

In 2014, pangolins were categorized as the most trafficked wild animal worldwide and the numbers of individuals seized are increasing exponentially annually (Challender, Waterman, & Baillie, 2014). All eight species were given the highest level of protection listed under CITES in 2016 (Convention of International Trade of Endangered Species), Appendix 1 (CITES, 2016). All four Asian species are categorized by the IUCN as either Critically Endangered or Endangered, whereas the four African species are listed as Vulnerable, Endangered, or Critically endangered (Pietersen et al., 2016; Pietersen et al., 2019). Poaching has severely depleted Asian pangolin populations, even suggesting local extinction of some species (Challender et al., 2014).

1.2.2 Phylogeny of pangolins

The phylogeny and taxonomy of pangolins is complex (Gaubert et al., 2020). The original association of pangolins with Xenarthrans (anteaters, armadillos, and sloths), other ant-eating mammals, existed from linking edentate mammals to one another based upon morphological similarities (Gaudin et al., 2009; Gaubert et al., 2020; Gaudin et al., 2020). DNA sequencing made it possible to understand the evolution of pangolins, demonstrating a closer link to the order Carnivora, which is considered a sister group (Gaudin et al., 2009; Gaubert et al., 2020; Gaudin et al., 2020). All extant species of pangolin are in the order Pholidota and the family

Manidae within 3 genuses: Manis, Phataginus, and Smutsia (Gaudin et al., 2009; Gaubert et al., 2020). There are eight extinct species of pangolin, with the first origin in Laurasia, as fossils have been found in Europe and North America (Gaubert et al., 2020). *Smutsia temminckii* was originally given the name *Manis temminckii,* however both ground dwelling African species were switched to Smutsia in the 1980's as more genetic information became available (Gaudin et al., 2009; Gaubert et al., 2020; Gaudin et al., 2020).

1.2.3 Asian species

The four Asian species include the Chinese pangolin (*Manis pentadactyla*)(Challender et al., 2019), the Indian pangolin (*Manis crassicaudata*) (Mahmood et al*.,* 2019), the Philippine pangolin (*Manis culionensis*)(Shoppe et al., 2019), and the Sunda pangolin (*Manis javanica*) (Challender et al., 2019). All species found in Asia are now endangered or critically endangered due to the pressure from Traditional Chinese Medicine (TCM) and their meat being eaten as a delicacy (Challender et al., 2019; Challender et al., 2019; Mahmood et al., 2019; Shoppe et al., 2019). Poaching has severely depleted Asian pangolin populations, even suggesting local extinction of some species in some areas (Challender et al., 2014). As these species are becoming harder to find within Asia, large shipments from Africa are being intercepted more and more frequently (Challender & Hywood, 2012; Challender et al., 2014; D'Cruze et al., 2018; Heinrich et al., 2016; Heinrich et al., 2017).

1.2.4 African species

The four African species include the Black-bellied pangolin (*Phataginus tetradactyla*) (Ingram et al., 2019), Giant pangolin (*Smutsia gigantea*) (Nixon et al., 2019), Temminck's pangolin (*Smutsia temminckii)*(Pietersen, Jansen, & Connelly, 2019)*,* and the White-bellied pangolin (*Phataginus tricuspis*)(Pietersen et al., 2019). All species in Africa range from being critically endangered to vulnerable, however little is known about the ecology and population sizes of those listed as (Pietersen, 2016; Pietersen, Jansen, & Connelly, 2019). Traditionally in Africa, pangolins have been used for sustenance, traditional medicinal, and spiritual or superstitious value (Baiyewu et al., 2018; Boakye et al., 2014; Boakye et al., 2015; Boakye et al., 2016; Boakye, 2018; Bräutigam et al., 1994;

Cunningham & Zondi, 1991; Ingram et al., 2018; Pietersen et al., 2014b; Pietersen et al., 2016; Pietersen et al., 2019; Setlalekgomo, 2014; Shepherd, 2017; Soewu & Ayodele, 2009). In recent years, they are becoming more threatened by the illegal global trade and electric fencing resulting in electrocution (Challender & Hywood, 2012; Challender, Waterman, & Baillie, 2014; Ingram et al*.,* 2017; Pietersen, 2013; Pietersen, McKechnie, & Jansen 2014a).

1.2.5 General literature on *Smutsia temminckii*

The Temminck's pangolin has many common names including ground pangolin, Cape pangolin, and Steppe pangolin (Jacobsen, 1991; Pietersen, Jansen, & Connelly, 2019). In Namibian local languages it is known as Ietermago, Ongaka, Ngaka, as well as several others. This long list of names is unsurprising given their large range, which spans eighteen African countries, from southern Africa north into Chad and Sudan (Pietersen et al*.,* 2016; Pietersen, Jansen, and Connelly, 2019; Skinner & Chimimba, 2005). *S. temminckii* is known as the only pangolin species that is water independent and adapted to arid regions of Africa and they can survive in areas with as little as 250 mm of rainfall (Pietersen et al*.,* 2016; Pietersen, Jansen, & Connelly, 2019). Sufficient prey and available burrows are considered important factors in their habitat suitability. Challender, Waterman, and Baillie (2014) recommend defining habitat suitability, where possible, along with studies of home ranges, movement, and distribution of pangolins through time, to further allow the identification of release sites for trafficked pangolins, as a top priority.

1.2.6 Existing research

Research on the Temminck's pangolin has been limited in comparison to Asian species as they are elusive, predominantly nocturnal, and live alongside dangerous wildlife (Pietersen & Challender, 2020). To date, research has focused on basic ecology including home range size, dietary preference, and foraging behavior, which has demonstrated variable results in different regions (Heath & Coulson, 1997a; Pietersen, McKechnie & Jansen, 2014a; Richer, Coulson, & Heath, 1997; Swart, 2013; van Aarde, Richardson & Pietersen, 1990). Morphological data is limited and demonstrates larger sizes (weight and length) in areas of higher rainfall (Heath & Coulson, 1998; Jacobsen, 1991; Pietersen, 2013, Pietersen et al., 2020). Ecological and behavioral observations on *S. temminckii* have been documented in the

Northern Cape, Limpopo, Mpumalanga provinces of South Africa (Jacobsen et al., 1991; Kyle R., 2000; Pietersen, 2013; Swart, 1996; Swart, 2013; van Aarde, Richardson, & Pietersen, 1990), north-western Zimbabwe (Heath & Coulson, 1997a; Richer, Coulson, & Heath, 1997), and southern Sudan (Sweeney, 1956).

These studies have collected spatial data from VHF tracking of resident individuals with data analysed utilizing MCP and 95% kernel density methodology with home range sizes of large variation ranging from 0.17 km^2 to 23.90 km^2. Heath and Coulson (1997a) found MCP home ranges from 0.17 km^2 to 23.38 km^2. In Mpumalanga, South Africa, Swart (2013) recorded a smaller variation of home range sizes with males ranging from 9.28 km^2 to 22.98 km^2 MCP and females ranging from 0.65 km^2 to 6.66 km^2 MCP. The MCP home ranges found by Van Aarde (1990) in Limpopo had an even smaller range from 1.30 km^2 to 7.9 km^2. Adult pangolins in the Kalahari of South Africa had home ranges varying from 0.69 km^2 to 23.90 km^2 (Pietersen, McKechnie, & Jansen, 2014b). Heath & Coulson (1997a) and Swart (2013) describe a polygamous mating system with males having overlap with multiple females and Pietersen, McKechnie, & Jansen (2014a) found male and female home ranges to be similar in size indicating a monogamous mating system.

Pitfall trapping was used in three instances to determine abundance of ant and termite prey species (Swart 1999, Pietersen 2013, Pietersen, McKechnie, & Jansen, 2014b). Diet and foraging behaviour varies amongst regions; however all research demonstrates prey preference for species typically not the most abundant in the habitat (Pietersen et al., 2016; Richer, Coulson, & Heath, 1997; Swart, 1996; Sweeney, 1956).

Multiple studies found pangolins predominantly utilize burrows dug by other species such as aardvark (*Orycteropus afer)*, Cape porcupines (*Hystrix africaeaustralis)*, and warthogs (*Phacochoerus* spp.*)* and occasionally rest in caves, thick vegetation, and hollowed out termitaria (Jacobsen et al*.,* 1991; Heath and Coulson, 1997a; Pietersen et al., 2014; Pietersen et al., 2020; Swart, 2013;).

Translocation and release actions have demonstrated both success and failures in South Africa (Jacobsen et al., 1991; Heath and Coulson, 1997b; Meyer, 2020). Jacobsen et al. (1991) tagged and released two trafficked pangolins; both were found dead of spear or knife wounds within 10 days of release. Heath & Coulson (1997b) relocated two resident females and released one juvenile rescued from the wildlife trade. One female returned to her original home range and the other lost the transmitter within 30 days of release; the released juvenile established a home range after 19 days of continuous movement. Meyer (2020) released 67 confiscated pangolins, of which 41 could be monitored and 29 survived. Following release, 17 individuals moved off-site, which is comparable to dispersal behaviour observed in Namibia, where 4 of 5 released pangolins left the reserve boundaries within 7 days (K. Prediger unpublished data).

Research into threats and local trade and utilization of *S. temminckii* has been described in Botswana, South Africa, and Zimbabwe (Baiyewu et al., 2018; Ingram et al., 2018; Pietersen et al., 2014b; Setlalekgomo, 2014; Shepherd, 2016).

Active research is being conducted at Tswalu Kalahari Reserve on the response of *S. temminckii* to climate change and the dispersal patterns of juvenile pangolins (Smith, 2019).

The only documented research in Namibia prior to this study was conducted from 2011-2013 in North-central Namibia. This data was preliminary and published in blog format (Nebe and Rankin unpublished data). The study concentrated on increasing knowledge of S. temminckii's basic survival strategies in dry-land savannahs and results included documentation of essential conservation practices and procedures.

The above research has helped contribute to a general understanding of pangolin ecology and their threats, however the variance of findings in the social structure and behaviors of this

species highlight the need for further work towards a better understanding across their vast geographical range.

1.3 Threats to pangolins

1.3.1 Global threats

Whole pangolins, scales, and parts used in Traditional Chinese Medicine (TCM) for superstitious value and consumption as a delicacy have severely depleted Asian pangolin populations, some to local extinction (Challender & Hywood, 2012; Challender, Waterman, & Baillie, 2014; D'Cruze et al., 2018; Heinrich et al., 2017). China and Vietnam view pangolins as a culinary delicacy and their cultures also believe pangolin scales and body parts to have healing powers in TCM (Heinrich et al., 2017; Pietersen, McKechnie, & Jansen, 2014a). The Asian market's continued and growing demand from Africa for whole pangolins and pangolin parts has resulted in African species being increasingly trafficked and intercepted from the illegal wildlife trade (Challender & Hywood, 2012; Challender, Waterman, & Baillie, 2014; Heinrich et al., 2017; Hornor, Thorne, & Shaver, 2020; Heinrich et al., 2017).

1.3.2 Local Threats

There are a number of natural and anthropogenic threats to the long term survival of Temminck's pangolin in Africa, which include predation, climate change, drought, veld fires, electrified fencing, road accidents, shifting land use, habitat fragmentation, bush clearing, use of herbicides and pesticides, drowning in open canals, and poaching for local or international trade (Pietersen, 2013; Pietersen, McKechnie, & Jansen, 2014a; Pietersen et al., 2016; Pietersen et al., 2019).Limited or non-existent data on population size and density, and any threats to the population remains an issue (Pietersen et al., 2019; Pietersen & Challender, 2020).

Pangolins are well protected by their armour of keratinous scales when rolled into a defensive ball (Wang et al., 2016). Adults can survive predation attempts, but pups and juveniles, who have thinner, less protective scales, are more vulnerable than adults. There are recorded instances of predation by lion, leopard, hyaena, honey badger and crocodiles.

Namibia is at the western edge of the Temminck's pangolin range and climate change is likely negatively to impact the population (Pietersen & Challender, 2020). Research shows many insectivorous mammal species and their prey are negatively affected by climate change (Weyer, 2019). Additionally, Namibia experiences regular periods of drought, which has negative effects on insect-eating populations, resulting in high mortality rates for pangolins because of reduced food supply (K. Prediger unpublished data; Weyer, 2019). Veld fires are also a common occurrence during dry months and reduce the natural cover for pangolins, making them more susceptible to poaching. Pangolins resting in grassy thickets or woody debris can also be physically injured or killed by fire.

Fencing is increasingly used as a management tool in domestic livestock and game farming (Beck, 2008; Pietersen et al., 2020). Research has shown electric fencing can cause death by electrocution or injuries that result in death (Pietersen, 2013; Pietersen et al., 2020). Pietersen (2013) found there is approximately 1 death per annum for every 11 km of electric fencing in South Africa. Impenetrable fences are increasingly used in small livestock farms and game farms for plains species across southern Africa. High tensile wire strands are placed at a maximum of 100 mm gaps up to half a meter high. In some cases, diamond mesh wire is used in combination with the high tensile wire strands. This prevents pangolin movement necessary for dispersal of juveniles and reproduction.

Mortalities resulting from bycatch in snares and gin-traps, road accidents, and habitat loss and fragmentation and considered a threat, however exact numbers are unknown (Ingram et al., 2018; Pietersen, 2013; Pietersen, McKechnie, & Jansen, 2014a). Increased poaching has been observed with changing land use such as mining, farming, and urbanization (Pietersen, 2013).

Further anthropogenic threats to Temminck's pangolins in Africa are related to traditional practices, which involve pangolins being killed for bushmeat, medicine, and spiritual rituals and beliefs. Traditional practices have likely followed sustainable use; however now that pangolins are increasingly targeted for international trade, this use is a concern (Challender & Hywood

2012). Some cultural groups commonly eat pangolins as a protein to meet nutritional requirements and hunt them opportunistically. This practice has previously not been considered a threat to pangolins. In Tanzania, pangolins are referred to as Bwana mganga, the doctor, because they believe every body part is of medicinal value. In southern Africa, pangolins are sometimes seen as good omens and bringers of luck or fortune, therefore they are presented to the local chief and often slaughtered with a sheep (Pietersen et al., 2020; K. Prediger unpublished data). Contrastingly, in other cultures pangolins are seen as bad omens and bringers of the drought and must be presented to the chief for sacrifice (K. Prediger unpublished data).

Wildlife crime is a rising threat to pangolin populations globally. In the past eight years in Namibia there have been over 400 suspects arrested on pangolin-related charges including possession, poaching, or trafficking (Namibian Chamber of Environment, 2018). In 2019 alone, there were 174 registered cases related to pangolins leading to the arrest of 160 suspects and the seizure of 123 pangolins (Ministry of Environment, Forestry, and Tourism, 2019). While wildlife crime directly and indirectly affects several African species, pangolins account for the largest number of cases and arrests in relation to wildlife crimes in Namibia (Ministry of Environment, Forestry, and Tourism, 2019; Ministry of Environment, Forestry, and Tourism, 2020). Notably, in many cases pangolins are trafficked alive; there have been 128 live individuals seized in Namibia since 2015 (Ministry of Environment, Forestry, and Tourism, 2019; Ministry of Environment, Forestry, and Tourism, 2020).

Overarchingly, limited research hinders the success of conservation efforts, creating a major challenge in mitigating the known threats to pangolin populations. There is a critical lack of baseline data on the spatial, behavioural, and feeding ecology; and preliminary research within Namibia suggests that pangolin ecology varies meaningfully across the different habitats within which it is found (Morin et al., 2020; Pietersen & Challender, 2020). This variability renders wide-reaching conservation decisions based on existing studies (and associated data) uncomfortable, and adds weight to the need for comprehensive studies and a better understanding to underpin

any mitigations to known threats and to enable conservation planning (Morin et al., 2020; Pietersen & Challender, 2020).

1.4 Importance of pangolins in an ecosystem

Pangolins provide a variety of valuable ecosystem services directly impacting many other species. Firstly, it is estimated one pangolin consumes approximately 70 million ants and termites per individual per year, providing a service to those animals feeding on plants targeted by the insects (Hua et al., 2015). Some of the preferred prey species of ants and termites are considered pests in agriculture because they can target crops and destroy them (Addison & Samways, 2000; Addison & Samways, 2006; Chao, Li, & Lin, 2020). As reported by Namibian Chamber of Environment (2018) an estimated 105,000kg of grass can be eaten by these ants and termites in an area home to 15 pangolins, which is equivalent to a food supply in excess of one year for 30 cows or 430 springbok. The report estimates N$600 million per year can be saved in crop loss due to the service provided by pangolins consuming ants and termites (Namibian Chamber of Environment, 2018). In addition to this quantifiable service, pangolins are burrowing mammals, which play important roles within ecosystems as ecosystem engineers (Chao, Li, & Lin, 2020). Pangolins turn over the soil during burrowing and feeding activities which can help aerate the soil and lead to increased plant productivity (Chao, Li, & Lin, 2020; Rodgers, Bilton, & Hauptfleisch, 2017).

1.5 Problem statement and objectives

Following a global increase in rhino poaching in the early 2000s (STR), pangolins have increasingly become the target of the illegal trade with 253 tonnes of pangolin scales and meat seized between 2015 and 2019 alone. This accounts for nearly 400% more than previous annual figures (Hornor, Thorne, & Shaver, 2020). As overexploitation drives species nearer and nearer to extinction, there is an urgent need to safeguard these highly targeted and trafficked species for conservation efforts without delay, before species are classified as critically endangered or worse, become extinct (Challender & Hywood, 2012; Challender, Waterman, & Baillie, 2014). This is especially important for keystone species, which play important roles within an ecosystem and whose extinction would cause a top-down effect, putting the integrity of entire ecosystems at

risk of harm (Cardinale, 2012). The regular large seizures of scales and carcasses suggests billions of individual pangolins are killed across the globe (Heinrich et al., 2016; Heinrich et al., 2017). All African pangolin species are under threat due to the global illegal trade of wildlife, which is growing exponentially as a direct result of rising demand from Asian markets who have depleted their own native wildlife (Challender, Waterman, & Baillie, 2014; Heinrich et al., 2017; Ingram et al., 2017; Hornor, Thorne, & Shaver, 2020).

Illegal trafficking of pangolins has also been on the rise in the past decade, earning all eight pangolin species the title as the most trafficked animal in the world (Challender, Waterman, & Baillie, 2014; Heinrich et al., 2017). Southern Africa's only pangolin species, the Temminck's pangolin, (*Smutsia temminckii*), is categorized as Vulnerable by the IUCN and population trends are decreasing with rising pressure from illegal wildlife trade (Challender, Waterman, & Baillie, 2014; Pietersen et al., 2016; Pietersen, Jansen, & Connolly, 2019). Despite this, the species is one of the most understudied and poorly understood southern-African mammal.

Generating basic biological data for a species is an important element in a successful conservation management plan, and is one part of the work presented in this thesis. In recent years, as live pangolins are more frequently being seized, it is imperative to know and understand their distribution and abundance, feeding ecology, and habitat preference in order to prioritize areas for anti-poaching activities and successfully rehabilitate and release live pangolins (Ministry of Environment, Forestry, and Tourism, 2019; Ministry of Environment Forestry, and Tourism, 2021); Prediger, 2021). Prior to this research, live confiscated pangolins were released without any information to inform decisions on ideal release sites and they were very rarely monitored for success. During the course of this study, four individuals were released with VHF transmitters from other areas of the country, three out of four left the reserve within seven days and one individual died of injuries from territorial fighting (Prediger unpublished data).

The overall aim of this study was to assess the home range size, prey preference, and burrow selectivity of resident pangolins and to gain insights about their behaviour, habitat preference, and survival strategies. The specific objectives of the study were as follows:

I. To determine population dynamics for the study area by assessing the number of male/female juvenile, sub-adult, and adult individuals and their respective home ranges;
II. To determine prey selectivity and preference; and
III. To investigate whether Temminck's pangolin select specific burrow types or dimensions for refuge.

This work will be directly applied to develop plans and guidelines for Temminck's pangolin and will be used to inform key areas and materially improve our current conservation goals.

Chapter 2: Methodology

2.1 Study area and site

2.1.1 Vegetation and habitat

The research described in this thesis was conducted in central Namibia's Thornbush Savanna (Barnard, 1998), on a private nature reserve in the Otjozondjupa region (Figure 1). The exact location cannot be specified for security reasons. The vegetation can be mainly described as tree and scrub savannah, interspersed with silver Terminalia (*Terminalia sericea*) and several *Senegalia* and *Vachellia* species (Curtis & Mannheimer, 2005; Dyer, 2014).

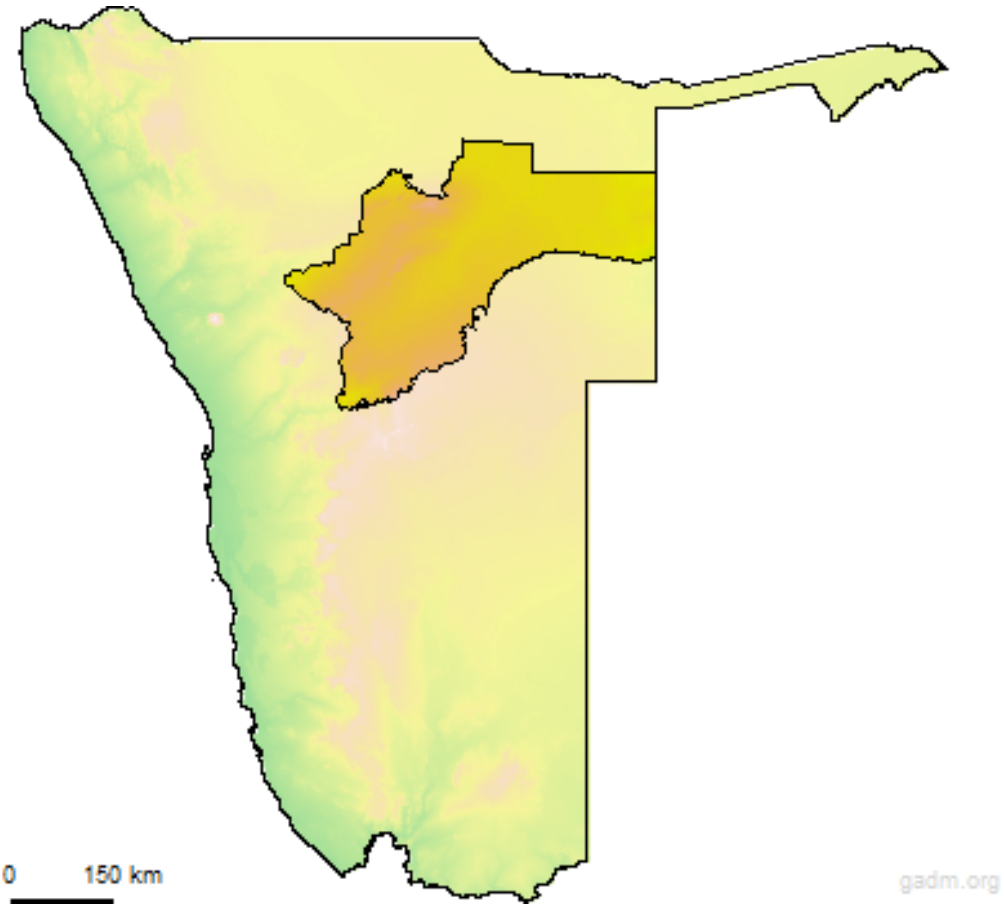

Figure 1: Map of Namibia with the Otjozondjupa region highlighted (Global Administrative Areas, 2018)

The land in the study area was used intensively for the purpose of cattle farming from 1920 until 1993, but since then the private nature reserve has been used exclusively for conservation and

tourism purposes. Internal gravel roads exist across the reserve for the purpose of tourism which allows widespread access for research, however driving is restricted to employees and thus, the chance of wildlife mortalities are low (Barnard, 1998).

The study area is fenced; the reserve is surrounded by a 96-km long electrified perimeter fence, completed in 2010, and is bordered entirely by commercial farmland. An additional electrified fence was erected within the reserve, creating a 20,000 ha reserve for wildlife with a 2 000 ha "lodge area" that includes lodges and campsites (Figure 2). The electrified fence has two low wire strands with the live wire 500 mm from the ground and a lower wire 300mm from the ground with no electrical current to eliminate the chance of electric shock fatalities to pangolins. These gaps under the fence also allow for movement of small mammals in and out of the enclosed reserve. A 100-meter broad strip of land surrounds the reserve, functioning as a buffer zone separating the protected land from surrounding commercial farmland.

The reserve is known for abundant wildlife including impala, gemsbok, springbok, zebra, kudu, eland, blue wildebeest, hartebeest, giraffe, white rhinocerous, and warthog. Predators living within the reserve in strong numbers include leopards, brown hyenas, and honey badgers. There are no lions, wild-dog or spotted hyena clans which are known to occasionally kill and play with pangolins (Pietersen et al., 2020; Skinner & Chimimba, 2005). The presence of aardvark on the reserve play a beneficial role in providing burrows for pangolins.

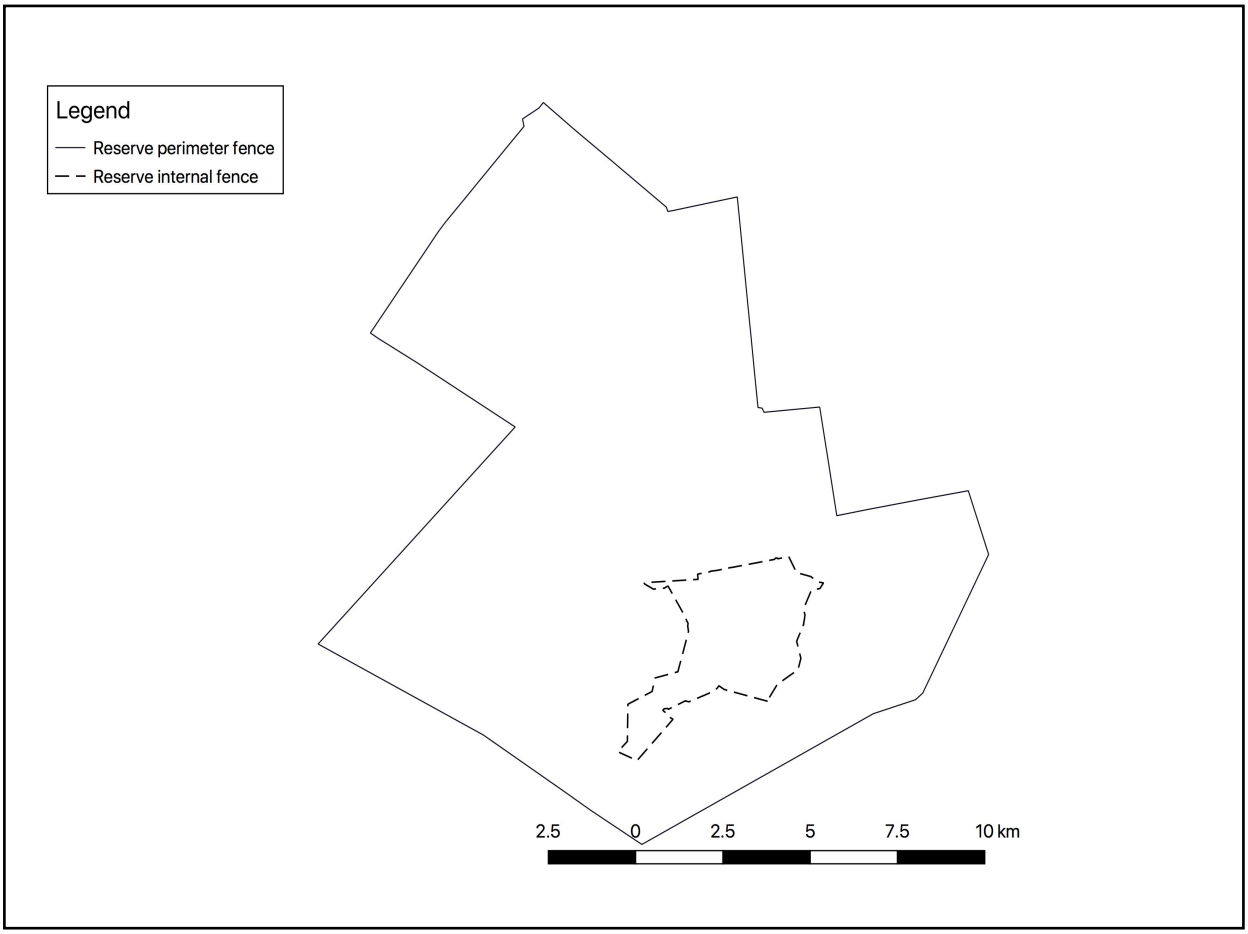

Figure 2: Map of the study area with boundary and internal fences marked

2.1.2. Climate

The study area is semi-arid and characterized by a marked seasonality. The average annual minimum winter temperature is 3-5 degrees C and the average annual maximum temperature is 34- 36 degrees C (Barnard, 1998). The average annual precipitation is approximately 450 mm (Okonjima Nature Reserve unpublished data), while artificially constructed water reservoirs ensure the perennial supply of surface water. For the 2018-2019 rainy season, the study site received only 218 mm of precipitation, of which 90% occurred from December 2018 to March 2019 and the last recorded rain for the season was 0.25 mm on the 28 April 2019 (K. Prediger *unpublished data*). During this season, the reserve was over-grazed by grazing wildlife whose diet needed to be supplemented by lucerne. Rainfall for the 2019-2020 rainy season was significantly higher with 451 mm of rainfall (K. Prediger *unpublished data*).

2.1.3 Soil and topography

The main landform for the reserve is a sandstone plateau with ridges and the reserve boundary traces a central plateau surrounded by mountains with an average altitude of 1600 meters (Barnard, 1998). Shallow organic loam, clay and red loamy sand soils are interspersed with rocky mountains and ridges.

2.2 Tagging and monitoring

2.2.1 Capture and attaching transmitters

There were 36 tagged study animals which were located by chance sightings of guide or employees (n=20), crossing the road in front of researcher (n=8), or found in the near vicinity of an already tagged study individual (n=8). To minimize handling time and risk to the individual, during the fitting of radio tags no animals were moved or put under chemical immobilization. This method was also used by Pietersen (2013) and Pietersen, McKechnie, & Jansen (2014b); and suggested by an on-site veterinarian (D. Rodenwaldt, personal communication, August 1, 2018). The tagging and measurements were done at the location of sighting. Due to the rolling up behaviour without anesthesia, it was not always possible to measure or determine the sex of the individual. When possible, morphometric data were collected and recorded in the data collection form. All individuals were weighed with a canvas sling and handheld scale then measured with a pee-wee tape measure and measurements were recorded on the tagging form. Additional information was also collected including how the individual was found, the location of tagging, sex (when possible), and the presence of parasites. Tagging was undertaken by a registered Namibian veterinarian under an ethics permit from the Ministry of Environment, Forestry and Tourism and research permit from the National Commission on Research, Science, and Technology.

2.2.2 Very High Frequency (VHF) tagging

In general, tracking devices are not ideal for attaching to pangolins because their small conical head and armored body make collars and backpacks not suitable (Ingram, Wilcox, & Challender, 2019; Sun, Pei, & Lin, 2019; Wilcox, Nash, & Trageser, 2019). The transmitter can be attached to

a scale in a number of methods including adhesive and/or bolts, however monitoring is challenging with a high transmitter failure rate up to 50-82% (Heath & Coulson, 1997b; Prediger unpublished data; Sun, Pei, & Lin, 2019).

In this study, three types of VHF transmitters (Advanced Tracking Systems, Minnesota, USA, model R2020, model M3430, and Africa Wildlife Tracking, Johannesburg, South Africa, pangolin model) were utilized (Pietersen, McKechnie, & Jansen, 2014b; Sun, Pei, & Lin, 2019). The placement and attachment method combines the methodology utilized by Heath & Coulson (1997), Pietersen (2013), Pietersen, McKechnie, & Jansen (2014b), and Sun, Pei, & Lin (2019). The transmitter was placed in a way that it doesn't restrict or limit the free movement of the overlapping scales when the animal moves or curls up into a protective ball. The tag was attached with a bolt to a single scale at the base of the tail where it meets the trunk, on the right or left side, by drilling one hole through the non-vascularized part of the scale with a cordless drill (Jacobsen et al*.,* 1991; Heath & Coulson, 1997a; Sun, Pei, & Lin, 2019). A doorstop was placed underneath the scale to prevent injury to the individual and the bolt heads were grinded down to less than half the original thickness to create a flush surface to avoid injury and rubbing. The bolt was inserted from underneath the scale with a washer already on it, then another washer was placed over the scale. The transmitter ear attachment was then put onto the bolt with a washer and nut. Before putting the nut on, non-permanent Locktite was used to ensure a secure hold.

From July 2018- July 2020 there were 46 resident pangolins identified (44 with known sex or weight) and four trafficked pangolins were released on the reserve. Of these, 36 resident pangolins were tagged with VHF transmitters and monitored for research purposes and, when possible, details of sex and weight measurements were recorded.

2.2.3 Global Positioning System (GPS)/ Ultra High Frequency (UHF) and GPS/ Satellite (SAT) tagging

Of the 36 VHF tagged pangolins, 16 were tagged with GPS/UHF transmitters (Africa Wildlife Tracking, Johannesburg, South Africa and Wireless Wildlife, South Africa). These transmitters

were bolted on in the previously mentioned method on the scale opposite the VHF transmitter. GPS/UHF transmitters were programmed to collect hourly GPS points on a schedule suitable for the season, while also collecting accelerometer and temperature data. Data were downloaded from the GPS/UHF transmitters to the UHF receiver when pangolins were located in near proximity <15 meters, which was then transferred to the AWT interface by downloading the data from the receiver to a computer.

2.3 Data Collection

2.3.1 Morphometric data

Pangolins were assigned three weight classes: under 6 kg (pup or juvenile); 6-10 kg (adult, and over 10 kg (adult) (Appendix 1). The last weight class was assigned because during this study, a female of 6.4 kg was found pregnant with a near full-term fetus at the time of her death. Additionally, it was observed that these weight groupings best represented fitness levels. Pietersen (2013) identified two weight classes for < 6kg as juvenile and > 6kg as an adult. Alternatively, Swart, Richardson, & Ferguson (1998) classified sub-adults under 8 kg. Of the 44 identified pangolins, a total of 16 females, 25 males, and three unsexed pangolins were measured and of these, 11 individuals were above 10 kg, 15 were between 6-10kg, and 18 were under 6 kg (Table 1).

Table 1: Population structure of study animals including sex (M, F, or unknown) and weight class (<6kg, 6kg-10kg, and >10kg)

Weight Class	Female	Male	Sex Unknown
> 10 kg	6	5	0
6-10 kg	6	9	0
< 6 kg	4	11	3
Total	16	25	3

2.4 Home range

2.4.1 Spatial data collection

VHF tagged individuals were located on foot by the researcher utilizing a handheld VHF receiver (Communication Specialists, Orange County, California, USA) to monitor movements, locate preferred burrows, and make behavioural observations. GPS coordinates of tagged individuals were recorded upon visual confirmation of the animal's position within +-5m accuracy using the Epicollect 5 (Imperial College, London) phone application used for collecting data. Other data recorded in this method include environmental conditions using a handheld anemometer (HoldPeak, Zhuhai, China), photos of the nearby habitat and burrows, and the behaviour of the individual. Additional spatial data including coordinates, time, temperature, and an accelerometer reading was collected through GPS/UHF logging transmitters with an accuracy of +- 50m. Of the 36 study animals, 14 adult pangolins, 4 males and 10 females, were tagged for a period of 16-22 months with 98- 873 GPS points collected per individual. Data were only analyzed for individuals with over 89 GPS fixes.

2.4.2 Statistical analyses

Heath & Coulson (1997) and Pietersen, McKechnie, & Jansen (2014b), outline methods for determining home ranges of VHF tagged individuals, however MCP (Minimum Convex Polygon) models often result in overestimating home range values because the outlying data points are included and for this reason, kernel density methods are reported to be more accurate in representing actual home range estimations (Pietersen, McKechnie, and Jansen, 2014b). KD (Kernel Density) methodology has limitations when physical boundaries exist as the analysis does not take this barrier into consideration, for example the external lodge fence and the external reserve fence. Even if no spatial data points exist on one side of a boundary, the KD analysis will include this area in part of the HR estimate. When no GPS points or observations were outside the reserve boundary fence-line or inside the internal fence-line; the MCP, 95KD, and 50KD home ranges were clipped along the boundary and analysed as mapped. CReSS (Complex Region Spatial Smoother) is able to account for physical barriers and will estimate the home range and core area while taking such boundaries into account (Scott-Hayward et al., 2011).

For comparison with the published literature, 95% and 50 % Kernel Density (95KD and 50KD) models were utilised to establish home ranges of 14 tagged individuals for growing and non-growing seasons. In order to account for the over-estimation, when no GPS points existed outside the physical boundary, 95KD and 50KD values were clipped to reflect this (for example, OST08 has GPS points across these boundaries, therefore the range was not clipped). In addition, CReSS analysis for home range (HR) and core area (CA) was conducted for all 14 individuals for both seasons while the MCP method was also used for the seven individuals who had sufficient data for both seasons.

When comparing home range sizes, the non-parametric Kruskal Wallis Analysis of Variance (ANOVA) was used to identify significant differences between groups, using a fixed level significance testing at the 5% level (and thus genuine differences were evidenced by *p*- values less than 0.05). When comparing multiple individual home range sizes the post-hoc test was used. Statistical analyses were performed using Statistica for Windows version 10 (StatSoft 2011) and Statistical Package for the Social Sciences (SPSS) (IBM SPSS 2013).

2.5 Prey preference

2.5.1 Ant and termite pitfall surveys

Pitfall trap surveys were conducted to determine species present at the study site (Swart, Richardson, & Ferguson, 1999; Pietersen, 2013; Pietersen et al., 2016). Pitfall traps were conducted for a total period of 28 days from January 2019- March 2020 with a total of 46,158 specimens collected (Appendix 7). Pitfall sites were chosen at random within the combined home ranges of all tagged pangolins in November 2018. A grid was placed over the study site and each cell was given a number; numbers were randomly generated for 5 sites. At each site a 50 m transect was laid out and 15 cups were dug into the ground at random at a distance no greater than 1 m from the transect line. Each hole had two cups, one as a placeholder and one for the collection; cups were closed with a lid when not active. Pitfall traps were opened once a month for 48 hours at 12 hour intervals to detect the potential activity patterns of the prey, following

similar methodology to Pietersen (2013) and Pietersen et al. (2016) and Swart, Richardson, & Ferguson (1999). At collection, the cups were filled with 100 ml of diluted soapy water and 10 out of the 15 cups were randomly selected for collection. The remaining 5 were discarded. This was done to account for consistent sample size from each pitfall trap as wildlife disturbance and evaporation would exclude entire cups. After collection, samples were transported back to the lab where they were filtered, dried, and then preserved into ethanol for later identification.

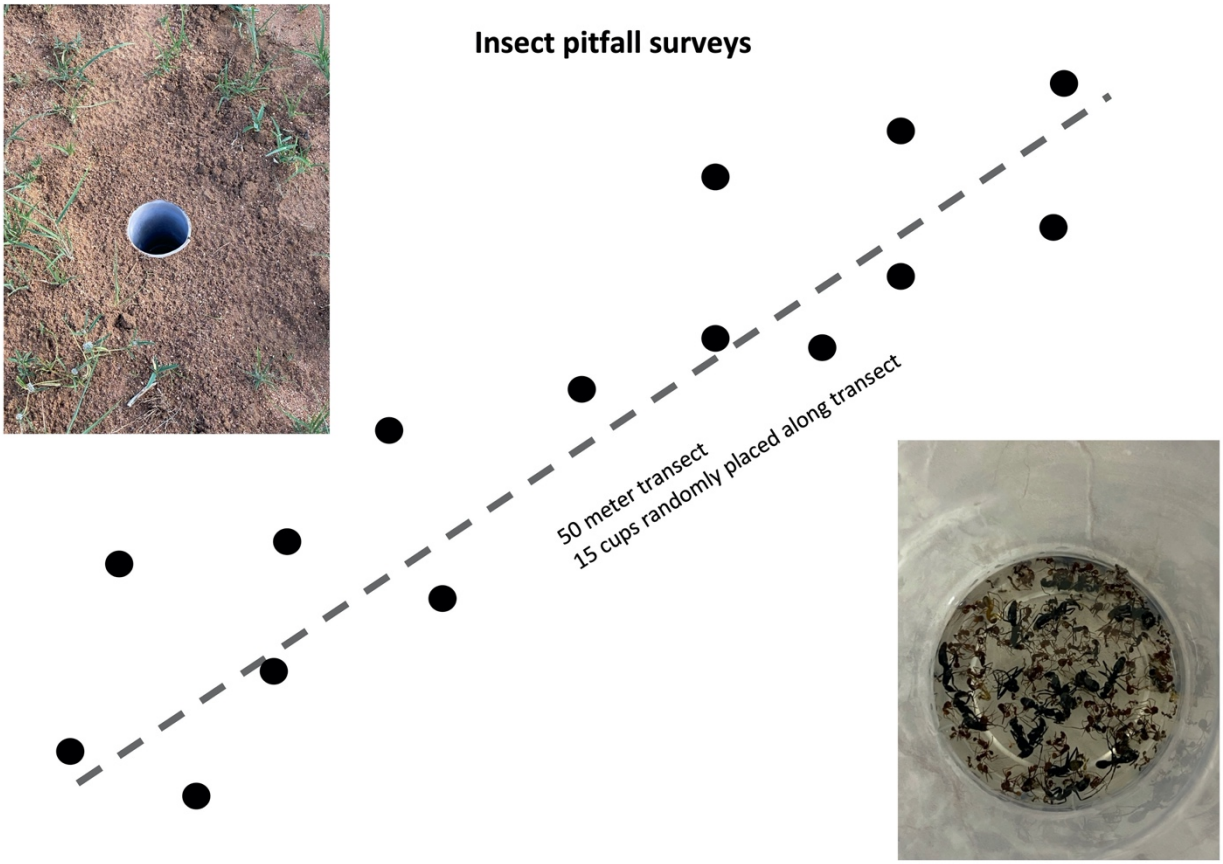

Figure 3: Diagram of the pitfall survey with photos from collection (upper left) and sorting in the lab (lower right)

2.5.2 Foraging samples

Pangolins were tracked and observed in order to collect data on prey selection, foraging methods and behaviour. When foraging was directly observed, ant and termite samples were taken in a sample vial or bag for preservation, and when possible the type of foraging was also recorded. Samples were taken opportunistically from September 2019- September 2020. Samples were collected, labelled with the individual ID, date, time, and sample number and stored in a plastic

bag or vial. The samples were identified to species level (when possible) by an entomologist from the National Museum of Namibia.

2.6 Burrow selection

2.6.1 Burrow Measurements

There were 171 burrows identified and 151 burrows belonging to 15 individuals which were assessed for height, width, internal and external temperature, characteristics, and associated plant species (Appendix 9). A form for data collection was created in EpiCollect5 (Imperial College, London). Measurements included the height and width of the burrow entrance measured with a tape measure (in cm). Additionally, unique characteristics were recorded including whether the burrow was located under a termite mound, under a tree (over 1 m), under a shrub (under 1 m), deeper than 1 m, shallower than 1 m, whether it had multiple entrances, or comprises part of a burrow complex, or a cave. Internal burrow temperature (C˚) was measured using a handheld infrared thermometer (Etekcity, Anaheim, California, USA) 1 m deep within the burrow and an external temperature (C˚) was measured at the surface of the burrow entrance. The main habitat type was recorded (Mahmood et al., 2013; Karawita et al., 2019) as either bush-encroached, riverine, mountainous/rocky hills, or open plains.

2.6.2 Statistical analysis

The non-parametric Kruskal Wallis Analysis of Variance (ANOVA)(Kruskal-Wallis H Test using SPSS Statistics) was used to test the null hypothesis of no significant differences between burrow preferences for sexes and individuals, using fixed level significance testing at the 5% level (and thus significant differences were evidenced by p- values less than 0.05). This non-parametric test was selected in order to remove the Normality assumption inherent in the traditional ANOVA method (Kruskal-Wallis H Test using SPSS Statistics).

While the ANOVA/Kruskal Wallis alternative provide valuable “one-way” methods, they only essentially consider one variable at a time and the research questions associated with burrow height, width and internal and external temperature involve several factors potentially operating together. For this reason, Generalized Additive Models (Wood, 2011; Wood, 2017) were used

instead to fit models for each of burrow height, width and both internal and external temperature as response variables.

GAMs expand the class of the more traditional linear model group by relaxing the 'straight-line' relationship assumption inherent in the linear model class, and allow the response data, given the model, to come from non-Normal distributions (Hastie & Tibshirani, 1990). These include distributions from the "exponential family" (which also includes the Normal distribution) and by employing "link functions".

While the burrow characteristics being modelled here are positive in value and are also likely to be positively skewed, a Normal errors model-based approach was trialled first for these response values in case that the modelled covariates trialled captured these right-skewed patterns in the response data and Normally distributed errors resulted (evidenced by normally distributed residuals). In practice, this Normal assumption for the errors (alongside the additional assumptions around constant error variance and independence in the errors) was checked post model fitting and if necessary, the model was revisited. Alternative approaches in this case for right-skewed errors using the GAM model framework include log-Normal models (via a log link function) and/or Gamma-based models (via appropriate link functions). In this thesis, GAMs were fitted using the mgcv library inside the free to use, `R` statistical software package (R Core Team, 2021).

Importantly, GAMs permit each covariate term to be included as a smooth term (e.g., as a nonlinear or curved relationship) or as a linear term and the mgcv associated output provides a significance testing approach to help the user decide between approaches for each term. Covariates which are included as categories (e.g., sex, habitat type) can also appear alongside linear and nonlinear terms in GAM-based models and so their relationships can be considered simultaneously with the response variable, rather than being considered separately using 'one-way' models.

Regarding model covariates, the explanatory variables: sex, habitat type and individual weight were all trialled as candidate variables in the model. Further, since individual weight can usefully be included 'as-is' or be represented using weight categories, an individual's weight was included in each model in both forms in order to determine the added value (or not) of including weight as a raw metric and/or categorizing the weight into meaningful classes. For this covariate, a model-based approach was used and the *p*-values determined the way in which an individual's weight was included: it was trialed first as a continuous metric and a smooth (i.e., nonlinear) term, was permitted in the model and if the associated *p*-value was less than 0.05 it was retained in this form. If the *p*-value from this first stage was in excess of 0.05, it was included instead as a linear term (and if the associated *p*-value was less than 0.05 it was retained in this form), or it was omitted altogether (if the *p*- values were larger than 0.05 in both cases).

2.7 Assumptions and limitations

2.7.1 Home range and core area sizes

Two limitations arose in this area. First, the non-growing season had 3,880 less recorded spatial points than the growing season which could result in underestimating home range sizes due to limited spatial data. Second, the analysis could have benefitted from data from more individuals; all 14 individuals were tagged with GPS/UHF transmitters for the growing season, however only 8 had GPS/UHF transmitters for the non-growing season.

2.7.2 Pitfall and foraging data

Smaller pitfall traps (plastic cups) were utilized in comparison to other studies (Pietersen et al., 2016) reducing the collection area and surface tension of the water. It is possible for insects to have escaped the pitfall traps, but this is a known limitation of pitfall traps (J. Irish, personal communication, October 15, 2020).

2.7.3 Burrow selection data

The results could be a poor representation of the types of burrows which are either very deep or at a large distance from the road. Specifically, there were some individuals who were rarely found in burrows during this study. This could have been due to the individuals having

extremely deep burrows or having burrows which are far from the road and therefore difficult to detect from roads using the fitted transmitters. Additionally, visual observations of some known burrows would only allow for a five-meter range or less in the VHF transmitter signal. The hardness of the ground and the depth of the burrow are known to affect the quality of the transmission signal.

Chapter 3: Results

3.1 Home range and core area

3.1.1 Population structure

Of the 44 identified individuals, 36 resident pangolins were tagged with VHF transmitters and monitored for research purposes and when possible details of sex and measurements were recorded (Appendix 1). A total of 16 females, 25 males, and three unsexed pangolins were observed and of these, 11 individuals were above 10 kg, 15 were between 6-10kg, and 18 were under 6 kg (Table 1).

3.1.2 MCP and KD home ranges for entire study period

Point data for 14 individuals tagged from July 2018 to April 2020 are illustrated in Figure 4 and MCP, 95% KD and 50% KD home range values are displayed in Table 2. MCPs ranged from 12.20 km^2 – 35.74 km^2 for males and were smaller for females, between 4.24 km^2 – 21.17 km^2 (Figure 5). For males, 95% Kernel Density home range sizes ranged from 15.43 km^2 – 38.77 km^2 and between 1.62 km^2 – 41.53 km^2 for females (Figure 6). Kernel Density (50%) core area sizes ranged from 2.87 km^2 – 6.21 km^2 for males and between 0.58 km^2 – 6.91 km^2 for females (Figure 7).

There was no significant difference between MCP, 95KD and 50KD home range sizes when different weight classes were compared.

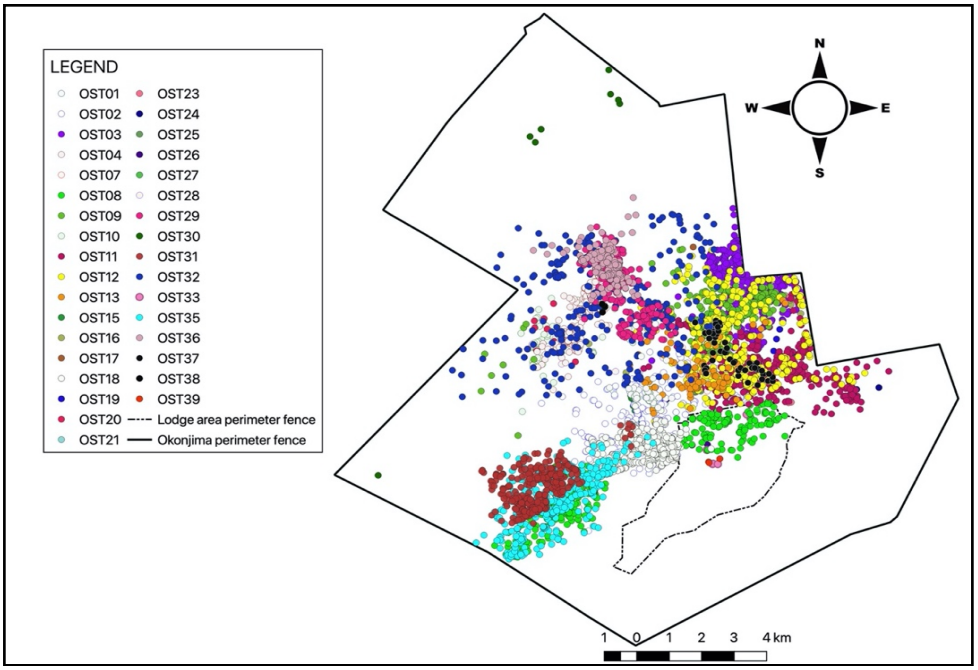

Figure 4: GPS points for all resident pangolins VHF tagged as a part of this study from August 2018 to July 2020

Table 2: Mean, median, maximum, and minimum MCP, 95KD, and 50KD home range values for males and females during entire tagging period						
	MCP		95KD		50KD	
	M	F	M	F	M	F
Mean	23.87	9.66	23.97	11.11	4.38	2.17
Median	23.76	7.91	20.85	8.95	4.23	1.51
Maximum	35.74	21.17	38.77	41.53	6.21	6.91
Minimum	12.20	4.24	15.43	1.62	2.87	0.58

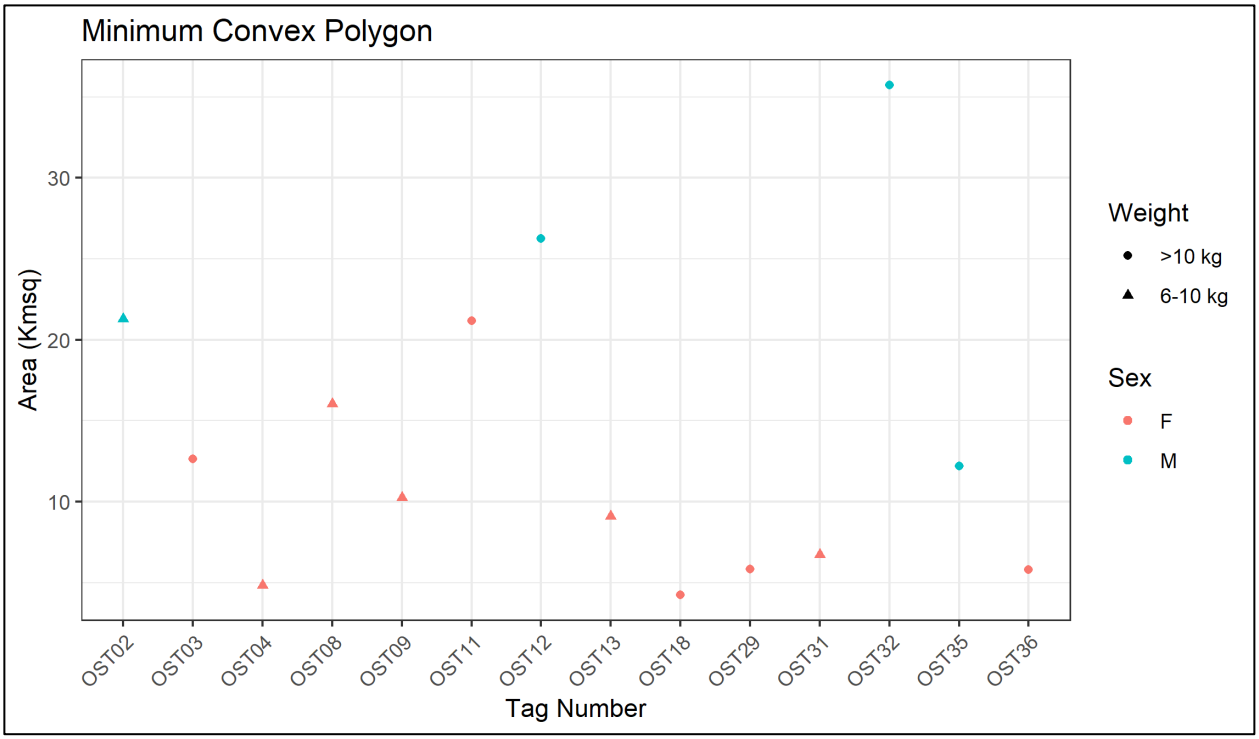

Figure 5: Overall MCP home range size for the duration of the study showing the sex and weight class of each individual

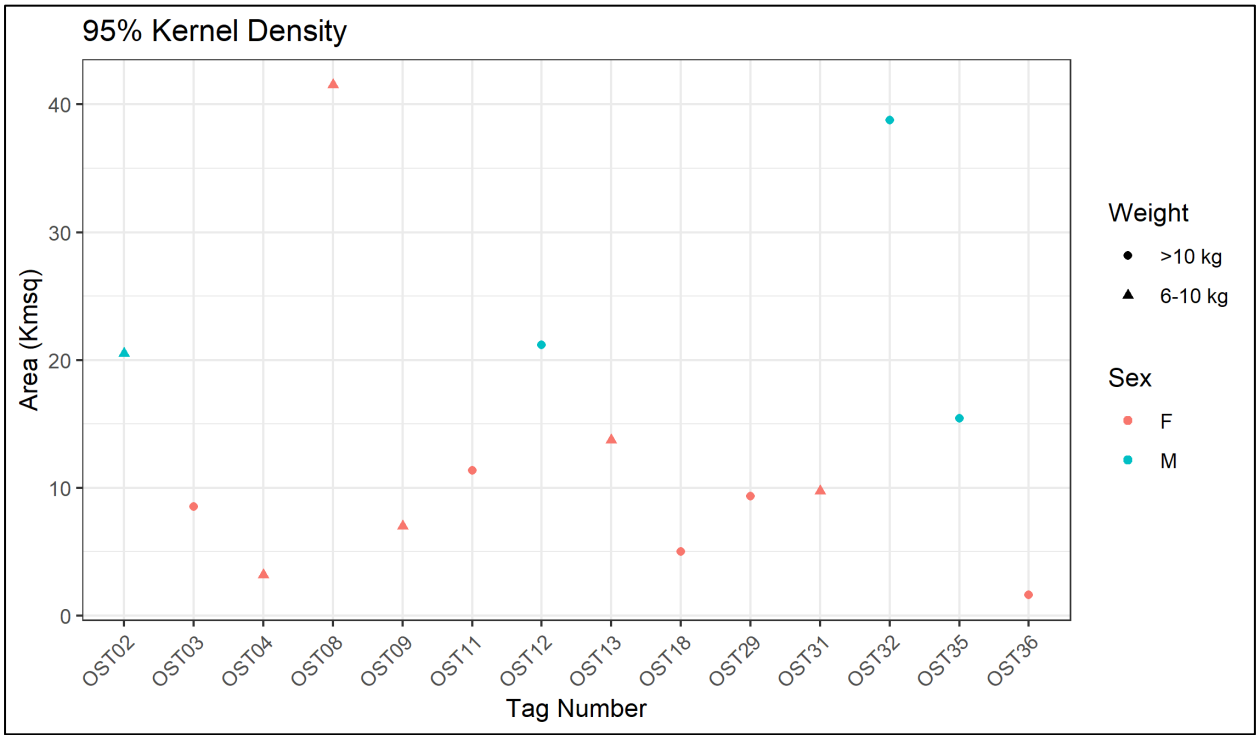

Figure 6: Overall 95KD home range size for the duration of the study showing the sex and weight class of each individual

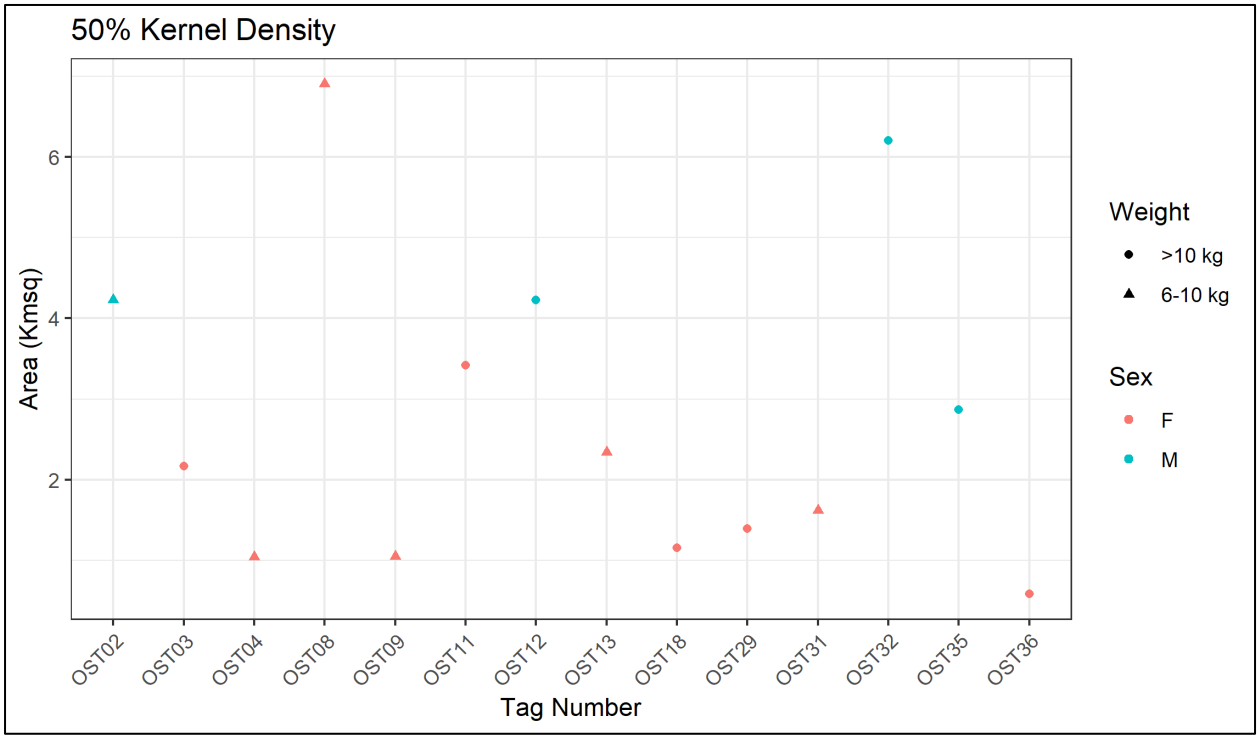

Figure 7: Overall 50KD home range size for the duration of the study showing the sex and weight class of each individual

Figure 7 represents GPS points for all resident pangolins that were VHF tagged as a part of this study. The centralized location of points within the reserve are likely a result of higher-traffic areas which resulted in more sightings and therefore tagging. It is very likely the areas without spatial points have untagged pangolins residing in them. Individuals moved in semi-separated ranges while the north-eastern boundary fence seemed to result in more overlap. When interpreted as home ranges there was marked overlap between most individuals at the 95KD level (Figure 8). However, core home ranges (50KD) had minimal same sex overlap.

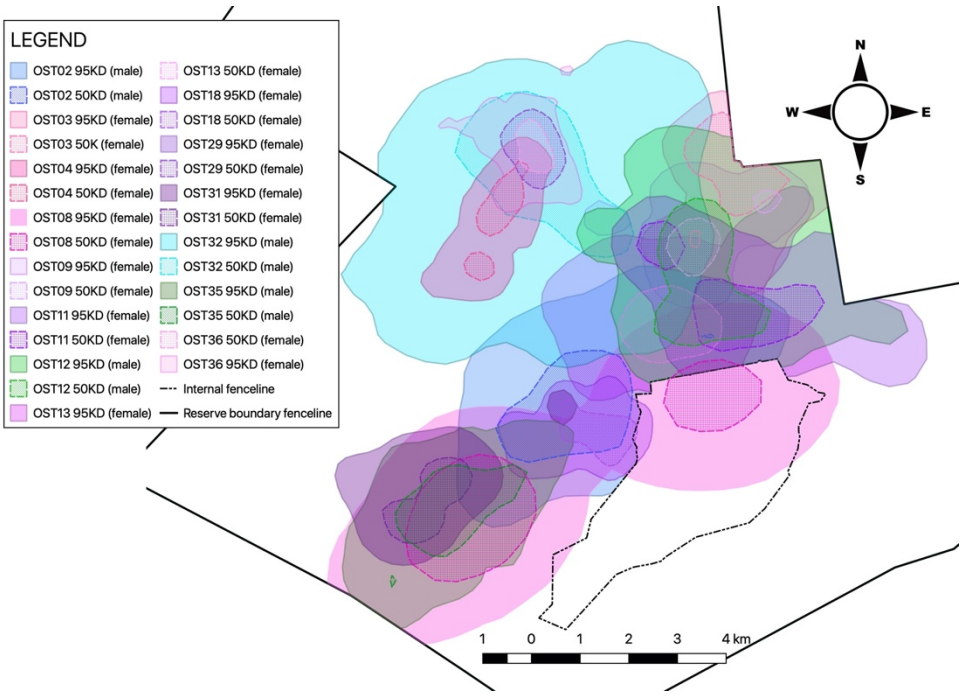

Figure 8: 95KD and 50KD home range sizes for 14 GPS/UHF tagged individuals

No GPS points were found inside the internal fence-line, therefore the MCP and 95KD home ranges were clipped along this fence. This was done for all animals where a clear boundary effect was detected. OST02 (male) was located near the road and from June 2018- April 2020 there were 574 GPS spatial points collected over the growing and non-growing seasons (Figure 9). This male was first tagged as a juvenile in June 2018 before losing his VHF transmitter in August 2018. He was retagged in July 2019 when spotted by a guide. His 50KD range demonstrates that he remained in his natal range which expanded once becoming an adult.

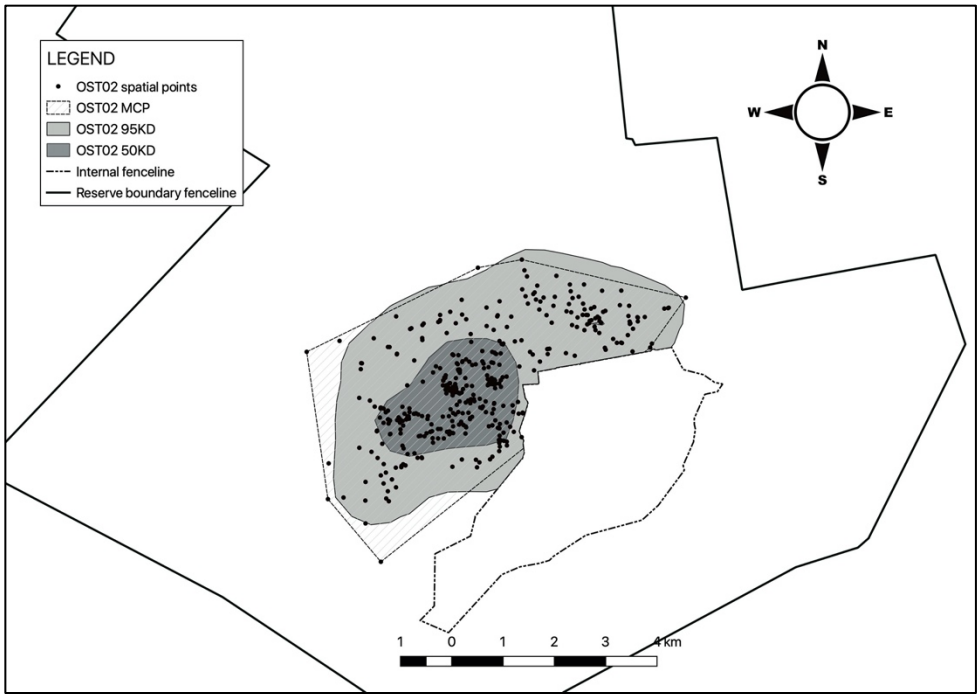

Figure 9: All spatial points, MCP, 95KD, and 50KD for OST02 (male)

OST03 (female) was located crossing the road and from July 2018- April 2020 there were 864 GPS spatial points collected over the growing and non-growing seasons (Figure 10). This individual was first tagged in July 2018 before losing her VHF transmitter in December 2018, she was then retagged in April 2019 which lasted until losing signal in April 2020.

OST04 (female) was found by a guide, being played with by a leopard. From August 2018- April 2020 there were 406 GPS spatial points collected over the growing and non-growing seasons (Figure 11). This individual had the smallest MCP home range size of all females (Appendix 2). OST04 was first tagged in August 2018 before losing her VHF transmitter three days later. She was then seen by a guide and retagged in July 2019. Burrow camera traps recorded OST32 (male) visiting OST04 multiple times.

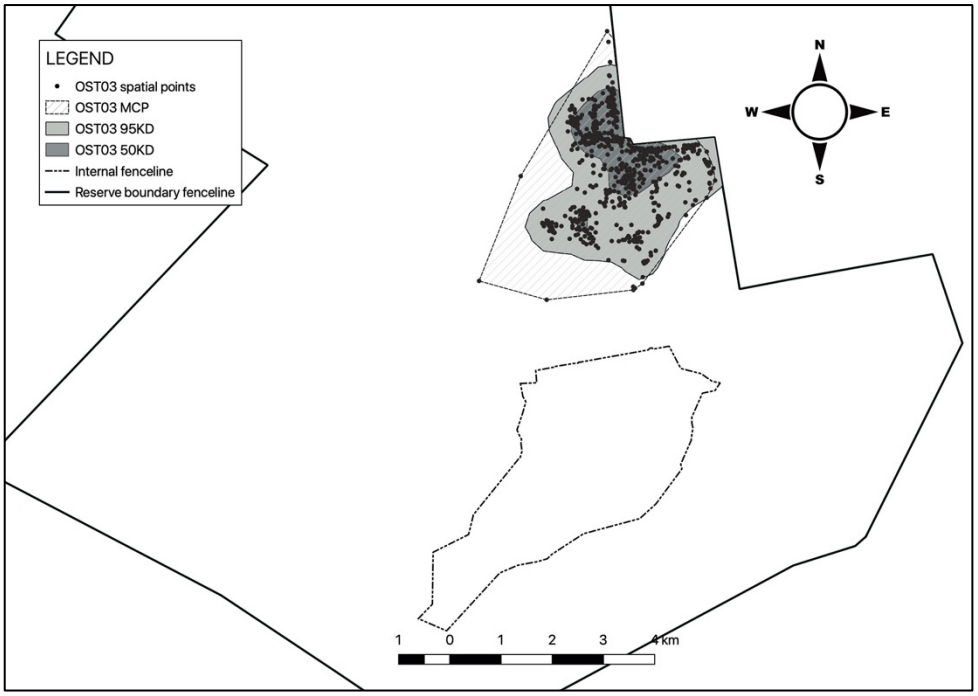

Figure 10: All spatial points, MCP, 95KD, and 50KD for OST03 (female)

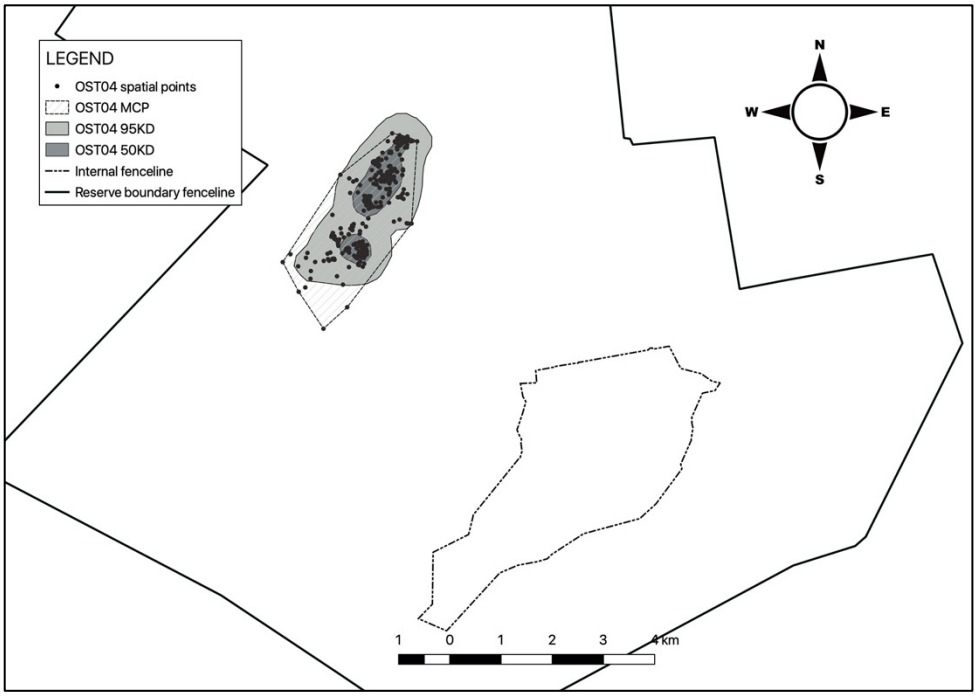

Figure 11: All spatial points, MCP, 95KD, and 50KD for OST04 (female)

OST08 (female) was observed crossing the road and from September 2018- April 2020 there were 443 GPS spatial points collected over the growing and non-growing seasons (Figure 12). This individual had the largest MCP, 95KD, and 50KD home range sizes of all females (Appendix 2). This individual did not lose her transmitter during the study period. Interestingly, she was utilizing a home range within the internal fenceline until December 2019 and her signal was quiet. She was later located nine kilometers from her original range, demonstrating the two focal areas in her range. The utilization of these two areas gives her the largest female home range sizes. Due to her movement across these boundaries, no home ranges were clipped. At one point she returned to the original home range within the internal fenceline. There are two possibilities to account for this behaviour. Firstly, it is possible she was pushed out of her range by a stronger female, however no females were observed in her range. Secondly, a male (OST33) was tagged in her home range in October 2019 died in the same month (from starvation); therefore she could have been seeking a mate.

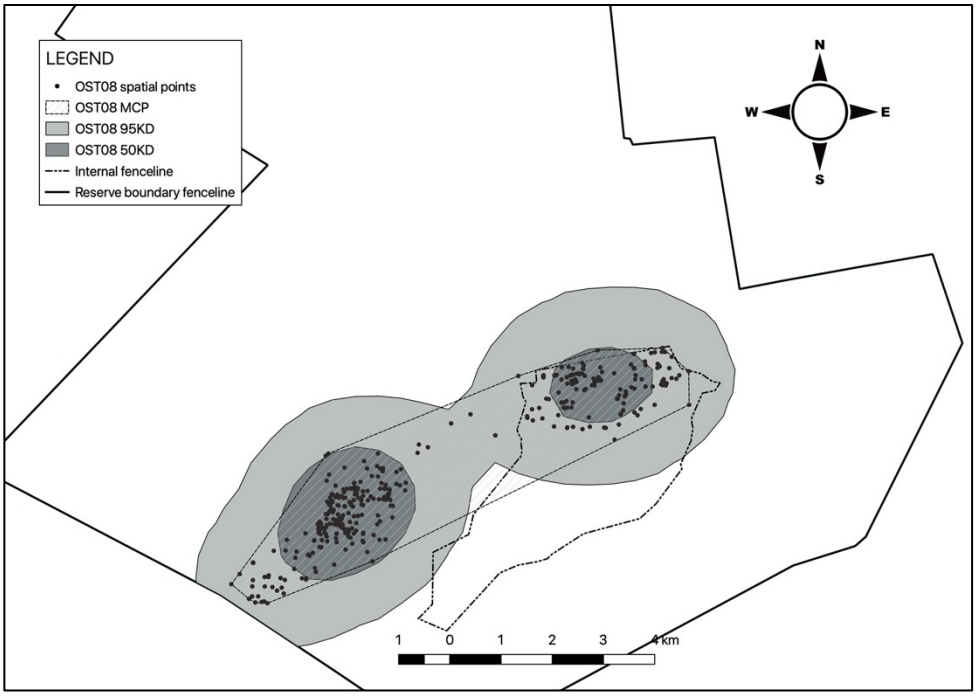

Figure 12: All spatial points, MCP, 95KD, and 50KD for OST08 (female)

OST09 (female) was found crossing the road. From October 2018- April 2020 there were 661 GPS spatial points collected for OST09 over the growing and non-growing seasons (Figure 13). This individual did not lose her transmitter during the study period. Compared to other individuals, she rarely used new burrows and was located sharing a burrow with OST12 (male) and OST37 (male) on many occasions. She was also observed fighting with OST11 (female) near and inside one of her main burrows in February 2019.

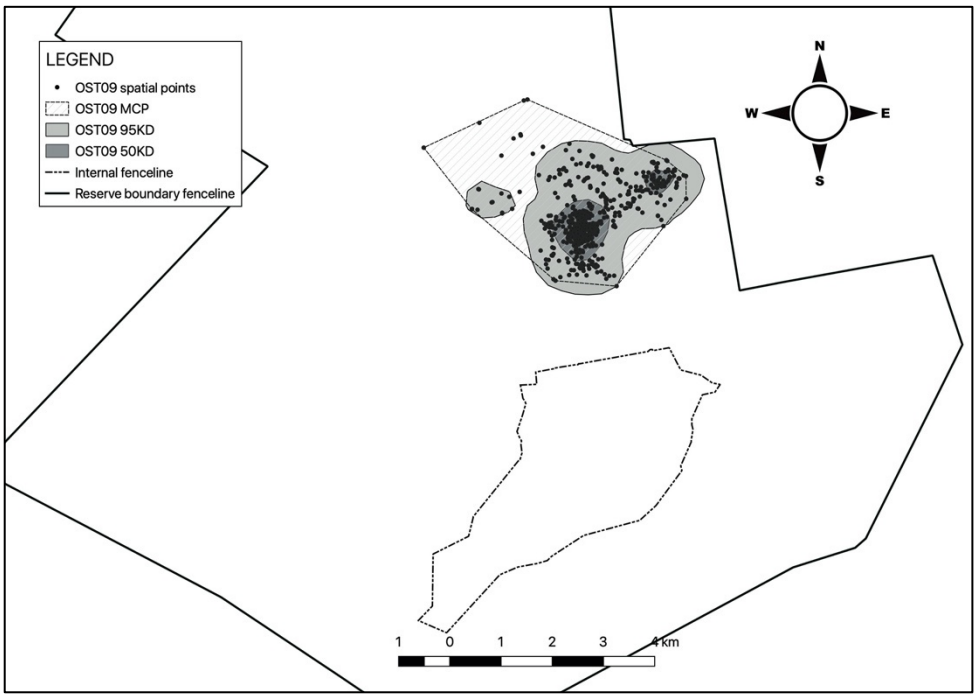

Figure 13: All spatial points, MCP, 95KD, and 50KD for OST09 (female)

OST11 (female) was initially located in the near vicinity of OST09 in October 2018 but was not tagged. She was later located in January 2019 next to the road. From January 2019- April 2020 there were 873 GPS spatial points collected over the growing and non-growing seasons (Figure 14). This individual did not lose her transmitter during the study period. Second to OST08, this was the largest female home range observed.

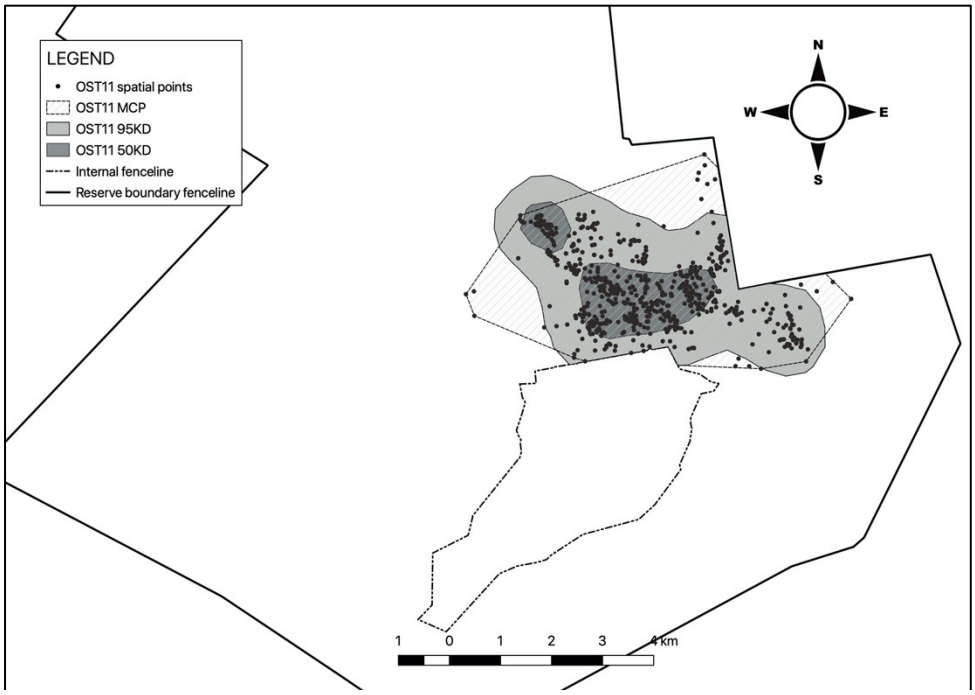

Figure 14: All spatial points, MCP, 95KD, and 50KD for OST11 (female)

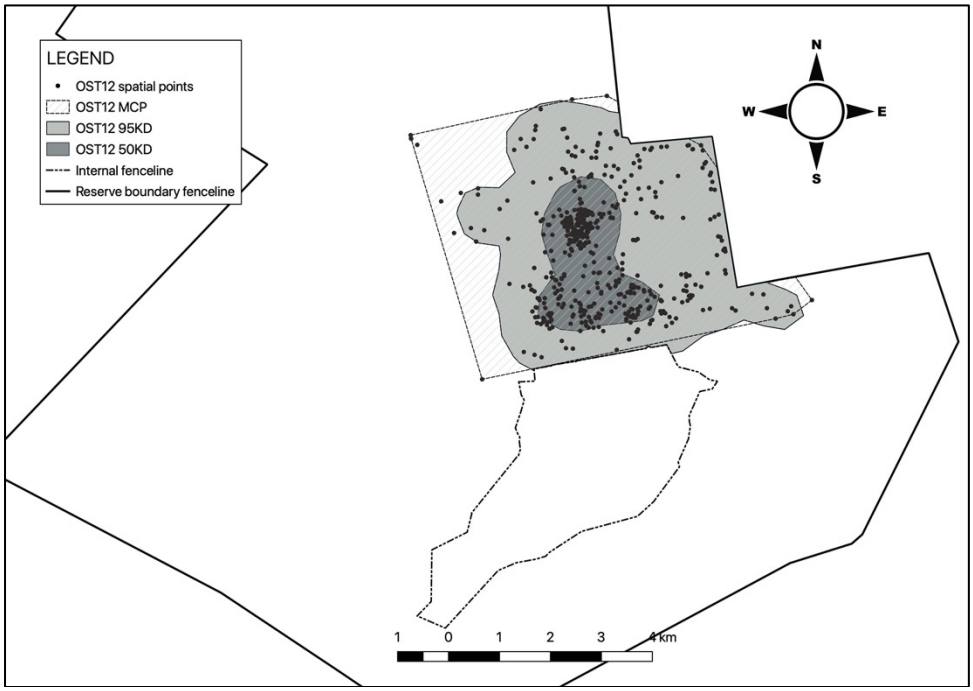

Figure 15: All spatial points, MCP, 95KD, and 50KD for OST12 (male)

OST12 (male) was initially located fighting a released confiscated pangolin in October 2018 but was not tagged at that time. He was later located in April 2019 in the near vicinity of OST11. From April 2019- April 2020 there were 532 GPS spatial points collected over the growing and non-

growing seasons (Figure 15). No GPS points were found outside the reserve boundary fence-line or inside the internal fence-line; therefore the MCP, 95KD, and 50KD home ranges were clipped and analysed as mapped. OST12 lost his VHF transmitter in May 2019 and was relocated near OST11 in the same month. OST12 was found visiting the burrows of five females (OST03, OST09, OST11, OST13, and OST25).

OST13 (female) was located near OST12. From April 2019- April 2020 there were 98 GPS spatial points collected over the growing and non-growing seasons (Figure 16). OST13 did not lose her VHF transmitter during the study period.

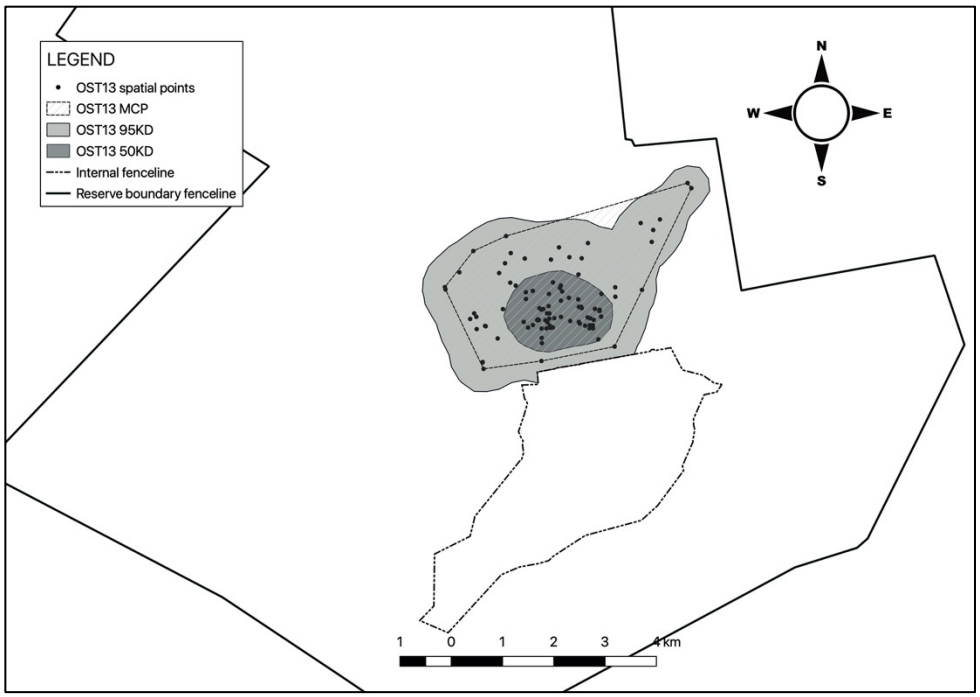

Figure 16: All spatial points, MCP, 95KD, and 50KD for OST13 (female)

OST18 (female) was located near OST02. From June 2019- April 2020 there were 450 GPS spatial points collected over the growing and non-growing seasons (Figure 17). OST18 did have GPS points within the internal fence-line; therefore no home ranges were clipped. She did not lose her VHF transmitter during the study period. OST18 and OST02 were observed sharing the burrow together on multiple occasions including with a newborn pup in December 2019.

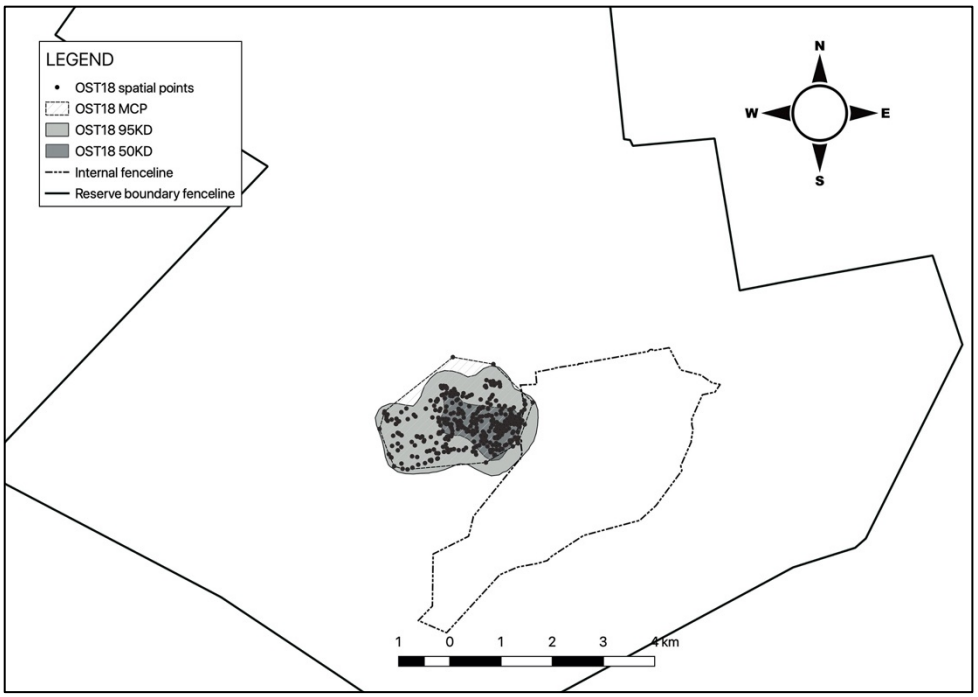

Figure 17: All spatial points, MCP, 95KD, and 50KD for OST18 (female)

OST29 (female) was located crossing the road. From August 2019- April 2020 there were 310 GPS spatial points collected over the growing and non-growing seasons (Figure 18). OST29 did not lose her VHF transmitter during the study period. OST29 was located in the same burrow as OST32 (male) and near OST36 (female).

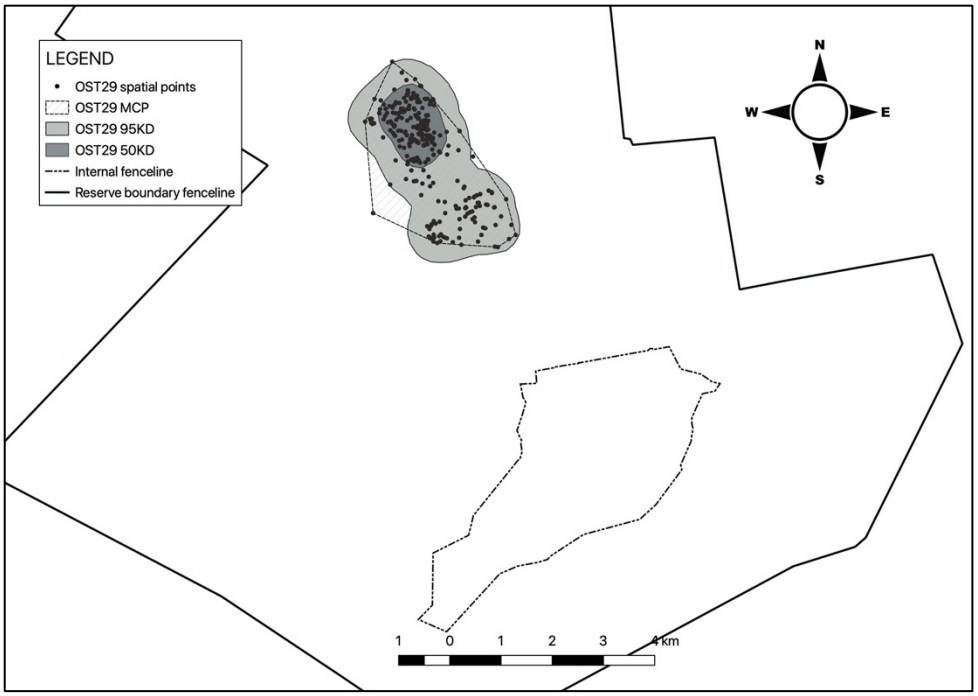

Figure 18: All spatial points, MCP, 95KD, and 50KD for OST29 (female)

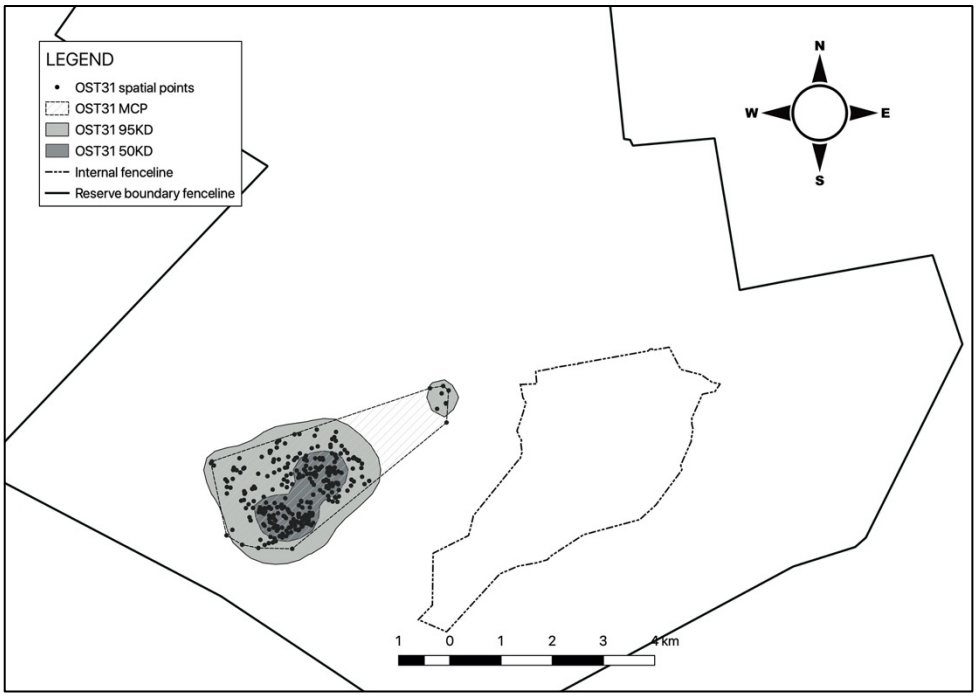

Figure 19: All spatial points, MCP, 95KD, and 50KD for OST31 (female)

OST31 (female) was located near the road. From September 2019- April 2020 there were 331 GPS spatial points collected over the growing and non-growing seasons (Figure 19). OST31 did

not lose her VHF transmitter during the study period. OST31 shifted her home range within a month of tagging and was not observed to return to this area for the rest of the study period.

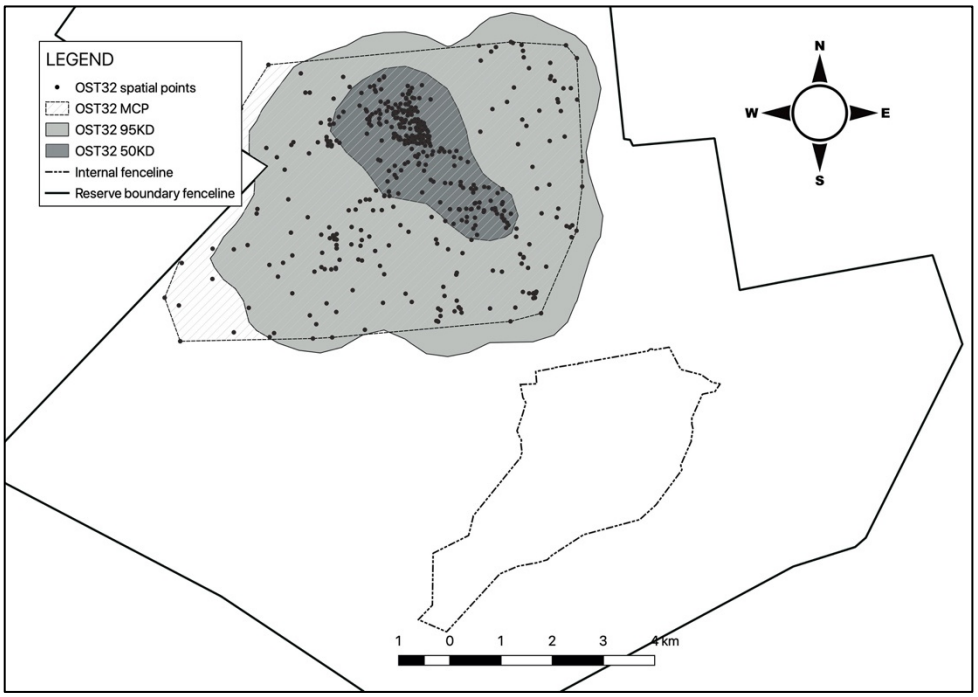

Figure 20: All spatial points, MCP, 95KD, and 50KD for OST32 (male)

OST32 (male) was located crossing the road. From September 2019- April 2020 there were 483 GPS spatial points collected over the growing and non-growing seasons (Figure 20). This individual had the largest MCP, 95KD, and 50KD home range sizes of all males (Appendix 2). OST32 did not lose his transmitter during the study period. OST32 had the largest home range sizes of all males.

OST35 (male) was located crossing the road a few hundred meters from OST31. From November 2019- April 2020 there were 433 GPS spatial points collected over the growing and non-growing seasons (Figure 21). This individual had the smallest MCP, 95KD, and 50KD home range sizes of all males (Appendix 2). OST35 did not lose his transmitter during the study period. OST35 was observed visiting the burrow of OST08 and OST31 and within the near vicinity of OST18.

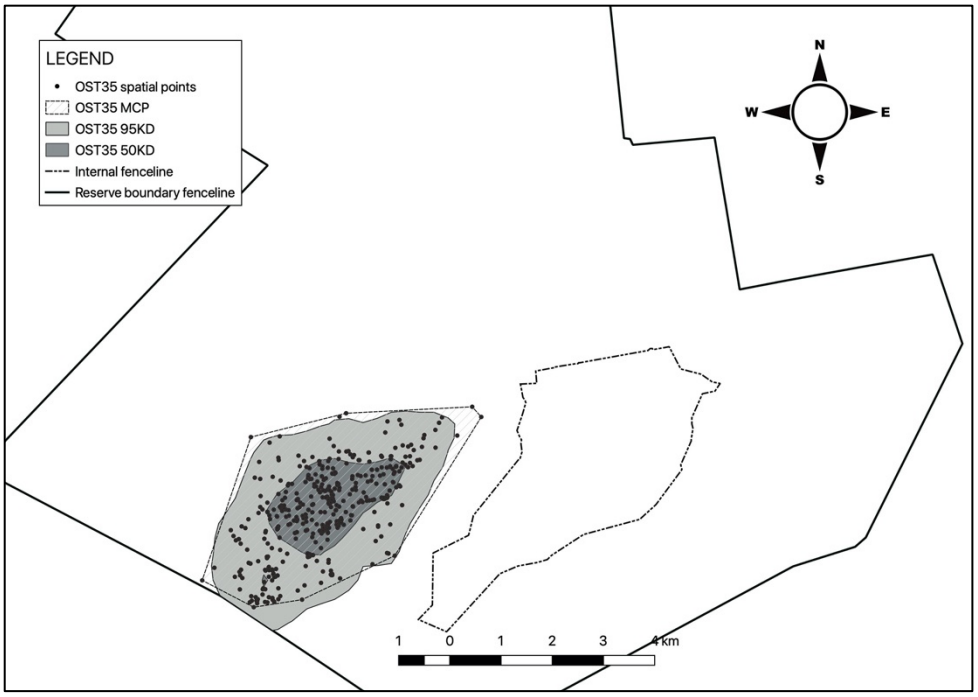

Figure 21: All spatial points, MCP, 95KD, and 50KD for OST35 (male)

OST36 (female) was located near OST29. From January 2020- April 2020 there were 246 GPS spatial points collected over the growing and non-growing seasons (Figure 22). This individual had the smallest 95KD and 50KD home range sizes of all females (Appendix 2). OST36 did not lose her VHF transmitter during the study period.

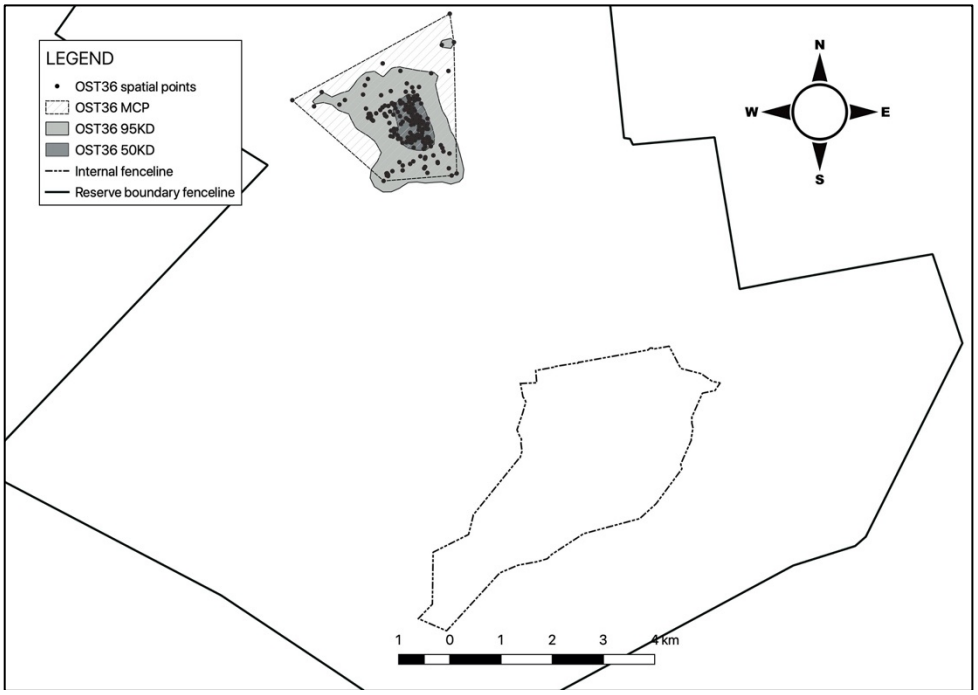

Figure 22: All spatial points, MCP, 95KD, and 50KD for OST36 (female)

OST37 (female) was located crossing the road. From February 2020- April 2020 there were 58 GPS spatial points collected over the growing and non-growing seasons (Figure 23). OST37 did not lose his VHF transmitter during the study period.

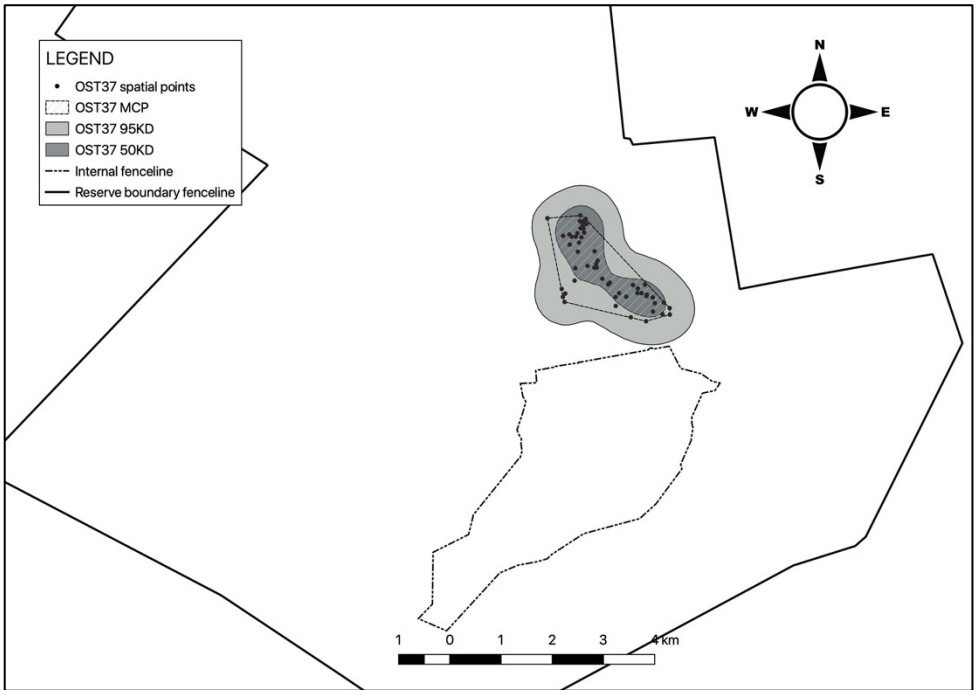

Figure 23: All spatial points, MCP, 95KD, and 50KD for OST37 (male)

3.1.3 Growing season

MCP and CReSS home ranges

The growing season was measured from December 2019- April 2020 and 5,464 GPS data points were collected and mapped for all 14 pangolins (Figure 24). Home range median, mean, maximum, and minimum values were calculated in Table 3, the median values were 5.10 km^2 for MCP, 6.30 km^2 for CReSS HR, and 2.11 km^2 for CReSS CA. MCP home ranges and KDE contours were mapped for seven individuals which had spatial data from both the growing and non-growing seasons (Figure 25). CReSS analysis was conducted for all individuals (Appendix 3) and the relative abundance, HR, and CA were mapped for all individuals (Figure 26 to Figure 39).

Growing season home ranges were similar in size and area of their overall home ranges for OST04 only (Figures 29 and 12). Growing season core area sizes were very similar in size and area for

OST03 (Figures 11 and 28), OST09 (Figures 14 and 31), OST11 (Figures 15 and 32), OST13 (Figures 17 and 34), OST29 (Figures 19 and 36), OST31 (Figures 20 and 37), and OST36 (Figures 23 and 40). For OST02 (Figures 10 and 29), OST18 (Figures 18 and 35), OST32 (Figures 21 and 38), and OST35 (Figures 22 and 39), the home range and core area sizes varied from their overall home range sizes, however the areas of their ranges are similar. OST03 showed a deviation from her overall home range (Figures 11) in that she mostly utilized the central part (Figure 28). OST08 also showed deviation from her overall home range (Figures 13) and utilized only the western section of their home range outside of the internal fenceline (Figure 30).

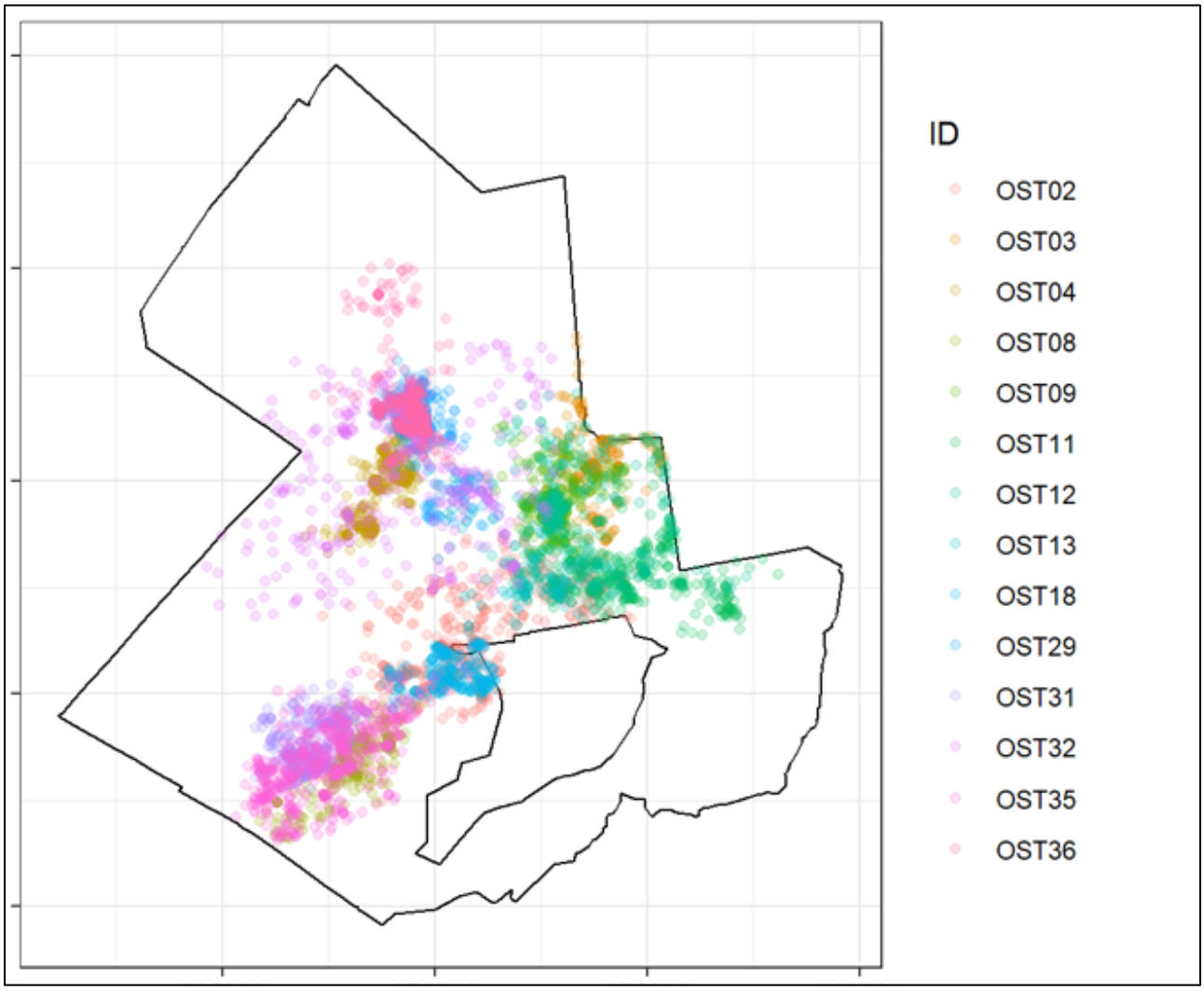

Figure 24: All spatial points for 14 individuals during the growing season

Table 3: Mean, median, maximum, and minimum for MCP, CReSS HR and CReSS CA values during the growing season			
	MCP (km^2)	CReSS HR (km^2)	CReSS CA (km^2)
Mean	7.04	9.47	3.33
Median	5.10	6.30	2.11
Maximum	16.08	33.98	11.77
Minimum	2.29	2.79	0.90

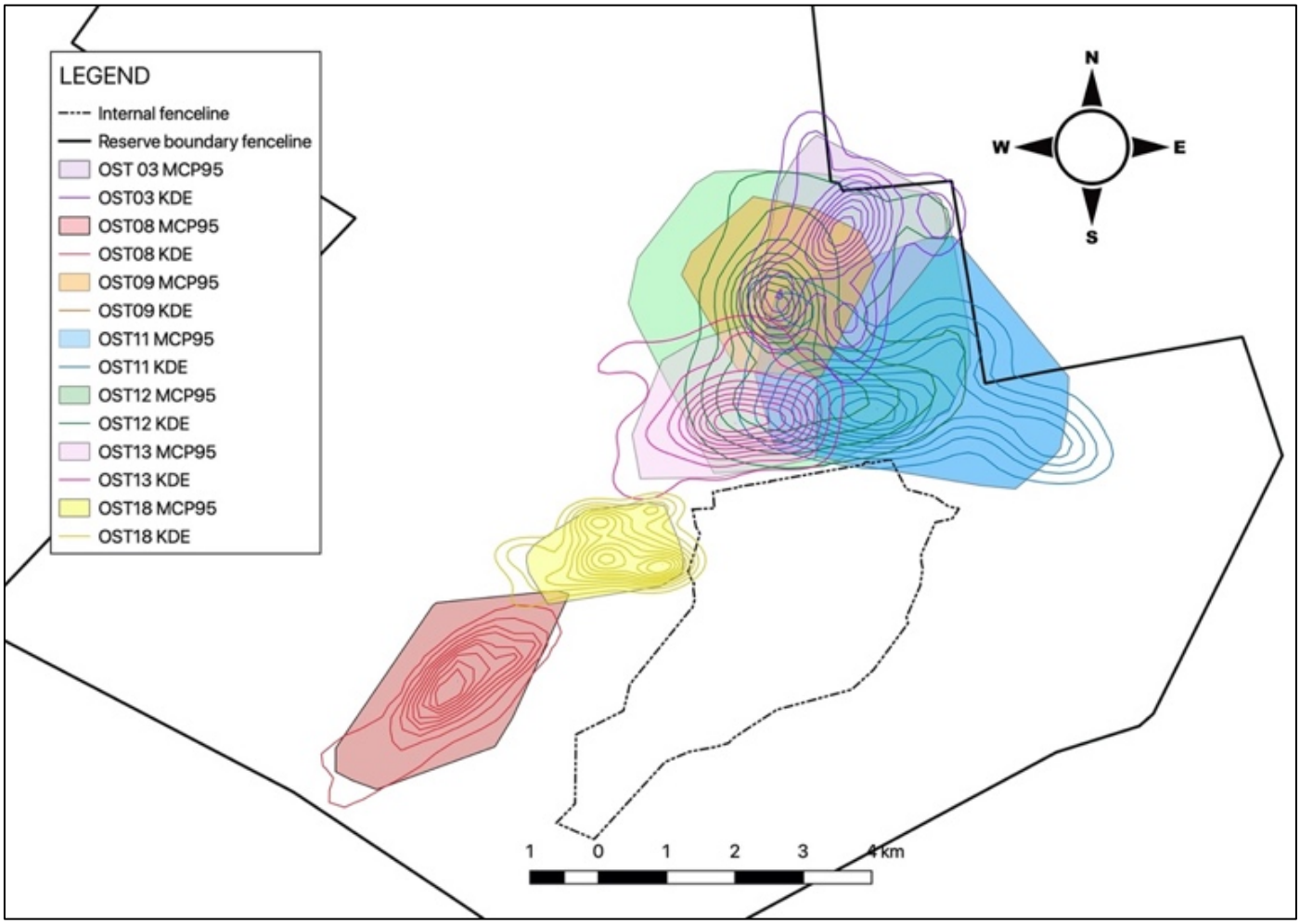

Figure 25: MCP (95) and KDE contours for seven pangolins during the growing season

Male OST12 had the largest home range of the animals where it was possible to determine growing season HR (Figure 26). It overlapped with four females OST03, OST09, OST11, and OST13 (Figure 12). Females in the same area, OST03, OST09, OST11, and OST13 had KDE overlap, however only on the outer extremes of their range (Figure 12). Females OST08 and OST18 had very little overlap with one another and other individuals.

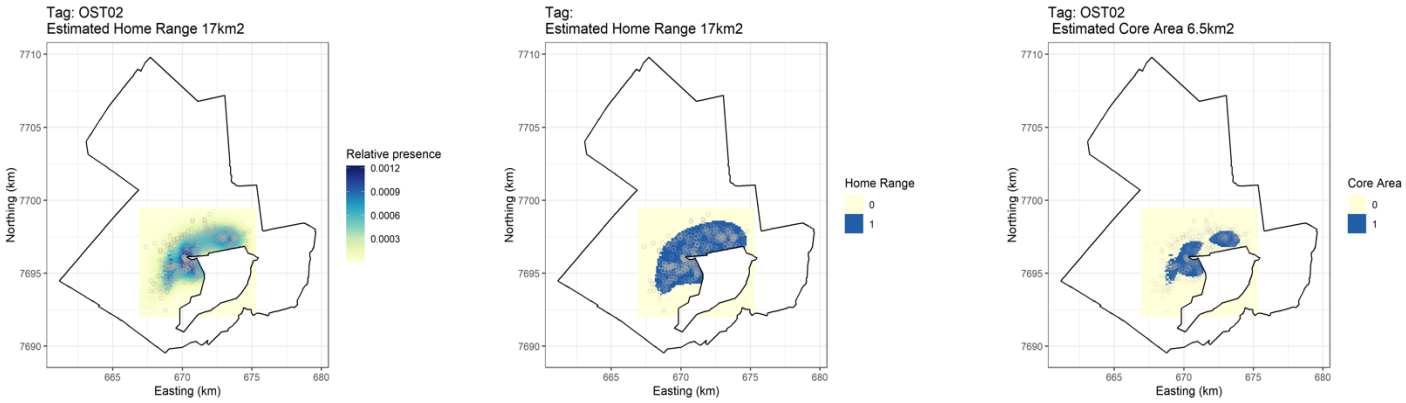

Figure 26: CReSS relative presence, HR, and CA during the growing season for OST02 (male)

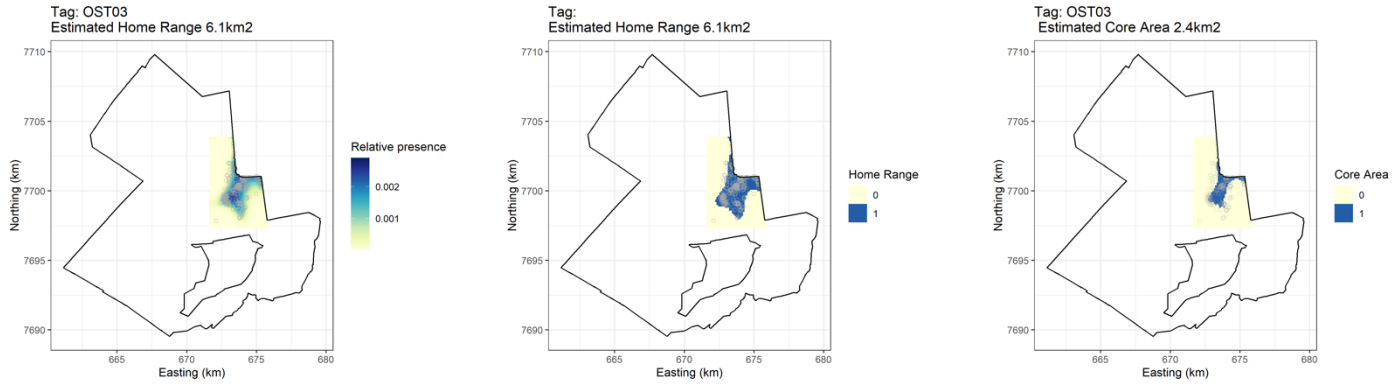

Figure 27: CReSS relative presence, HR, and CA during the growing season for OST03 (female)

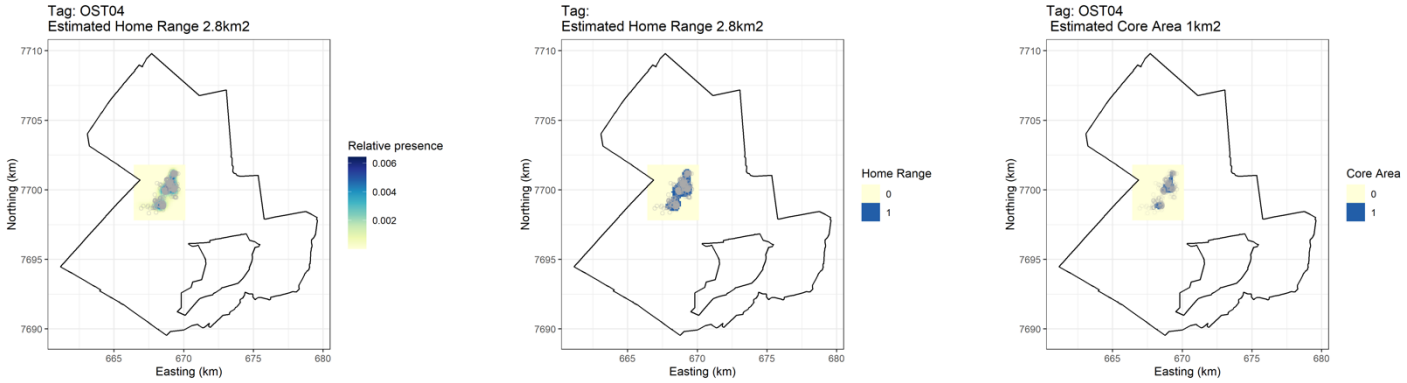

Figure 28: CReSS relative presence, HR, and CA during the growing season for OST04 (female)

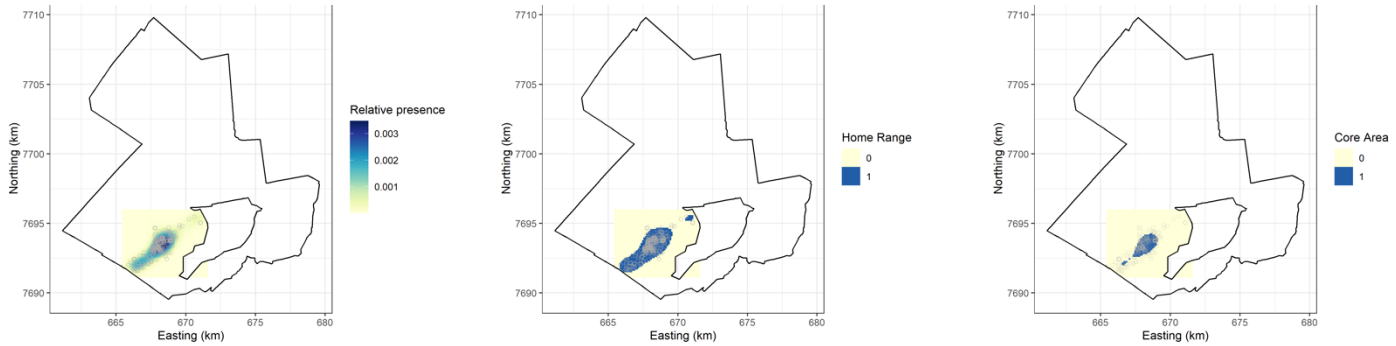

Figure 29: CReSS relative presence, HR, and CA during the growing season for OST08 (female)

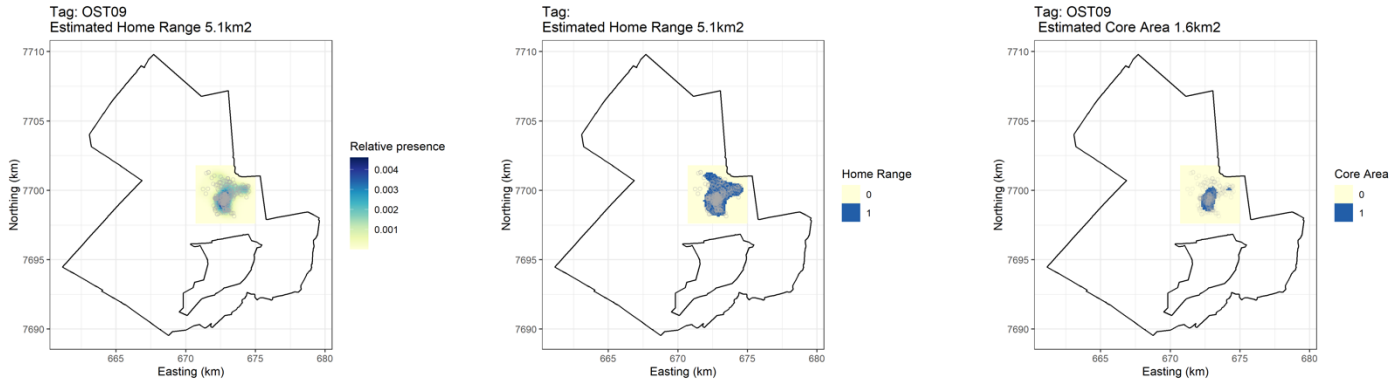

Figure 30: CReSS relative presence, HR, and CA during the growing season for OST09 (female)

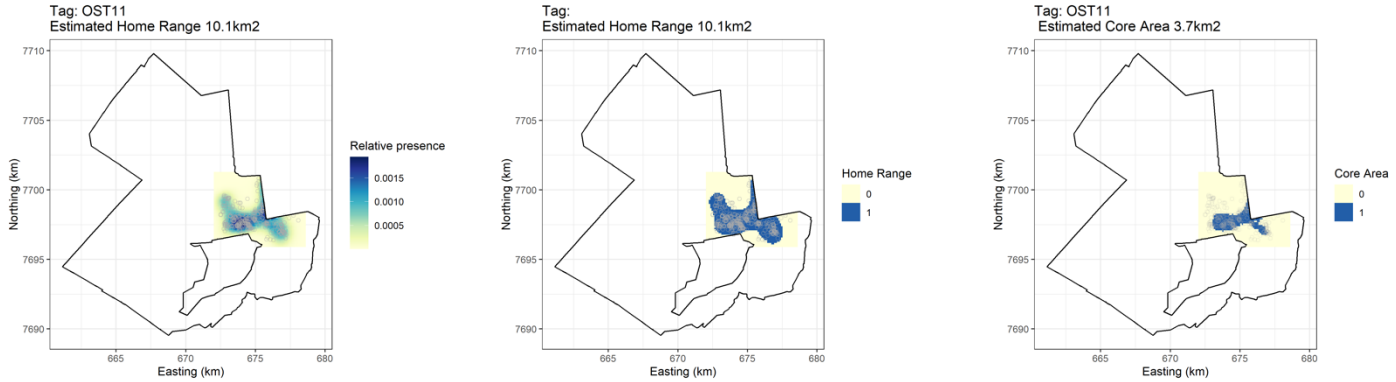

Figure 31: CReSS relative presence, HR, and CA during the growing season for OST11 (female)

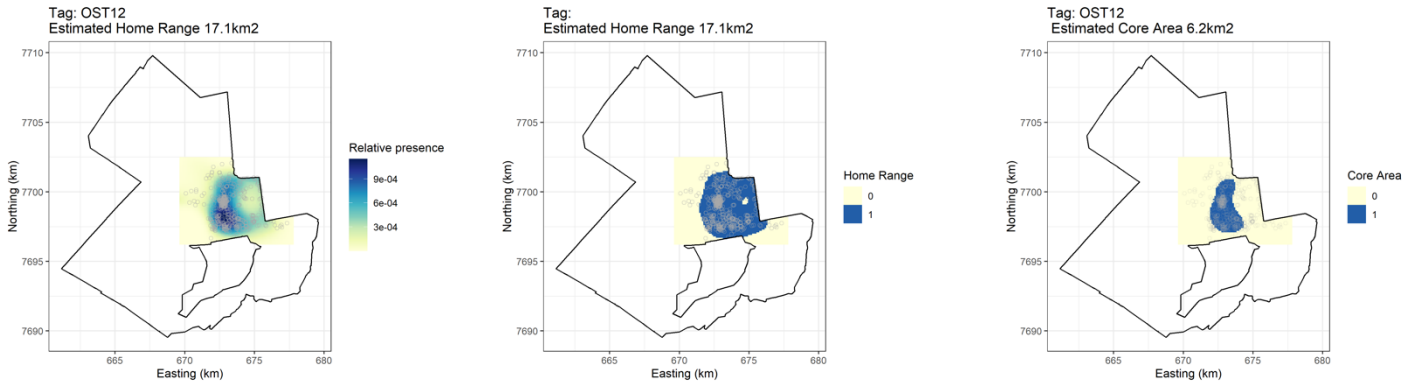

Figure 32: CReSS relative presence, HR, and CA during the growing season for OST12 (male)

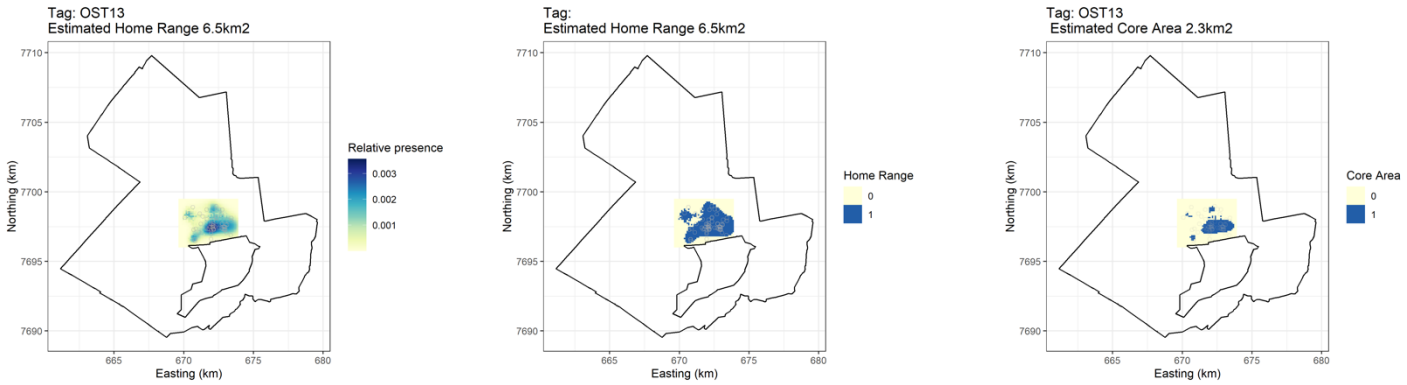

Figure 33: CReSS relative presence, HR, and CA during the growing season for OST13 (female)

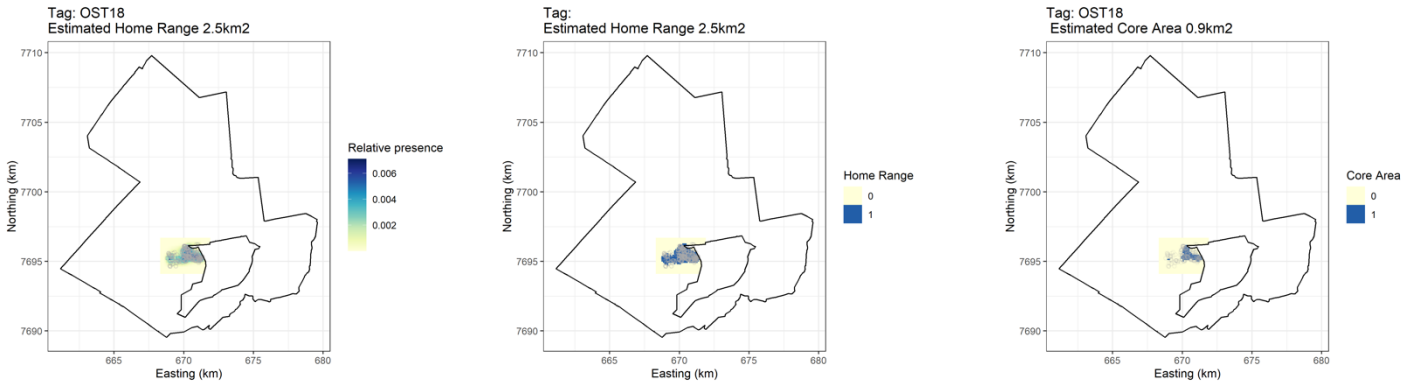

Figure 34: CReSS relative presence, HR, and CA during the growing season for OST18 (female)

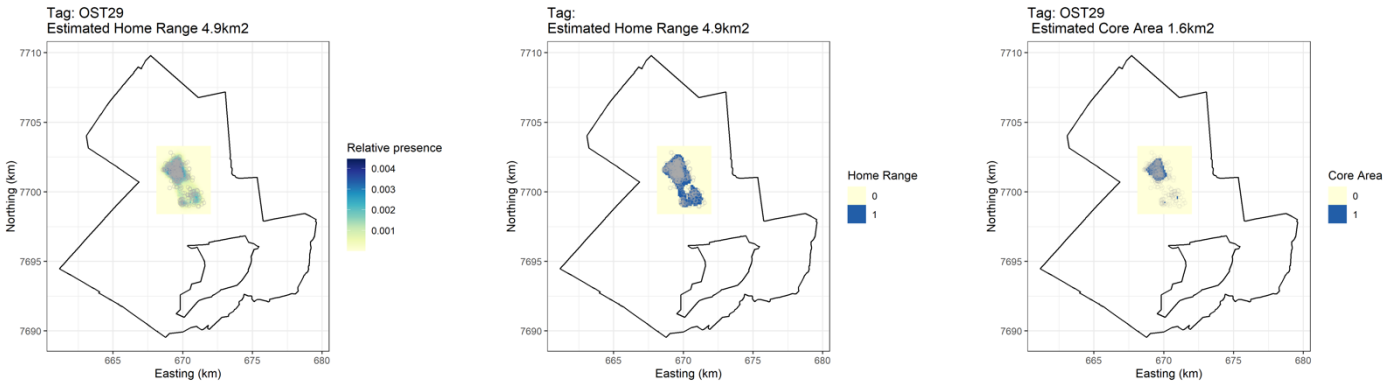

Figure 35: CReSS relative presence, HR, and CA during the growing season for OST29 (female)

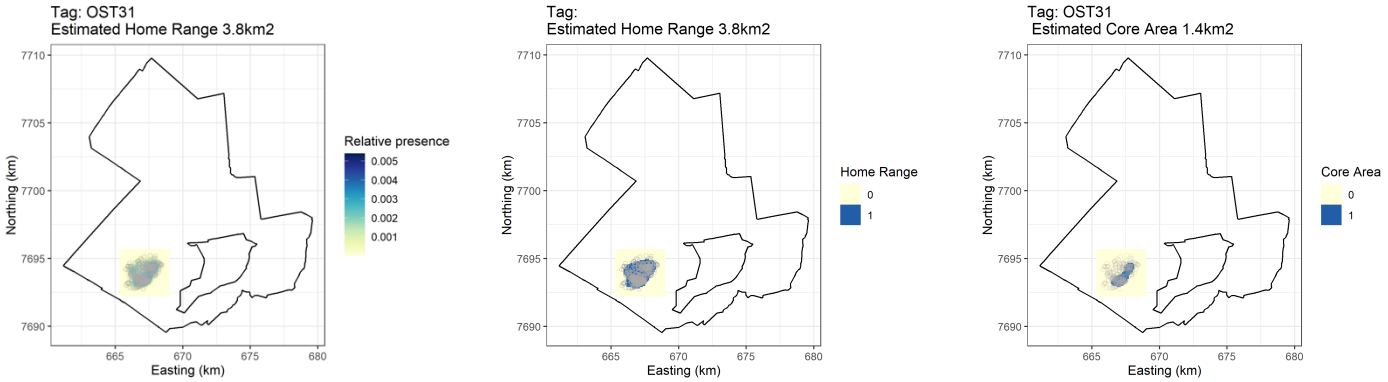

Figure 36: CReSS relative presence, HR, and CA during the growing season for OST31 (female)

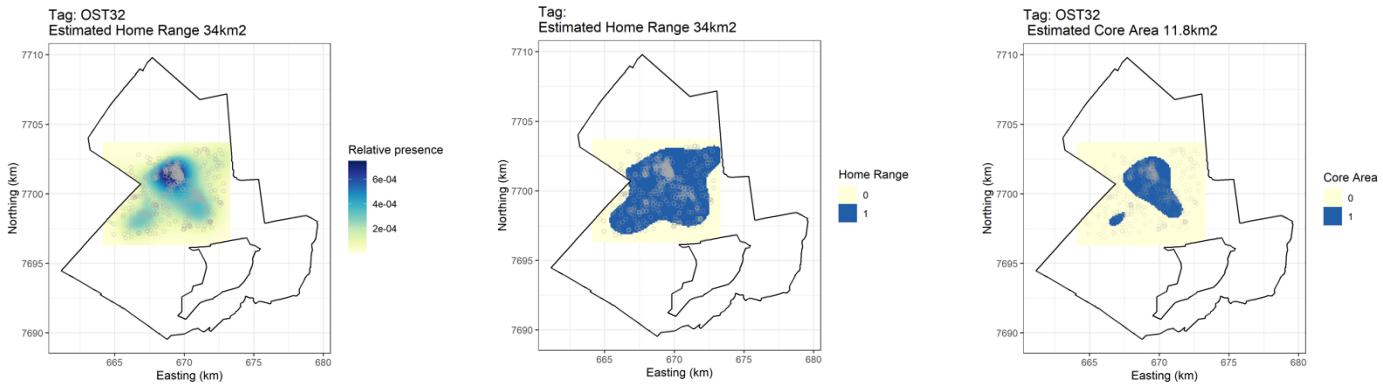

Figure 37: CReSS relative presence, HR, and CA during the growing season for OST32 (male)

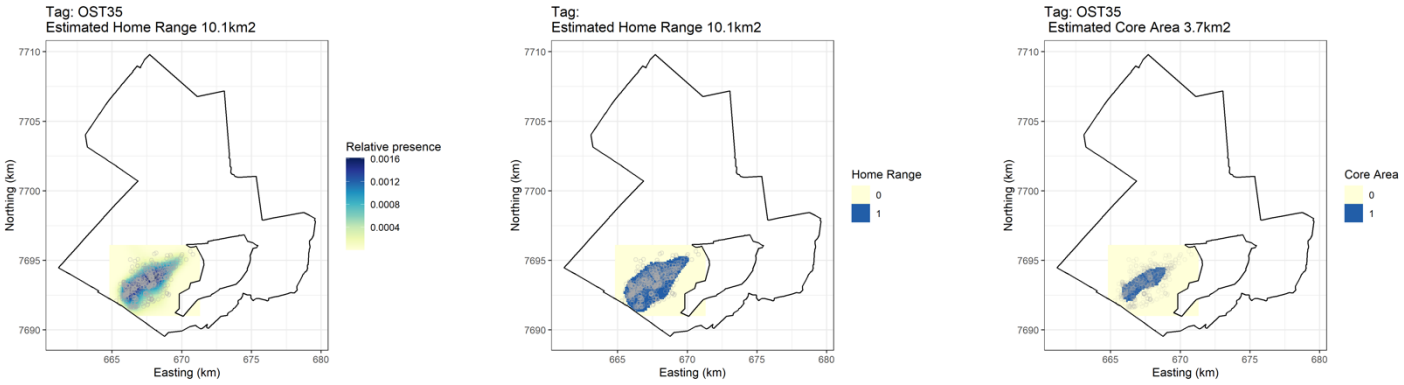

Figure 38: CReSS relative presence, HR, and CA during the growing season for OST35 (male)

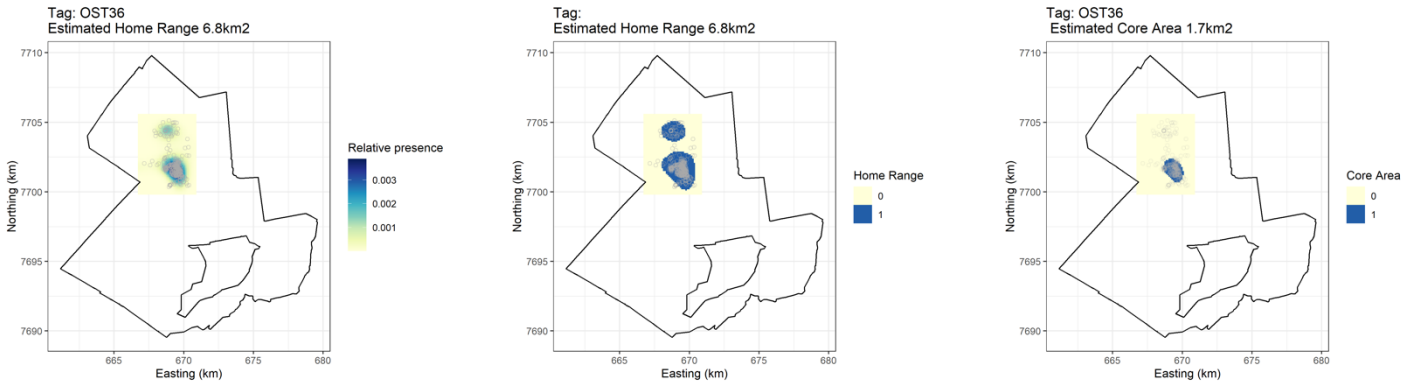

Figure 39: CReSS relative presence, HR, and CA during the growing season for OST36 (female)

3.1.4 Non-growing season

MCP and CReSS home ranges

The non-growing season was measured from July 2019-November 2019 and 1,584 GPS data points were mapped for all eight pangolins during the non-growing season (Figure 40). Home range median, mean, maximum, and minimum values were calculated in Table 4, the median values were 4.85 km^2 for MCP, 6.05 km^2 for CReSS HR, and 1.65 km^2 for CReSS CA. MCP home ranges and KDE contours were mapped for seven individuals which had spatial data from both the growing and non-growing seasons (Figure 41). CReSS analysis was conducted for all individuals (Appendix 3) and the relative abundance, HR, and CA were mapped for all individuals (Figure 42 to Figure 49).

Non-growing season home ranges and core areas were similar in size and area of their overall home ranges for OST03 (Figures 12 and 43), OST09 (Figures 14 and 45), OST11 (Figures 15 and 47), OST13 (Figures 17 and 49), and OST18 (Figures 28 and 50). OST08 demonstrated deviation from her overall home range (Figures 13) and utilized only the eastern section of their home range within the internal fenceline (Figure 44). There was no analysis in the growing season for OST10 because it died during the drought before enough data points were collected (Figure 46). OST12 utilized a similar area of its home range to the overall home range, however the home range and core area size was significantly smaller (Figures 16 and 48).

Female OST11 had the largest home range of the animals where it was possible to determine non-growing season HR (Figure 42). It overlapped with three females OST03, OST09, OST11, and OST13 and one male, OST12 (Figure 42). Similar to the growing season, females in the same area, OST03, OST09, OST11, and OST13 had KDE overlap, however only on the outer extremes of their range (Figure 12). Also, similar to the growing season, females OST08 and OST18 had very little overlap with one another and other individuals.

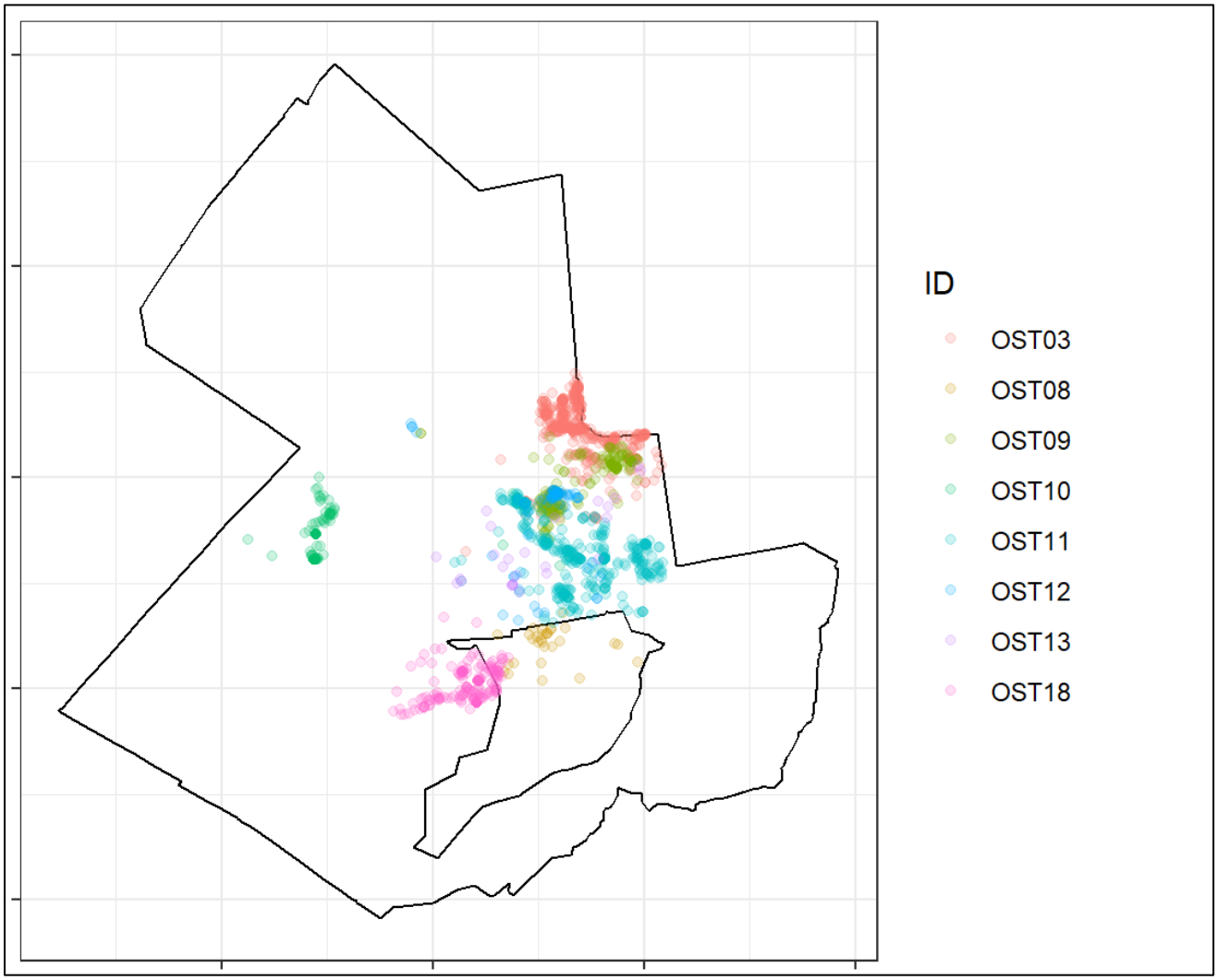

Figure 40: All spatial points for 8 individuals during the non-growing season

Table 4: Mean, median, maximum, and minimum for MCP, CReSS HR and CReSS CA values during the non-growing season			
	MCP (km^2)	CReSS HR (km^2)	CReSS CA (km^2)
Mean	4.31	5.41	1.76
Median	4.85	6.05	1.65
Maximum	7.15	8.17	3.23
Minimum	2.14	2.86	0.86

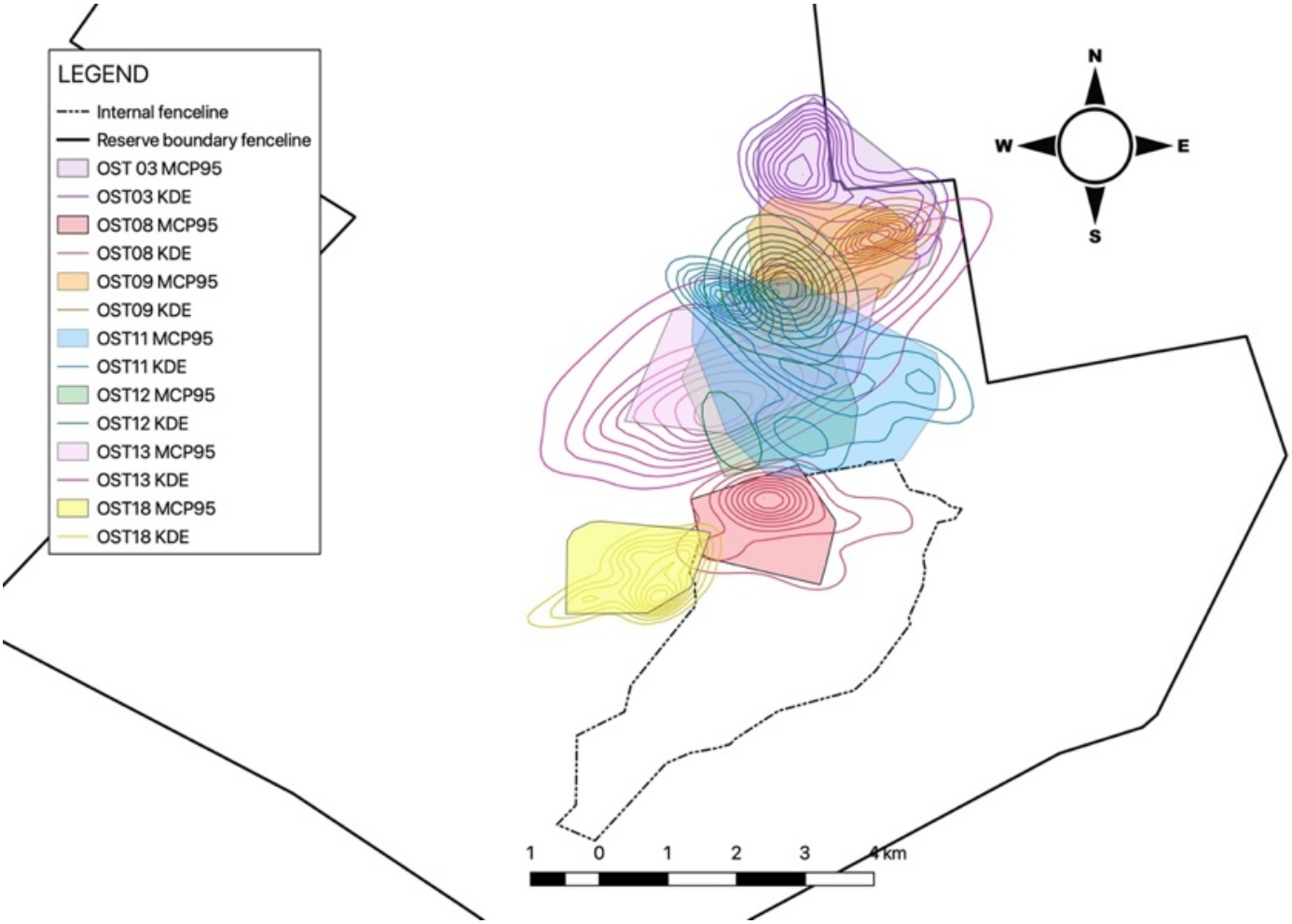

Figure 41: MCP 95 and KDE contours for seven pangolins during the non-growing season

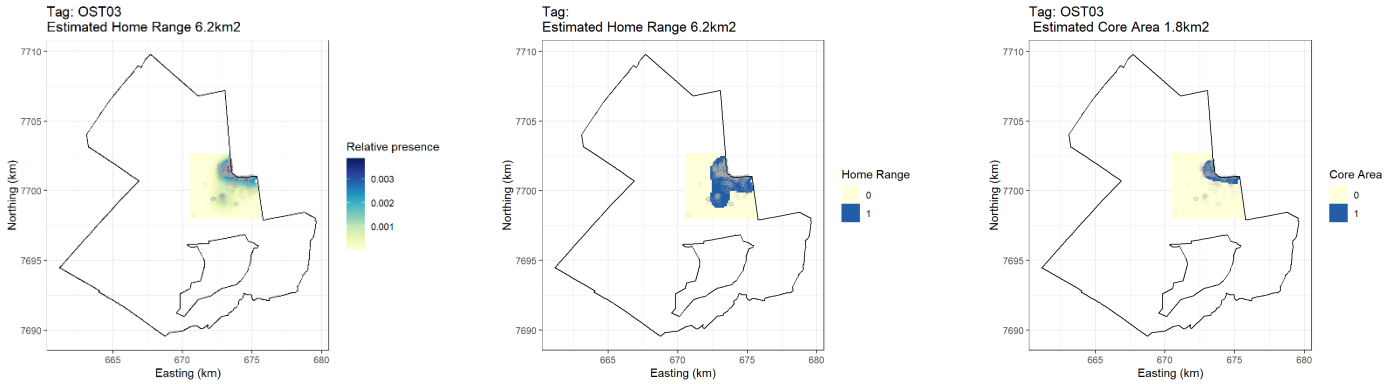

Figure 42: CReSS relative presence, HR, and CA during the non- growing season for OST03 (female)

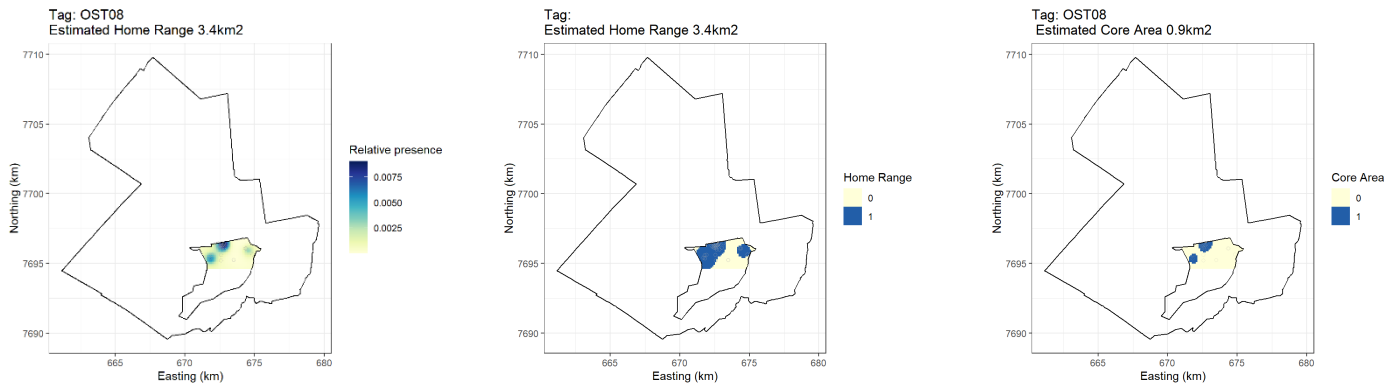

Figure 43: CReSS relative presence, HR, and CA during the non- growing season for OST08 (female)

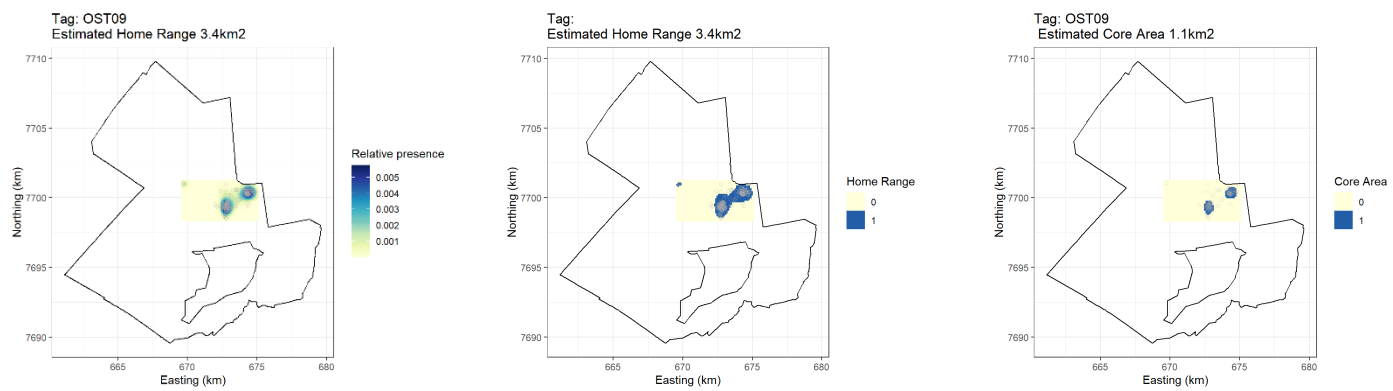

Figure 44: CReSS relative presence, HR, and CA during the non- growing season for OST09 (female)

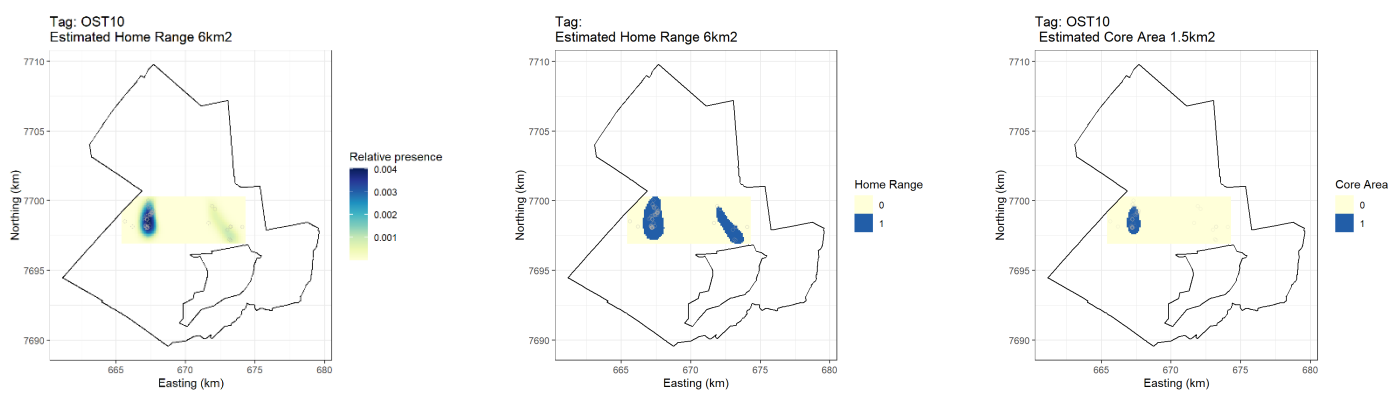

Figure 45: CReSS relative presence, HR, and CA during the non- growing season for OST10 (male)

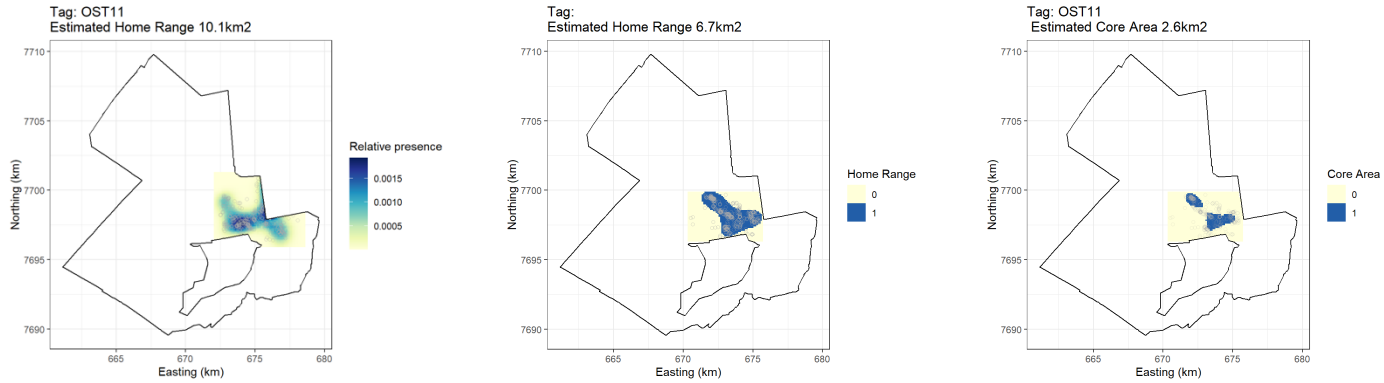

Figure 46: CReSS relative presence, HR, and CA during the non- growing season for OST11 (female)

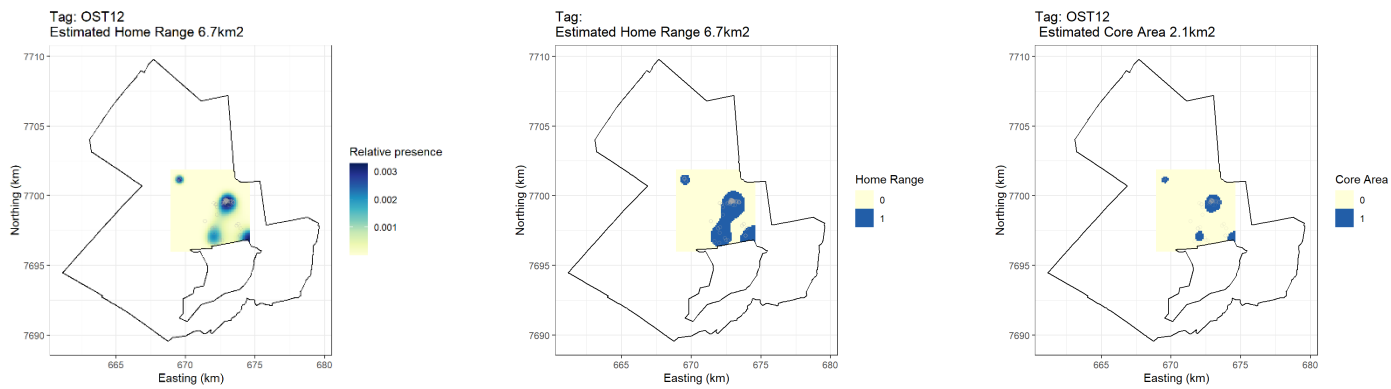

Figure 47: CReSS relative presence, HR, and CA during the non- growing season for OST12 (male)

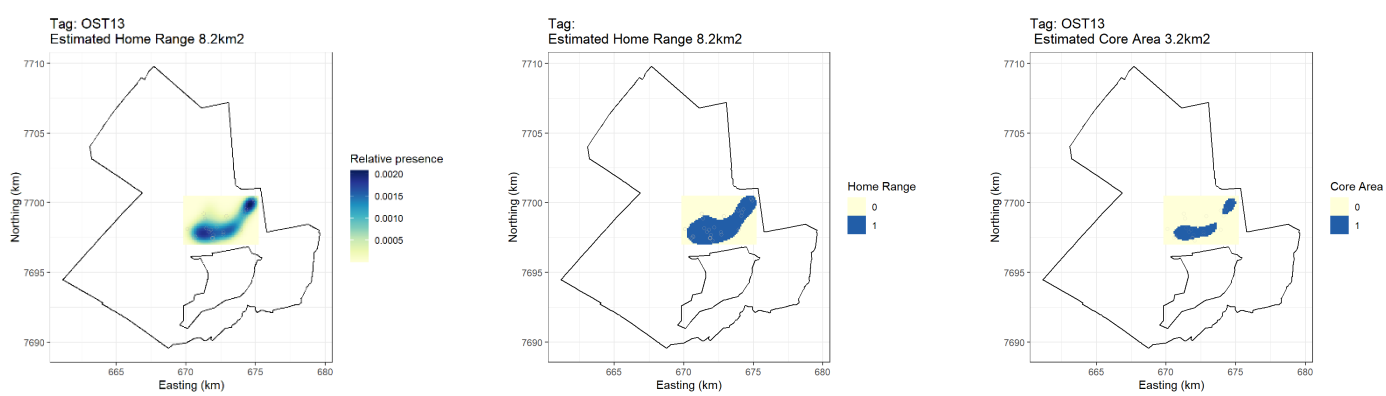

Figure 48: CReSS relative presence, HR, and CA during the non- growing season for OST13 (female)

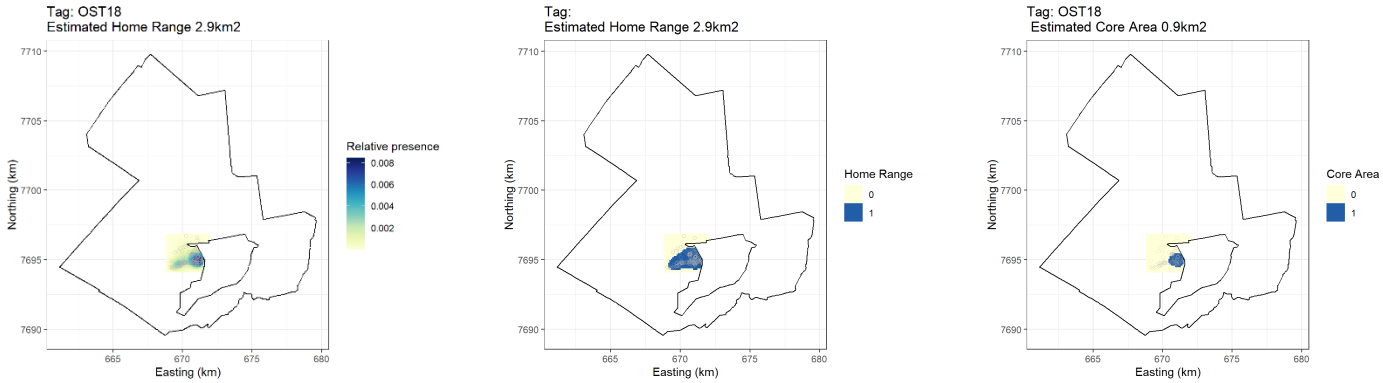

Figure 49: CReSS relative presence, HR, and CA during the non- growing season for OST18 (female)

3.1.5 Growing vs Non-growing seasons

There was no significant difference for MCP home ranges sizes between the non-growing and growing seasons, between the weight classes, nor between the sexes (Figure 50, Figure 51, and Figure 52), although the variance of home range sizes in the growing season was markedly greater.

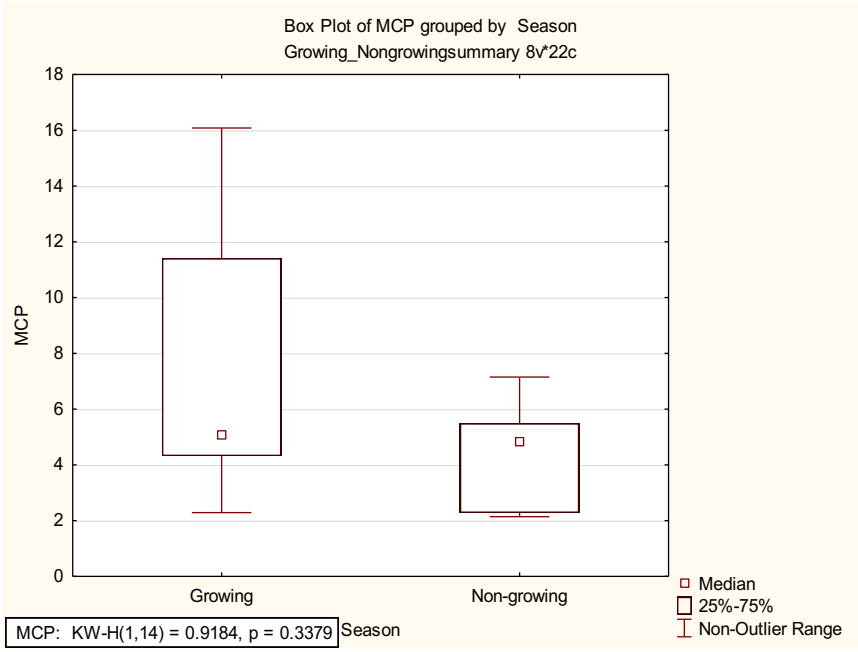

Figure 50: Box plot comparing the MCP home range sizes between the growing and non-growing season (p=0.3379)

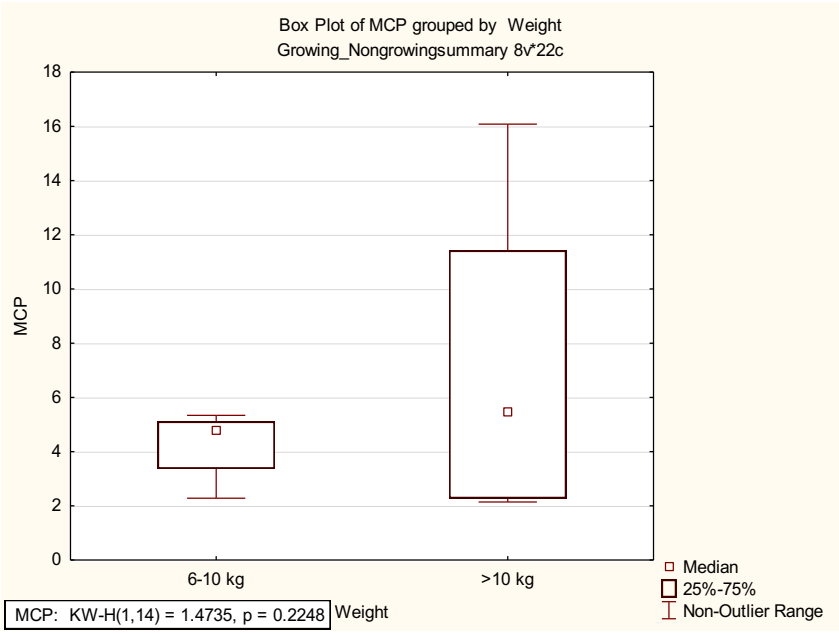

Figure 51: Box plot comparing the difference in MCP home range sizes between weight classes (6-10kg and >10kg)(p= 0.2248)

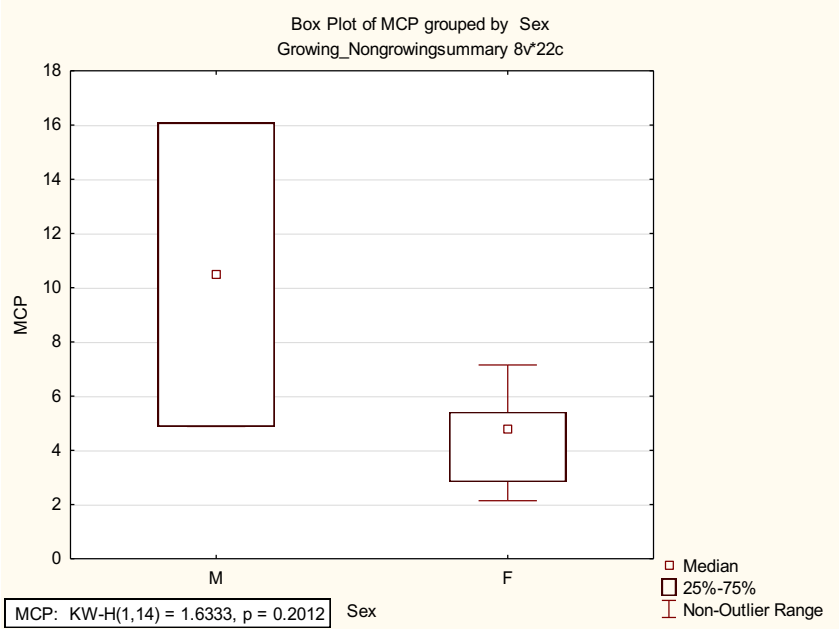

Figure 52: Box plot comparing the MCP home range sizes between males and females (p=0.212)

There was no significant difference between CReSS home range sizes for the growing and non-growing seasons or for home ranges size of different weight groups (Figure 53 and Figure 54).

However, the home range size of males was significantly larger than females (p< 0.01) (Figure 55).

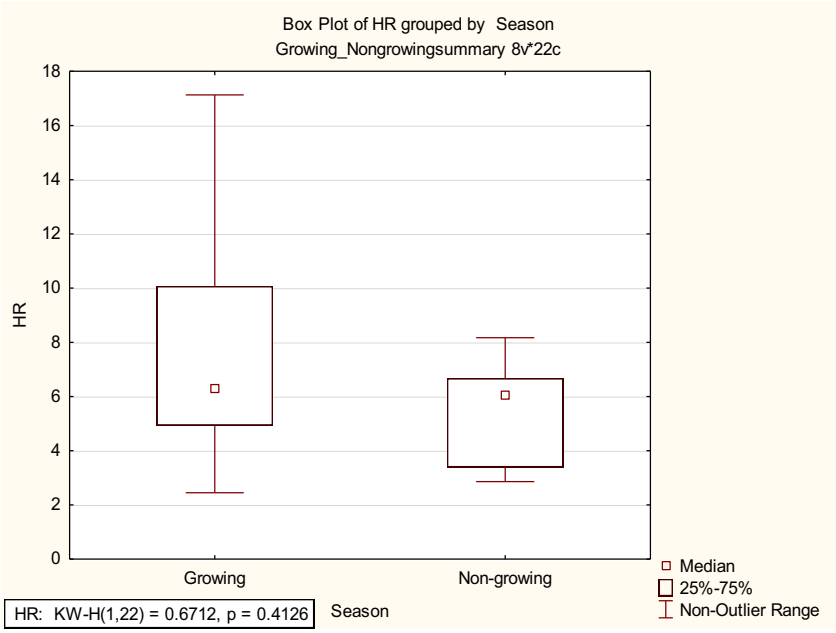

Figure 53: Box plot comparing the CReSS home range sizes between the growing and non-growing seasons (p= 0.4126)

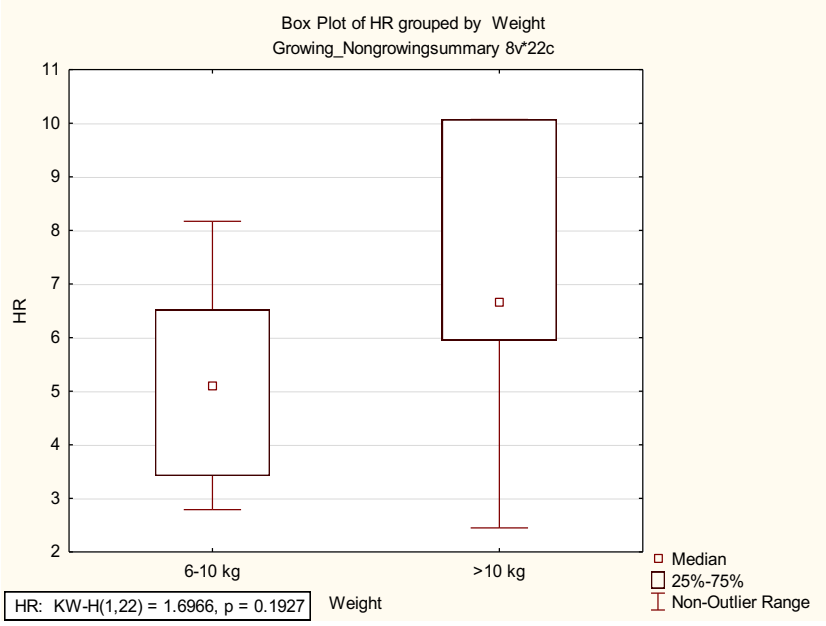

Figure 54: Box plot comparing the CReSS home range sizes between weight classes (6-10kg and >10kg)(p= 0.1927)

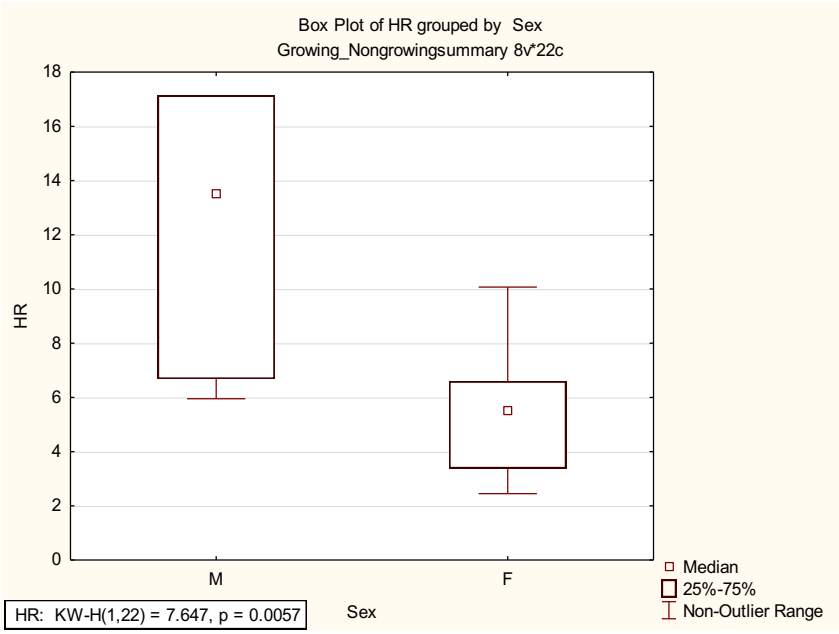

Figure 55: Box plot comparing the CReSS home range sizes of males and females(p= 0.0057)

Comparing growing and non-growing season individual CReSS home range sizes, there were a number of individuals whose home range sizes were significantly different (See post-hoc Table in Appendix 4). OST32 (male) home range size was significantly larger ($p<0.05$) than all other 13 individuals. OST02 (male) home range size was significantly larger ($p<0.05$) to the home range size of eight of the ten females (OST03, OST04, OST08, OST09, OST13, OST18, OST29, and OST31) and significantly larger for two of the four males (OST32, OST10). OST12 (male) home range size was significantly larger ($p<0.05$) than the home range size of three of the ten females (OST04, OST09, OST18) and significantly smaller than one of the four males (OST32).

There was no significant difference in CReSS core area sizes comparing the growing and non-growing seasons or for core area size of different weight groups (Figure 56 and Figure 57). However, as with home range size, male core areas were significantly larger than females ($p< 0.05$) (Figure 58).

Comparing individual CReSS core area sizes, OST32 (male) and OST02 (male) core area sizes were significantly larger than all other 12 pangolins (See post-hoc Table 2- Appendix).

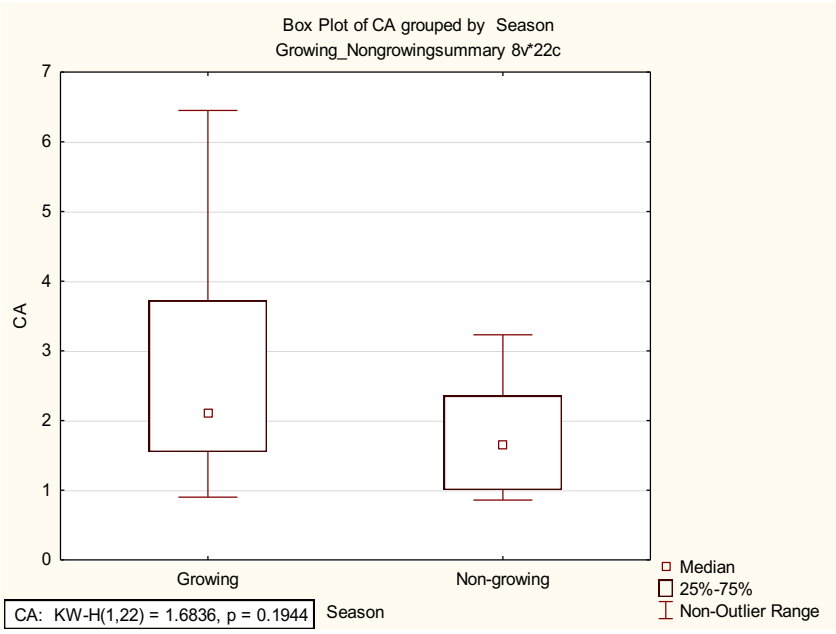

Figure 56: Box plot comparing CReSS core area sizes between the growing and non-growing seasons (p=0.1944)

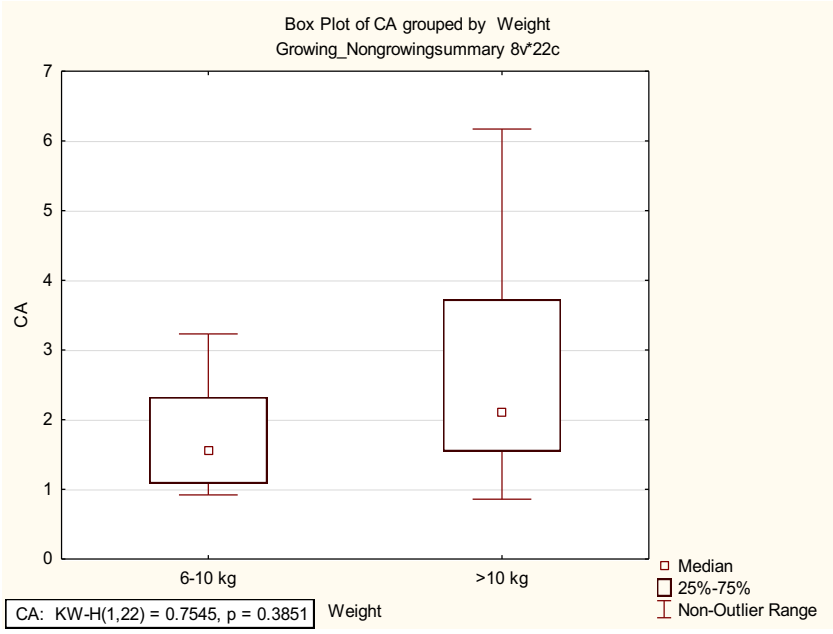

Figure 57: Box plot comparing the CReSS core area sizes between weight classes (6-10kg and >10kg) (p=0.3851)

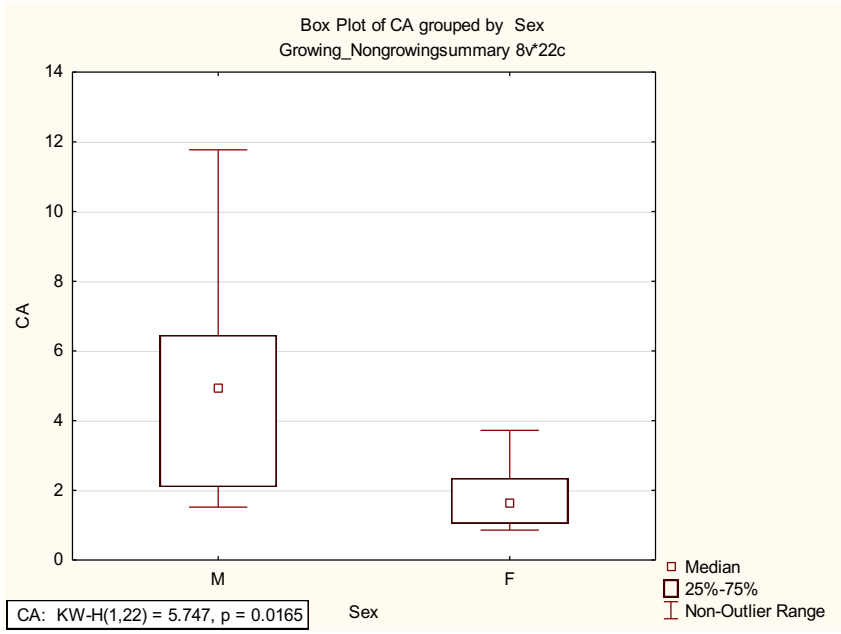

Figure 58: Box plot comparing the CReSS core area sizes between males and females (p=0.0165)

3.1.6 Male vs. Female growing season

During the growing season from December 2019- April 2020, 5,464 GPS data points were mapped for 14 pangolins, four males and 10 females, to determine CReSS home range and core area sizes (Figure 59). Male CReSS home range sizes were significantly larger than that of females and this was graphed (Figure 60 and Figure 61). The mean, median, maximum, and minimum were calculated separately for males and females for both CReSS HR size and CReSS CA size (Table 5). Median CReSS HR values were 17.07 km^2 for males and 5.51 km^2 for females. Median CReSS CA values were 6.31 km^2 for males and 1.65 km^2 for females.

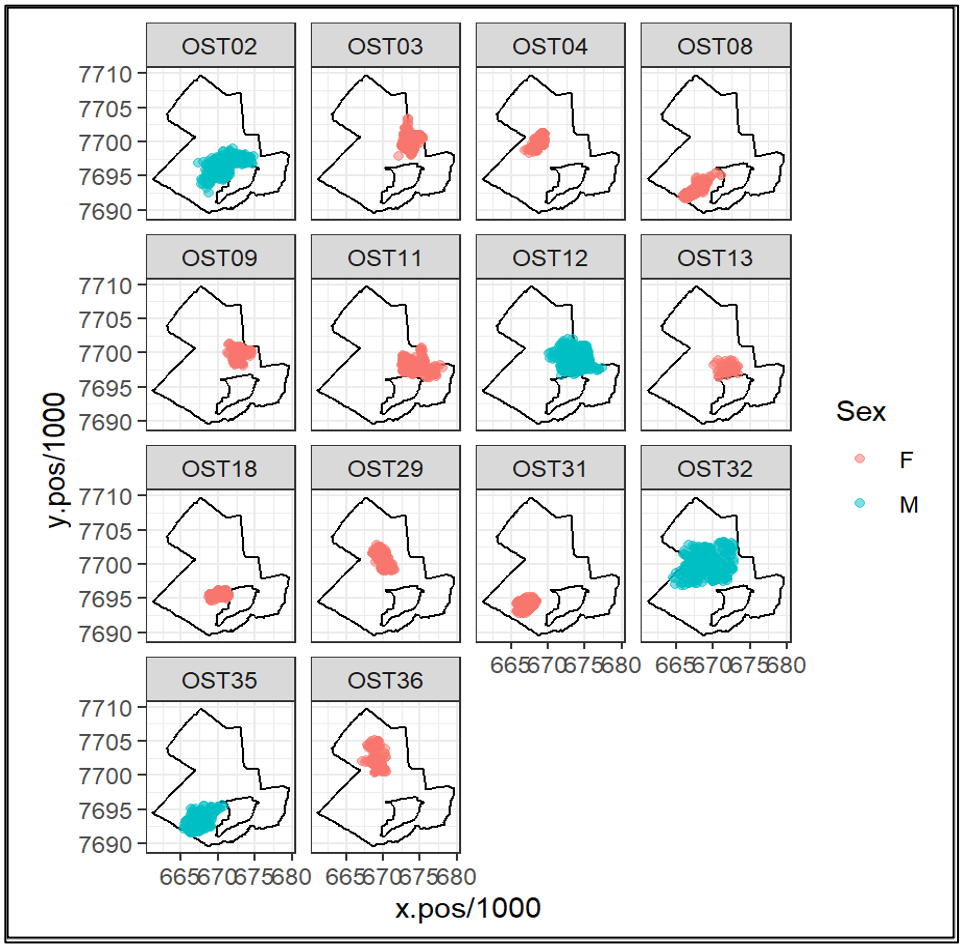

Figure 59: All spatial points for male (blue) and female (red) individuals mapped separately for the growing season

Table 5: Mean, median, maximum, and minimum for CReSS HR and CReSS CA values for both males and females during the growing season

	CReSS HR (km^2)		CReSS CA (km^2)	
Sex	M	F	M	F
Mean	19.55	5.44	7.03	1.85
Median	17.07	5.51	6.31	1.65
Maximum	33.98	10.07	11.77	3.72
Minimum	10.07	2.45	3.72	0.90

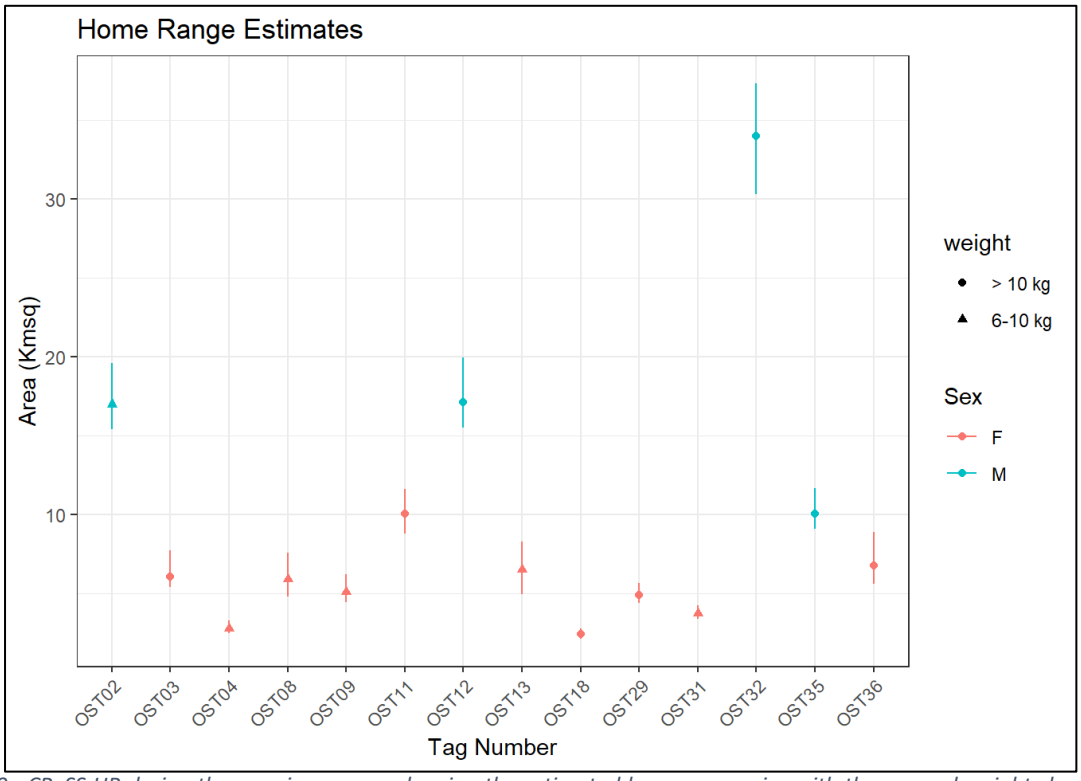

Figure 60: CReSS HR during the growing season showing the estimated home range size with the sex and weight class of each indvidual noted

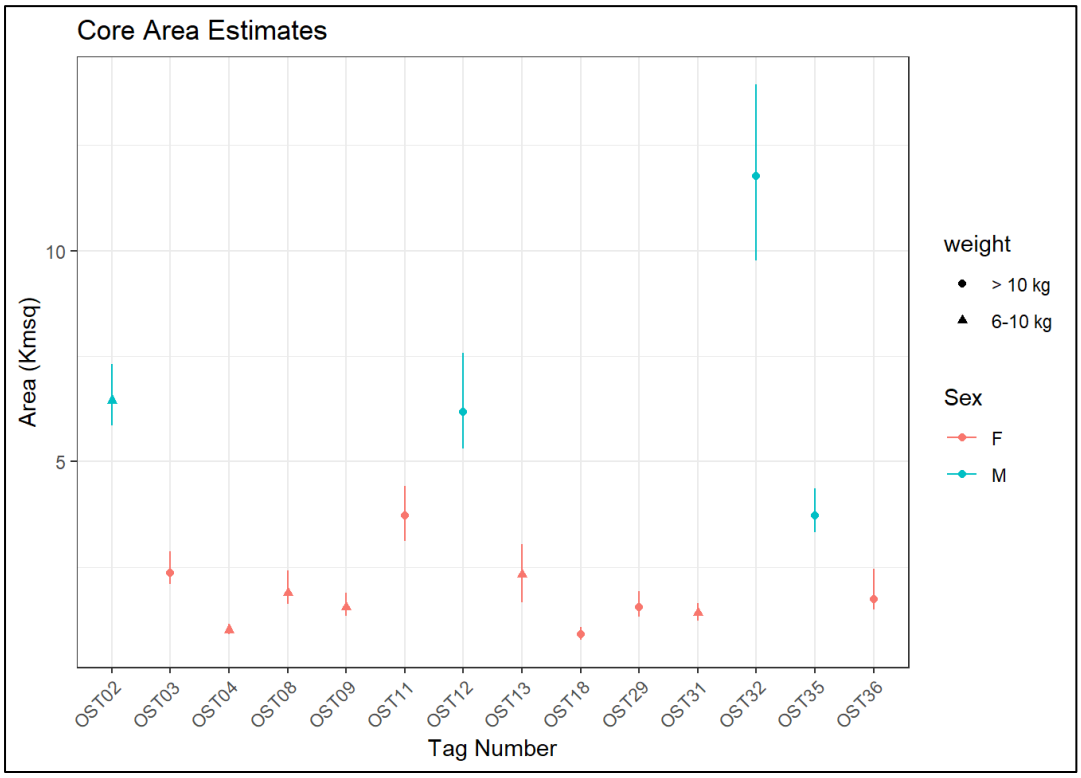

Figure 61: CReSS CA during the growing season showing the estimated core area size with the sex, and weight class of each indvidual noted

3.1.7 Male vs. Female non-growing season

During the non-growing season from June 2019 to November 2019, 1,584 GPS data points were collected for eight pangolins, two males and six females, to determine CReSS home range and core area sizes (Figures 62). Male CReSS core area sizes were significantly larger than that of females (Figure 63 and Figure 64). During the non-growing season the mean, median, maximum, and minimum were calculated separately for males and females for both CReSS home range size and core area size (Table 6). Median CReSS HR values were 6.32 km^2 for males and 4.79 km^2 for females. Median CReSS CA values were 1.81 km^2 for males and 1.43 km^2 for females.

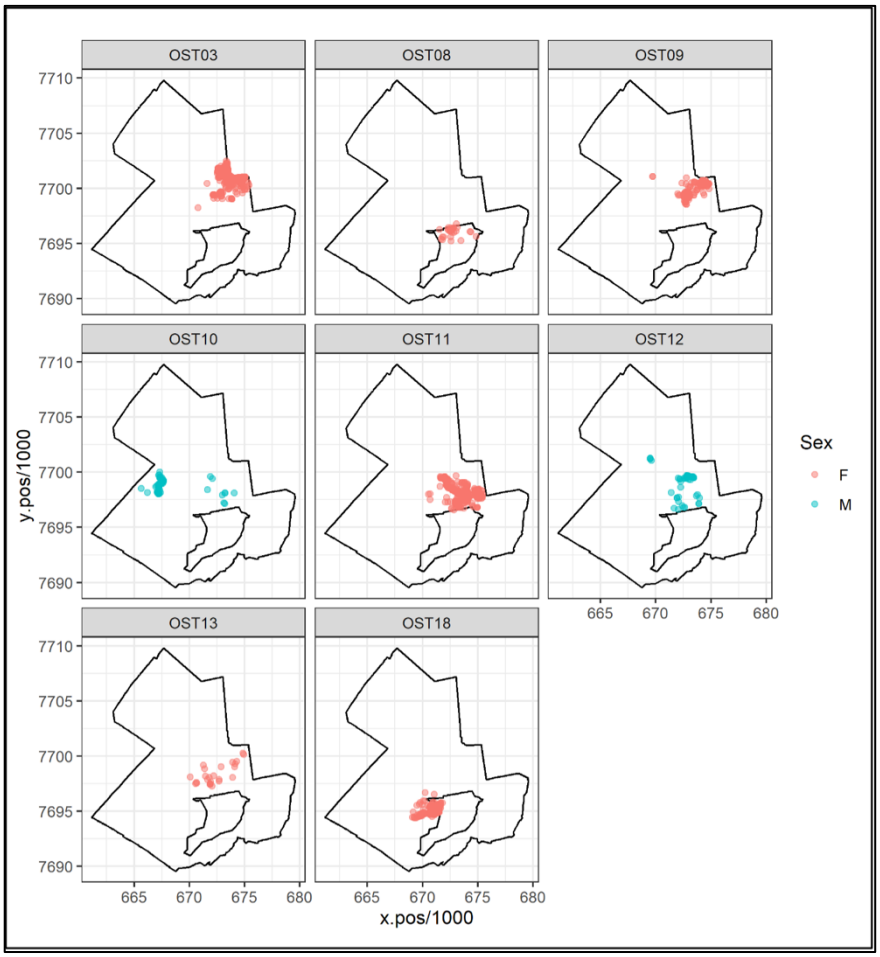

Figure 62: All spatial points for male (blue) and female (red) individuals mapped separately for the non-growing season

Table 6: Mean, median, maximum, and minimum for CReSS HR and CReSS CA values for both males and females during the non-growing season				
	CReSS HR (km^2)		CReSS CA (km^2)	
Sex	M	F	M	F
Mean	6.32	5.10	1.81	1.75
Median	6.32	4.79	1.81	1.43
Maximum	6.69	8.17	2.10	3.23
Minimum	5.95	2.86	1.52	0.86

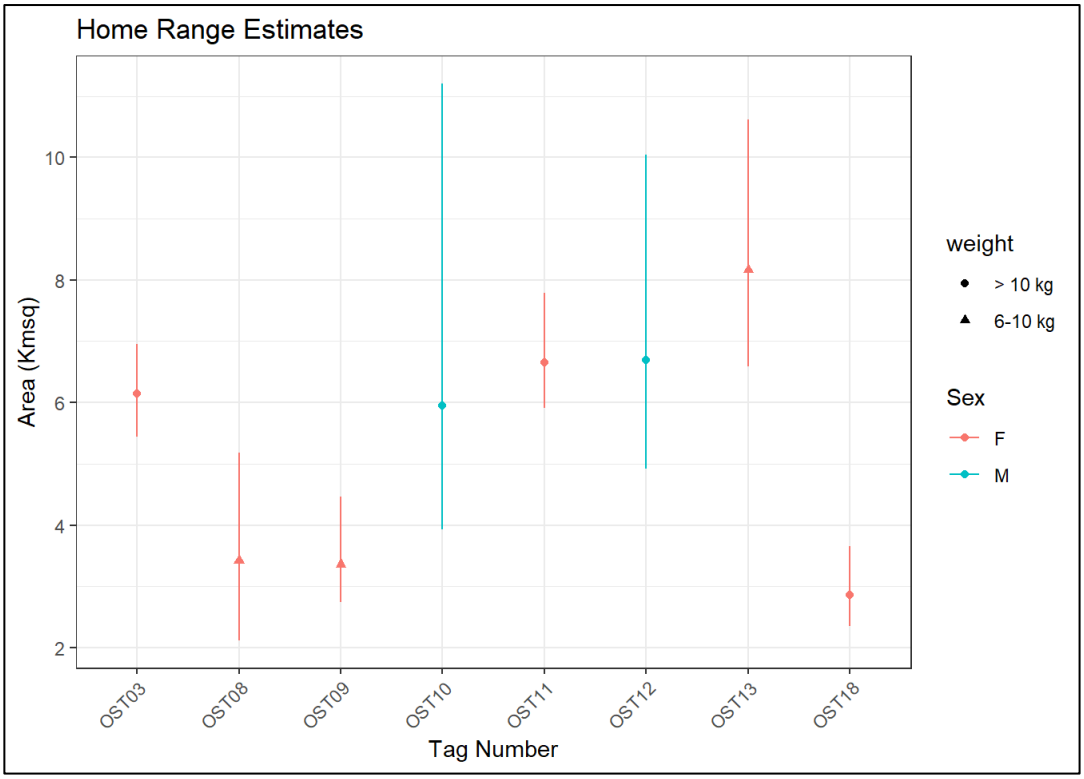

Figure 63: CReSS HR during the non-growing season showing the estimated home range size with the sex, and weight class of each indvidual noted

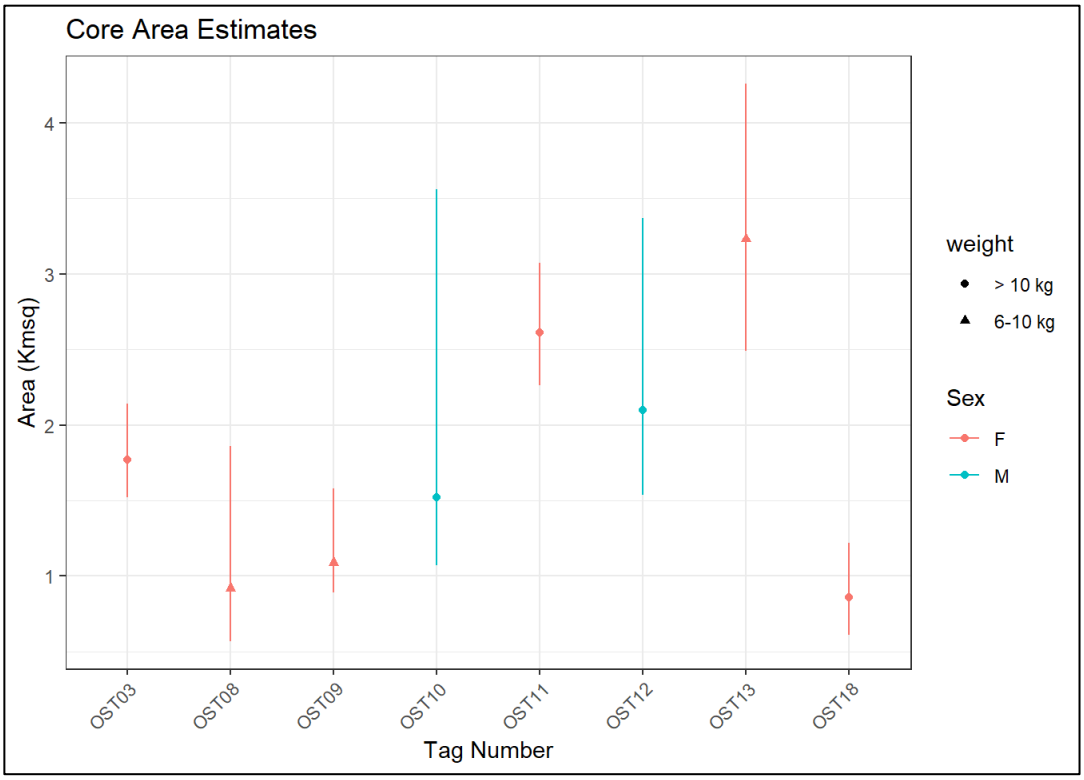

Figure 64: CReSS CA during the non-growing season showing the estimated core area size with the sex, and weight class of each indvidual noted

3.1.8. Spatial overlap

Pangolin home ranges and core areas had overlap between the same sex, mixed, and multiple individual overlap. Analysis was conducted to estimate overlap per non-growing (eight individuals; two males and six females) and growing seasons (fourteen individuals; four males and ten females) for all male and female pangolins. Male home ranges overlap with multiple female home ranges, suggesting a polygamous mating system. During the non-growing season there was never any male-male home range or core area overlap and during the growing season there was never any female-female or female-female-female home range or core area overlap.

Growing season overlap

During the growing season there were 53 cases of home range overlap. Eighteen instances involved two pangolins overlapping, sixteen involved three pangolins overlapping, ten involved

four overlapping, seven involved five overlapping, and two involved six overlapping (Figure 65 and Figure 66). The maximum home range overlap was between OST35 (male) and OST08 (female), with 3.43 km^2 overlap (Appendix 5). The median overlap for male-female home range was 1.66 km^2 and male-male overlap was 0.53 km^2 (Appendix 5).

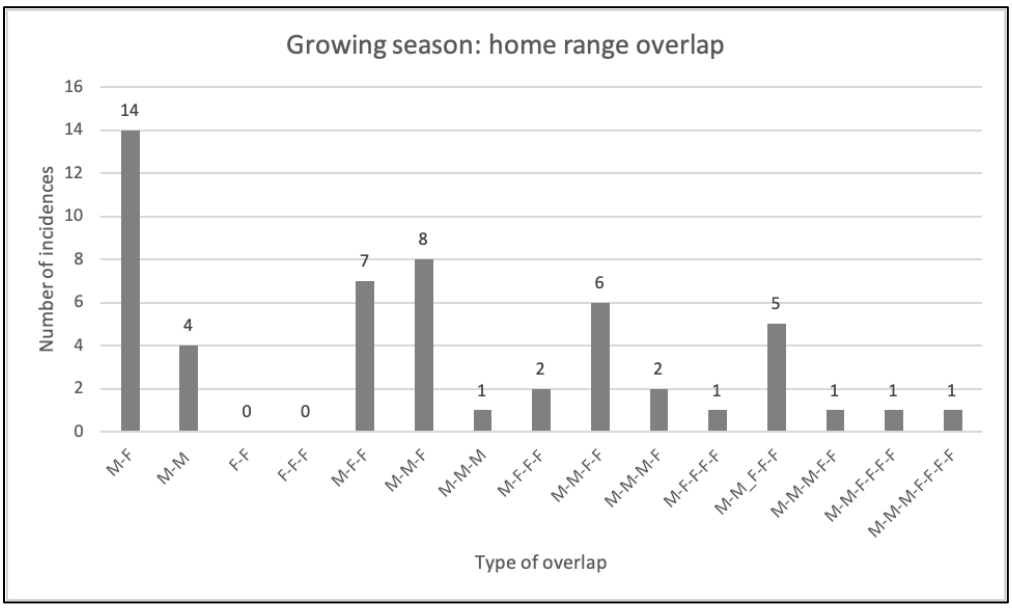

Figure 65: Instances of individual CReSS home range overlap during the growing season

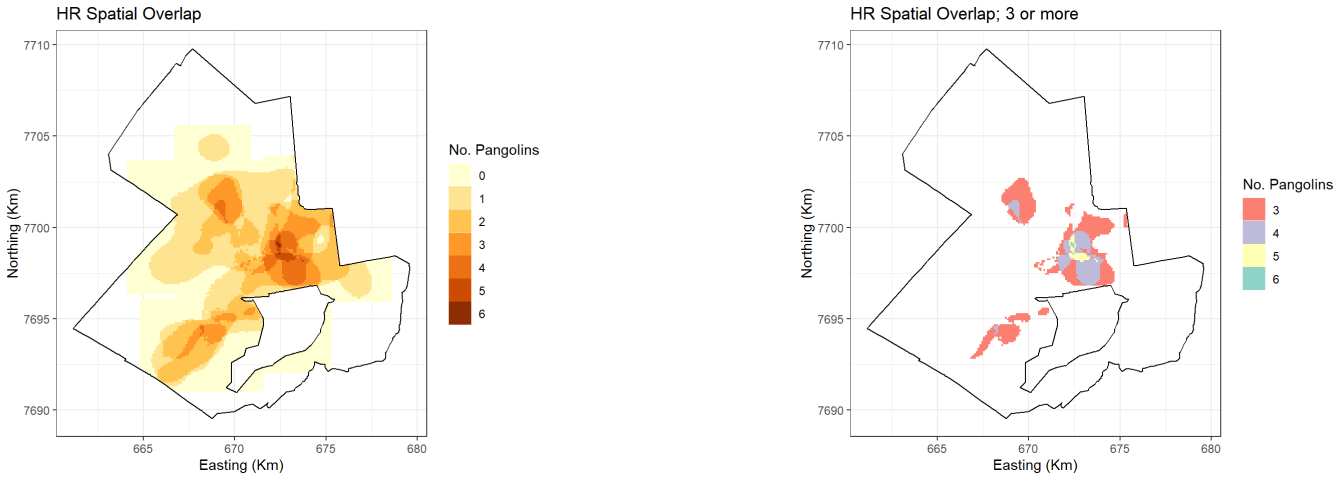

Figure 66: All individual CReSS HR overlap during the growing season for 0-6 individuals (left), CReSS HR overlap for 3- 6 individuals (right)

During the growing season there were twenty-three cases of core area overlap. Thirteen involved two pangolins overlapping, eight involved three pangolins overlapping, and two involved four pangolins overlapping (Figure 67 and Figure 68).

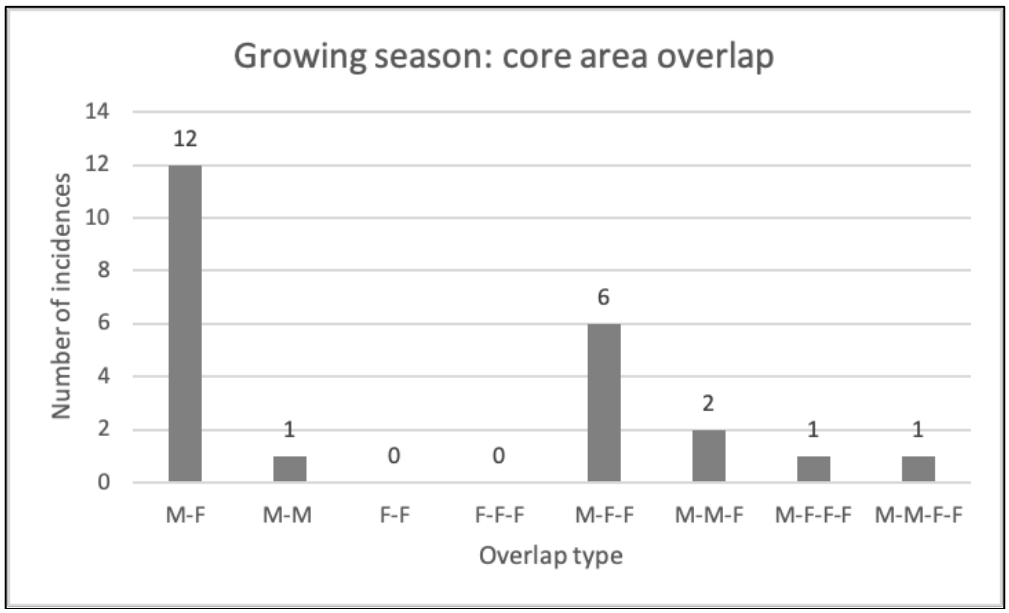

Figure 67: Instances of individual CReSS core area overlap during the growing season

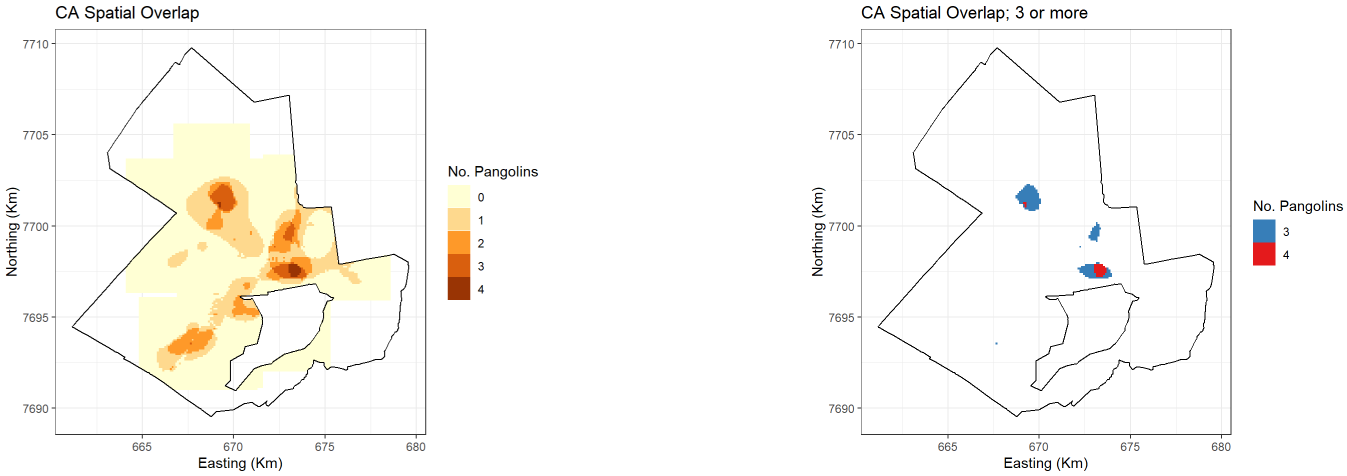

Figure 68: All individual CReSS CA overlap during the growing season for 0-4 individuals (left), CReSS CA overlap for 3- 4 individuals (right)

Same-sex overlap for CReSS HR was more common with females than males, with up to four females overlapping. Males rarely overlapped with another male (Figure 69). Same-sex overlap for CReSS core areas was much less common for females and there was only one example of males overlapping CA (Figure 70).

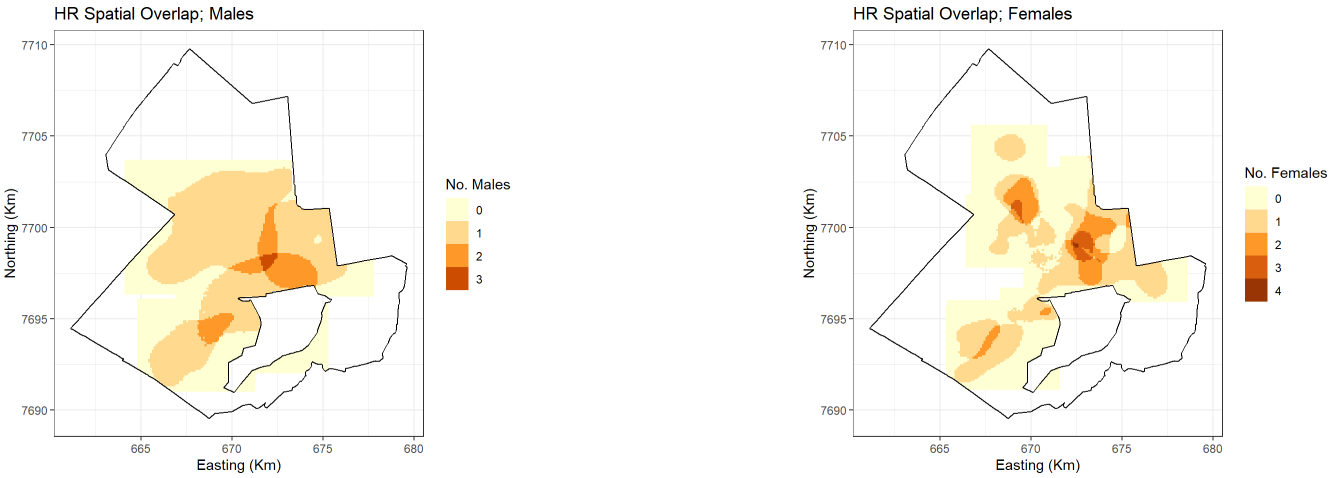

Figure 69: CReSS HR overlap in the growing season for males (left) and females (right)

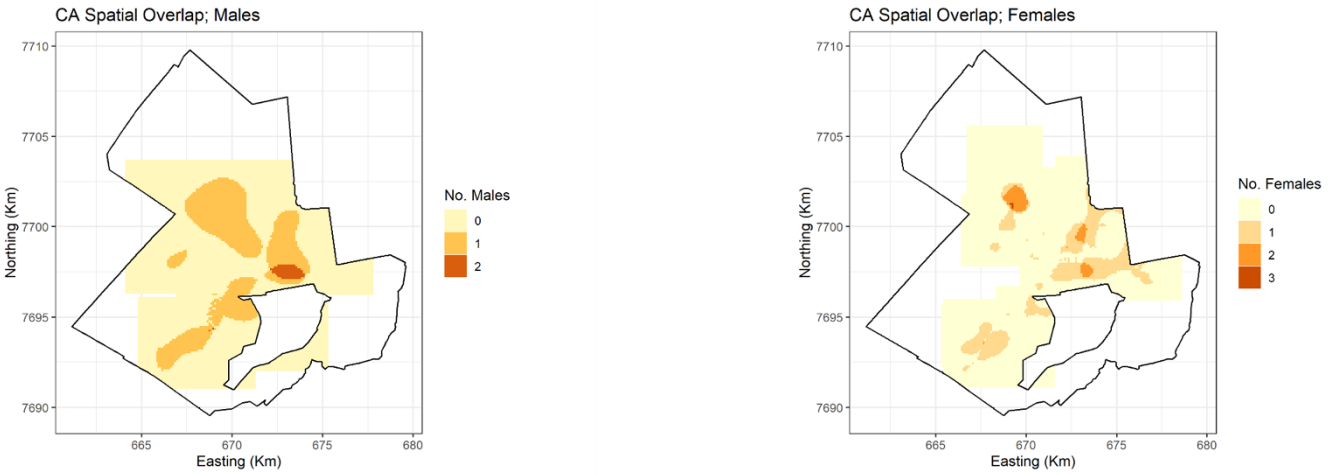

Figure 70: : CReSS CA overlap in the growing season for males (left) and females (right)

Non-growing season overlap

During the non-growing season there were 25 cases of home range overlap. Ten involved two pangolins overlapping, eight involved three pangolins overlapping, five times involved

overlapping, and two involved five overlapping (Figure 71 and Figure 73). The median overlap for male-female home range was 0.532 km^2 and for female-female overlap was 0.292 km^2 (Appendix 6).

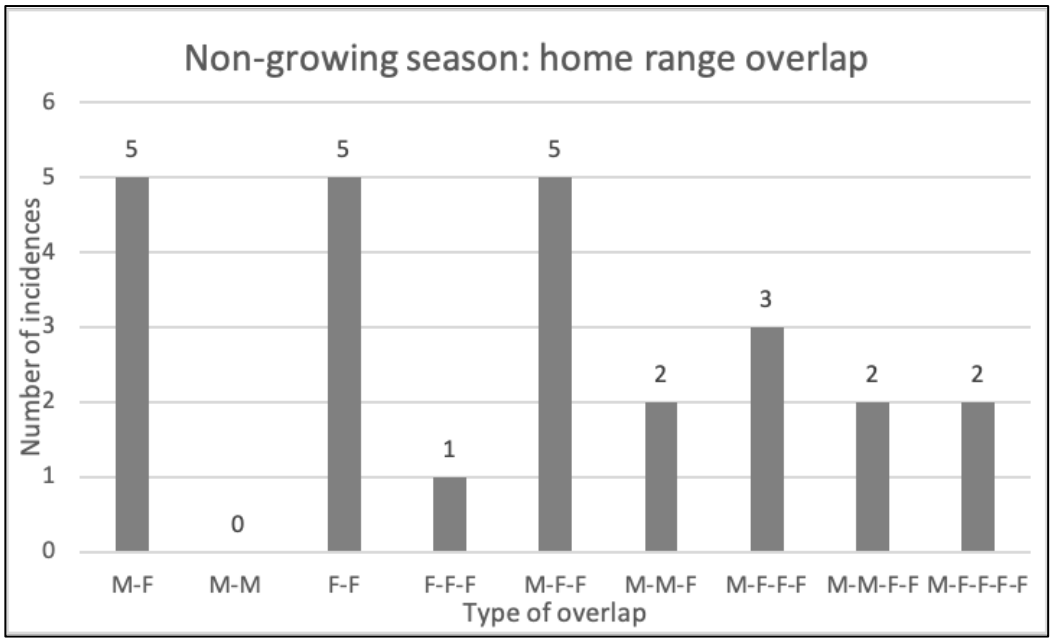

Figure 71: Instances of individual CReSS home range overlap during the non-growing season

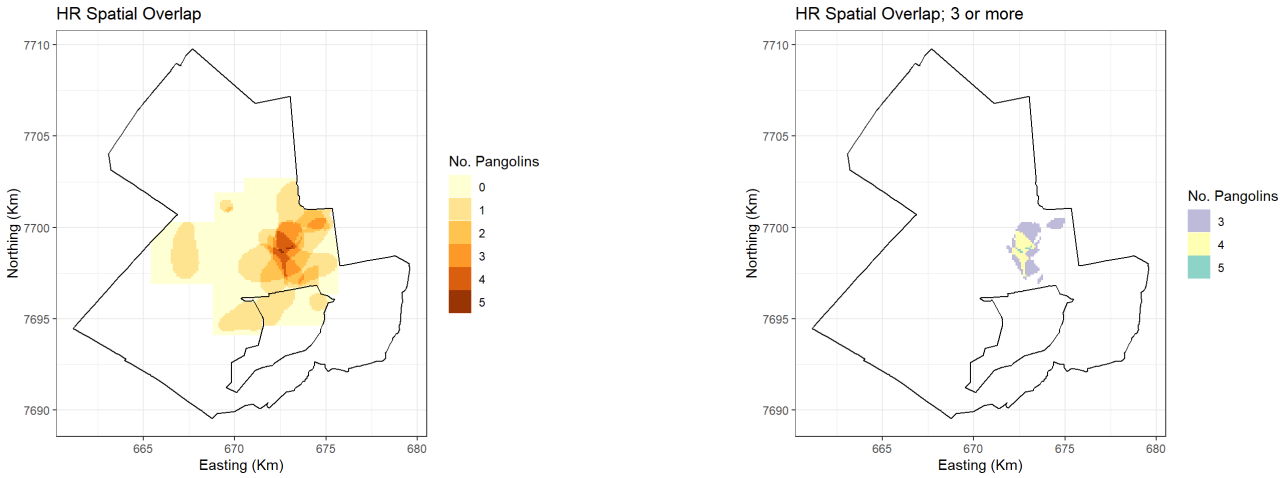

Figure 72: All individual CReSS HR overlap during the non-growing season for 0-5 individuals (left), CReSS HR overlap for 3- 5 individuals (right)

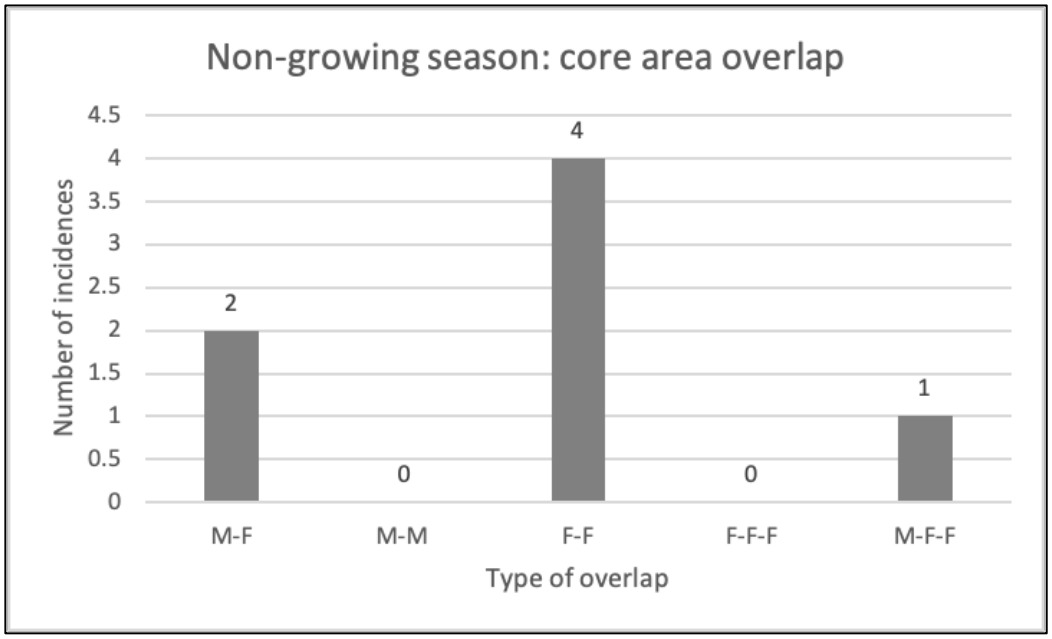

Figure 73: Instances of individual CReSS core area overlap during the non-growing season

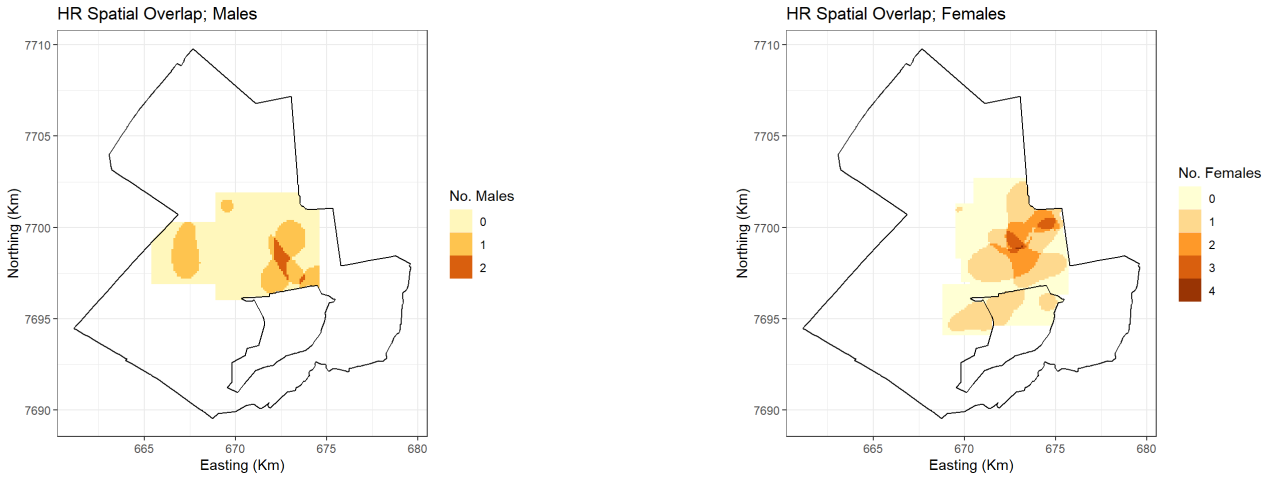

Figure 74: CReSS HR overlap in the non-growing season for males (left) and females (right)

Same-sex overlap for the CReSS HR area during the non-growing season was more common for females; there was only one instance with males (Figure 74). There was minimal same-sex overlap for CReSS CA during the non-growing season (Figure 76). During the non-growing season there were seven cases of core area overlap. Six cases involved two pangolins overlapping and one involved three pangolins overlapping (Figure 72 and Figure 74).

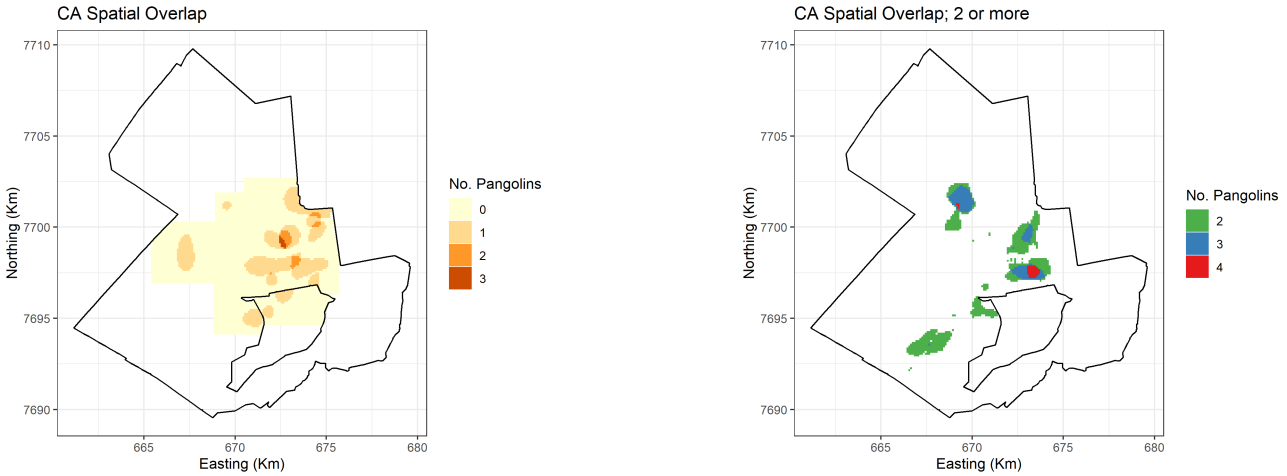

Figure 75: All individual CReSS CA overlap during the non-growing season for 0-3 individuals (left), CReSS HR overlap for 2-3 individuals (right)

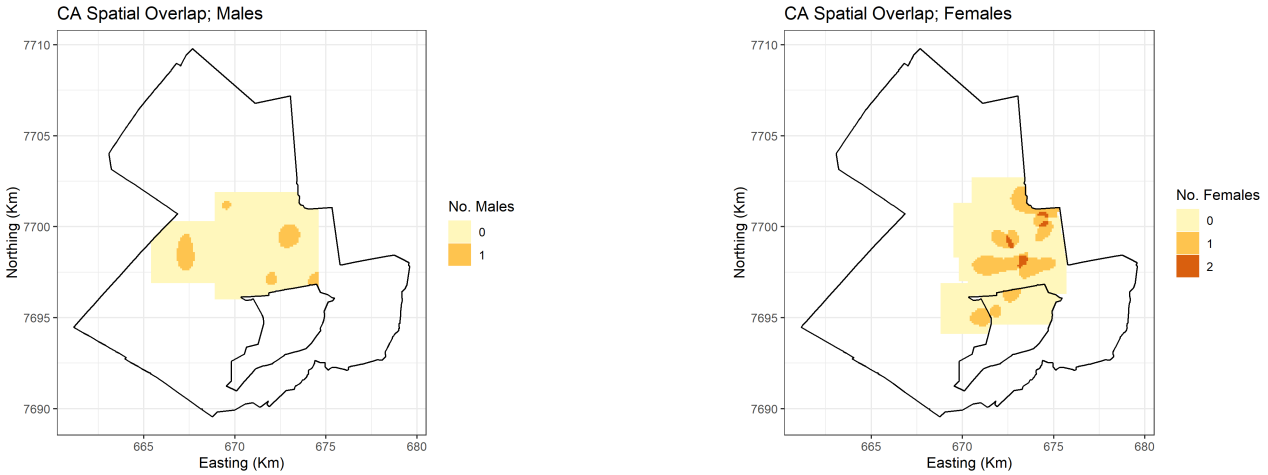

Figure 76: CReSS CA overlap in the non-growing season for males (left) and females (right)

3.2 Prey Preference

3.2.1 Ant and termite pitfalls

A total of 46,158 specimens were collected and 23,079 (50%) of all specimens were non-target taxa. Any species not an ant or termite was considered non-target taxa. Twenty genera of ant (family Formicidae) were represented across four subfamilies with a minimum of 24 species collected and 3 genera of termites were represented with a minimum of 3 species collected (Appendix 7 and Figure 80). Two ant subfamilies were equally common, Myrmicinae (35%) and Ponerinae (35%), followed by Formicinae (25%), and Pseudomyrmecinae (5%) (Figure 76). There were three termite (Order Isoptera) genera represented across two families: Hodotermitidae (83%) and Termitidae (17%) (Figure 78).

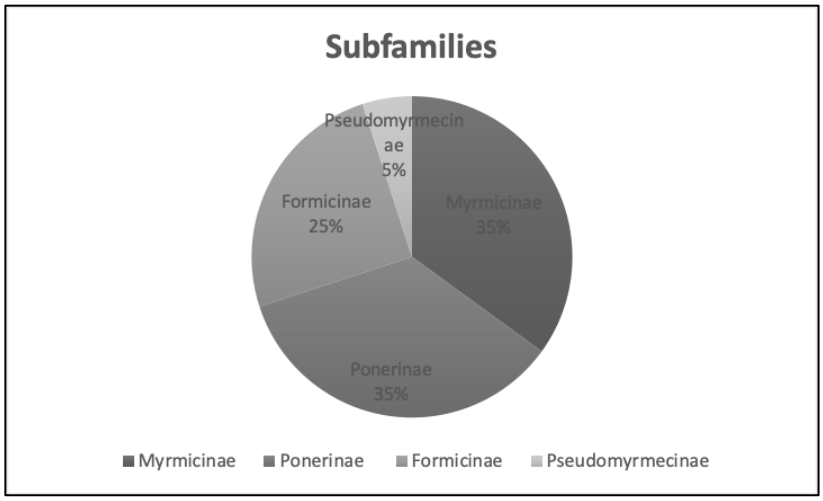

Figure 77: Percentage of ant subfamilies collected in pitfall traps

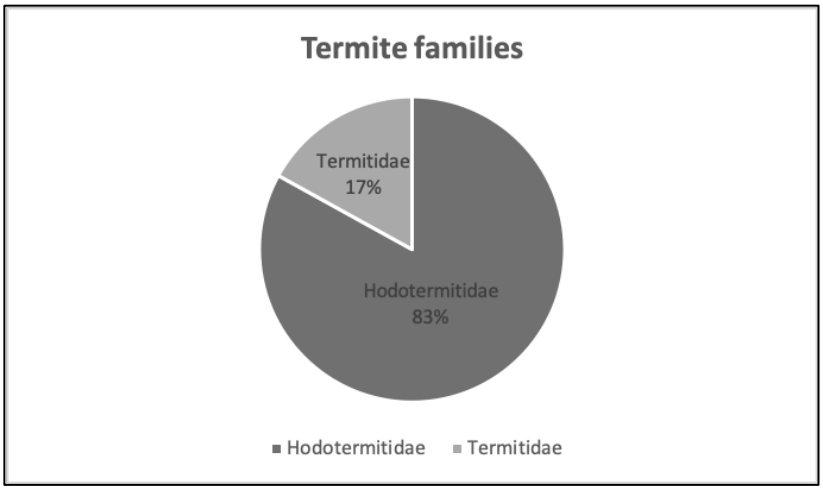

Figure 79: Percentage of termite families collected in pitfall traps

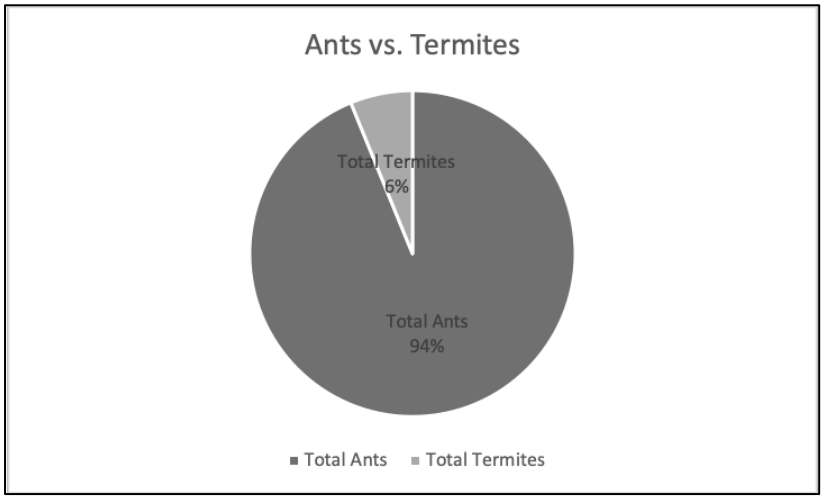

Figure 80: Percentage of ant and termite species collected in pitfall traps

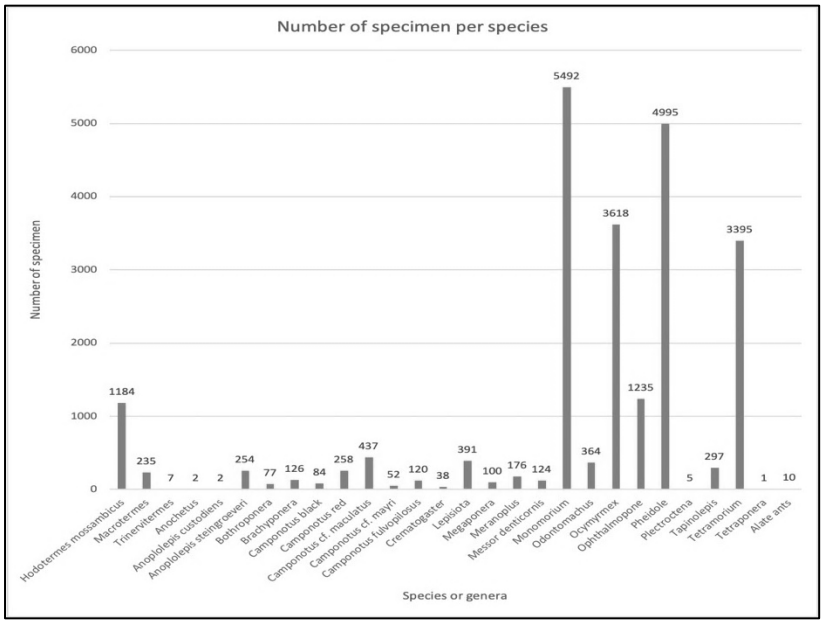

Figure 78: Number of specimen of each species collected in pitfall traps

The total target taxa specimen collected was predominantly ants (94%) with fewer termite specimen (6%) (Figure 77). Of the total number of ant specimen collected, the subfamily Myrmicinae was predominantly represented (82%), followed by Ponerinae (9%) and Formicinae (9%), with very little Pseudomyrmecinae (<1%). Of the total number of termite specimen collected, the family which was predominantly represented was Hodotermitidae (83%) followed by Termitidae (17%).

3.2.2 Prey preference

Foraging samples (n = 156) were collected from 17 different individuals from February 2019-August 2020 (Appendix 9). Pangolins preyed upon four species of ants and two species of termites. Ants were the preferred prey and selected 82% of the time; 18% of the time termite species were selected (Figure 81). Of the four subfamilies identified, two ant subfamilies were preyed upon by pangolins. Formicinae was predominantly foraged (94%), followed by myrmicinae (6%) (Figure 84). The most frequently preyed-upon ant species was *Anoplolepis custodiens* (48%), followed by *Anoplolepis steingroeveri* (29%), *Crematogaster* sp. (5%), an *Monomorium* sp. (1%). There was only one family (and two subfamilies) of termite foraged, Termitidae. The most frequently preyed-upon termite species was *Trinervitermes* sp. (16%) and the other was *Macrotermes* sp. (1%) (Figure 82 and Figure 83).

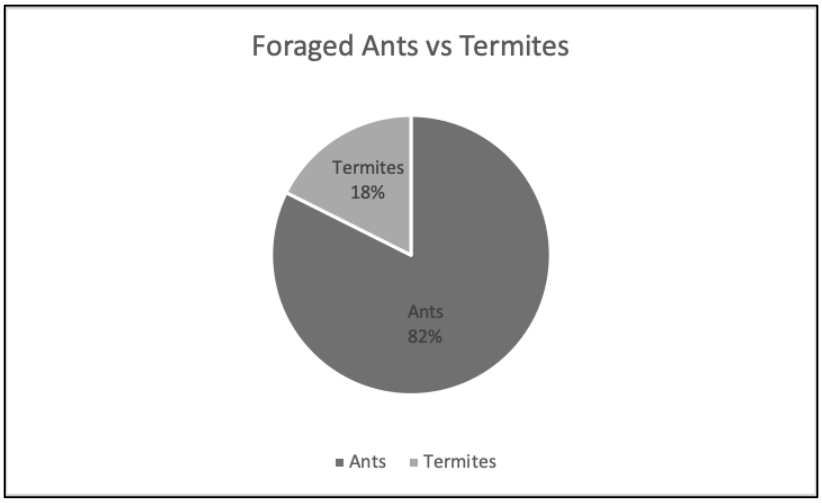

Figure 81: Percentage of pangolin prey preference based upon collected foraging samples

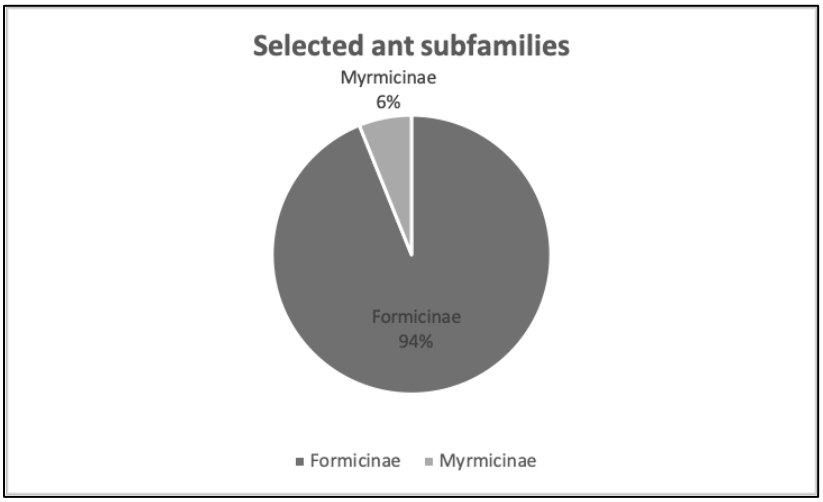

Figure 82: Percentage of ant subfamilies preyed upon

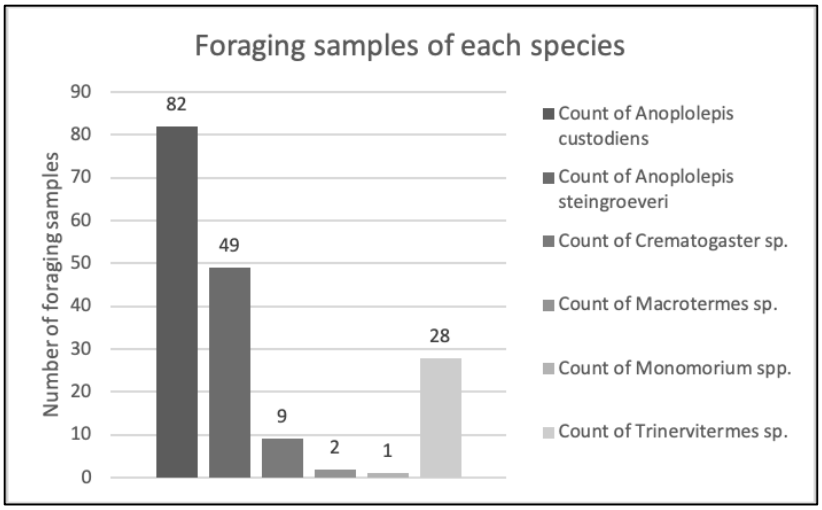

Figure 83: Number of foraging samples for each species preyed upon

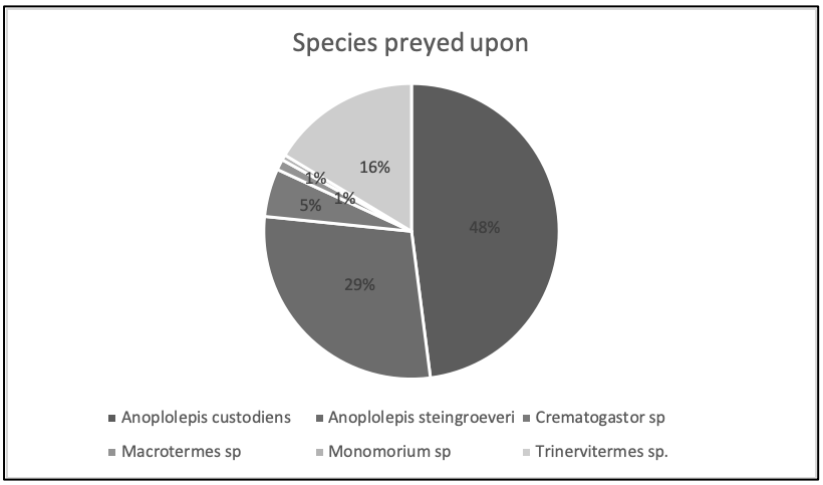

Figure 84: Percentage of each species preyed upon

There were 71 observations made on the method of foraging utilized by the pangolins (Appendix 9). Eighty six percent of the time the pangolins targeted a nest under or above ground. The nest was dug open more frequently (66%) than it was left intact (34%) (Figure 85). In addition to digging, pangolins targeted surface-active individuals only eleven percent of the time and only with *Crematogaster* sp. When termite nests on logs were targeted three percent of the time (species not identified).

50 foraging observations were made where both the species and the method of foraging were identified (Appendix 9). These observations were only made for four of the identified prey species: *Anoplolepis custodiens, Anoplolepis steingroeveri, Crematogaster* sp*.,* and *Trinervitermes s.p.* None of them were observed clawing at nests on logs (Table 7).

Table 7: Foraging methods for each prey species

	Nest no digging	Nest digging	Surface active	Clawing logs
Anoplolepis custodiens	7 (33%)	14 (67%)	0	0
Anoplolepis steingroeveri	0	4 (100%)	0	0
Crematogaster sp.	0	0	4 (100%)	0
Trinevitermes sp.	7 (33%)	11 (53%)	3 (14%)	0

When *A. custodiens* and *A. steingroeveri* were preyed upon only nests were targeted; surface active individuals were never consumed and they do not nest on logs. *A. custodiens* nests were dug up sixty seven percent of the time and the other thirty three percent of the time there was no digging at the nest. *A. steingroeveri* nests were dug up one hundred percent of the time. *Crematogaster sp.* were targeted when surface active one hundred percent of the time.

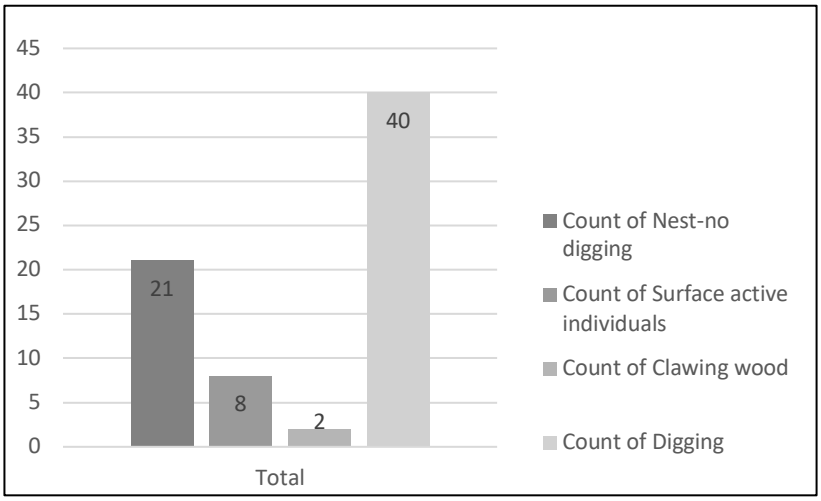

Figure 85: The number of different methods of foraging

3.3 Burrow Selection

3.3.1 Burrow results

Of 151 burrows monitored, 89 (59%) remained intact long enough after use and were able to be assessed (Appendix 10; Figure 82). There were 65 burrows assessed for female individuals and 24 burrows assessed for male individuals (Figure 83). Various burrow characteristics were assessed for all 89 intact burrows and many burrows had more than one characteristic (Appendix 11). Burrow characteristics were identified in the following incidents and respective percentages; under a termite mound 55 burrows (62%), under a tree over 1 m 42 burrows (47%), under a shrub under 1 m 17 burrows (19%), multiple entrances 1 burrow (1%), in a burrow complex 1 burrow (1%), and caves 2 (2%). Table one shows the number of burrows assessed and the selected characteristics for each individual. 70 burrows (79%) were deeper than 1 m and 19 burrows (21%) were shallower than 1 m. Habitat types for each intact burrow were categorized as 62 bush encroached (70%), 13 riverine (15%), 10 open plains (11%), and 4 mountainous/rocky (4%) (Figure 95).

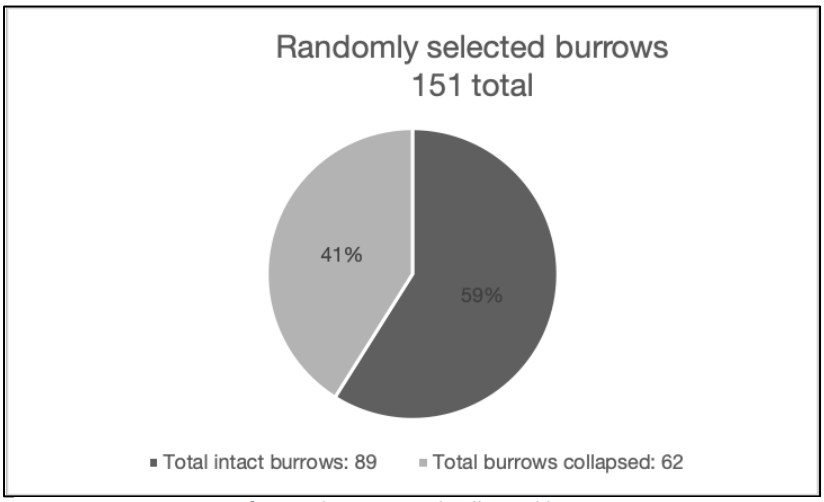

Figure 86: Percentage of intact burrows and collapsed burrows

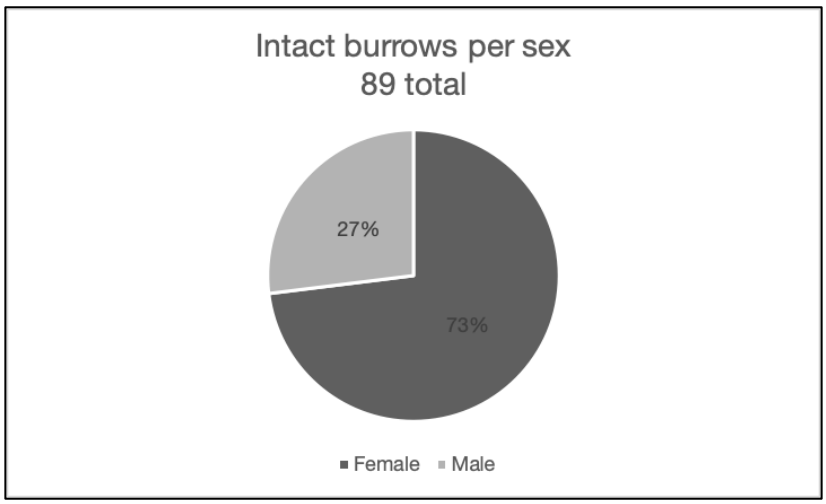

Figure 87: Percentage of intact burrows for each sex

The mean, median, maximum, and minimum burrow height and width was determined (Table 8) and individual models (one for each covariate separately) and selected models (when all terms were included together) were used to assess any effects due to sex, weight and habitat type on each response (Table 9 and Table 10). Burrow height was also compared across individuals and not found to be significantly different (Figure 88). There was compelling evidence that male burrow heights were significantly taller than that for females (p=0.000169) and on average 7.39 cm taller (p=0.000806) (Figure 90). Additionally, the burrow height was significantly higher with increased individual actual weight (p=0.009420), for every 1 kg increase in bodyweight, burrows

were on average 1.78 cm taller (p=0.048018). There was no evidence found for a relationship between burrow height and either weight group or habitat type. There was no evidence that burrow width varied significantly with individual (Figure 89), sex (Figure 91), weight group, or habitat type. There was however, weak evidence for a positive relationship with actual weight and burrow width, however it was not deemed significant at the 5% level (p=0.07).

Table 8: Mean, median, maximum, and minimum burrow height and width

	Height (cm)	Width (cm)
Mean	33.79	34.19
Median	33.00	33.00
Maximum	74.00	65.00
Minimum	15.00	17.00

Table 9: P values for comparing burrow characteristics with individual models (i.e., each term was fitted in a model separately with burrow characteristics)

	Sex	Actual weight	Weight Group	Habitat type
Height	0.000169	0.009420	0.107200	0.928500
Width	0.248	0.07	0.29	0.5628
Internal Temperature	0.443	0.628	0.626	0.1033
External Temperature	0.0948	0.405	0.731	0.0531

Table 10: Coefficients and P values for the selected models associated with each burrow characteristic (based on multiple terms trialled in each model)

	Sex	Actual weight
Height	7.39 cm (p=0.000806)	1.78 cm/ kg (p=0.048018)
External Temperature	5.62°C (p=0.029)	*individual model: p=0.0569 *selected model: p=0.0217

*Non-linear relationship

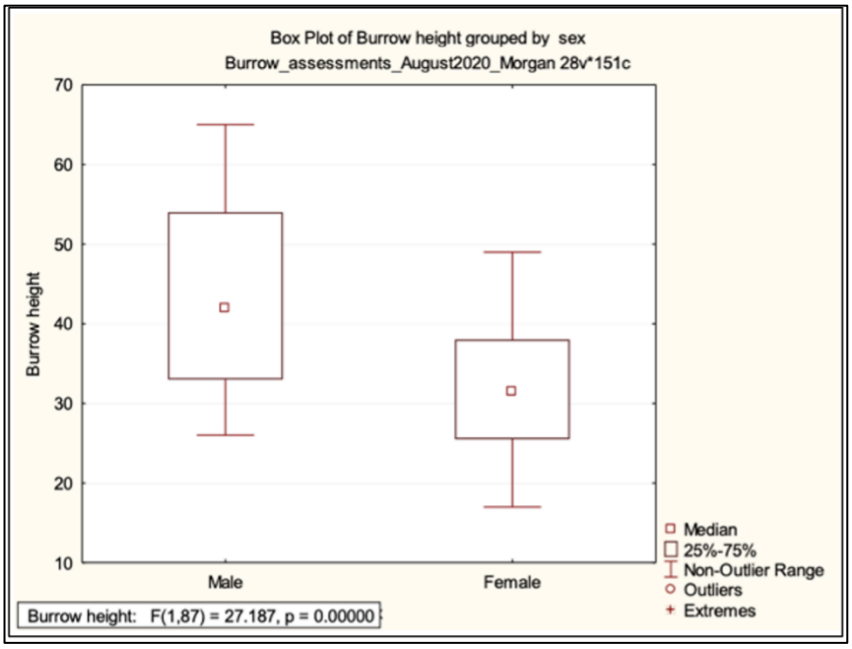

Figure 88: Box plot comparing the burrow height between males and females (p= 0.0000)

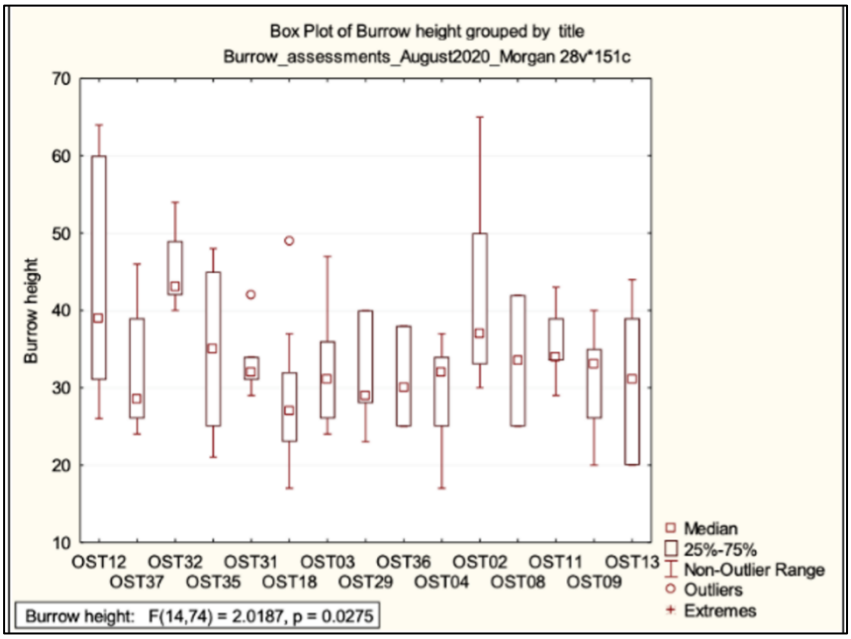

Figure 89: Box plot comparing the burrow height between individuals (p= 0.0275)

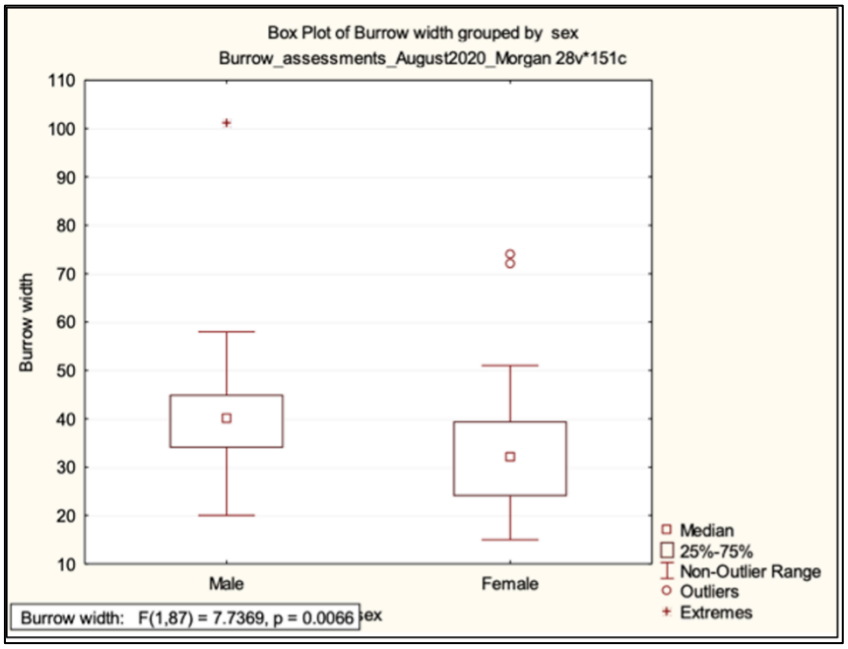

Figure 90: Box plot comparing burrow width for males and females (p=0.0066)

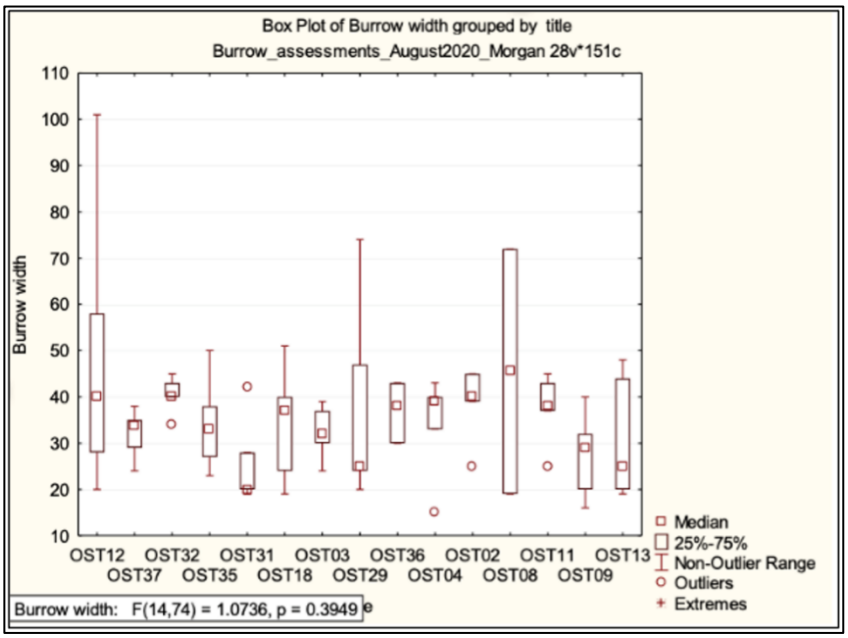

Figure 91: Box plot comparing burrow width for all individuals (p=0.3949)

The mean, median, maximum, and minimum internal and external burrow temperatures determined (Table 11) and individual models and a selected model (when all terms were trialled together) were used to assess covariate relationships (Table 9 and Table 10). Internal temperatures were much lower than external temperatures with much less deviation. Internal temperature did not significantly vary with individual (Figure 92), sex, actual weight, weight group, or habitat type. External burrow temperatures did not significantly vary with individual (Figure 93) or weight group. In the individual models (where each term was considered separately with the response), there was very weak evidence that male burrow external temperatures were approximately 4 °C cooler (p=0.0948) than the external temperatures for females, however in the selected model, the external temperatures were estimated to be significantly cooler by an average of 5.62 °C (p=0.029) than for females. This difference in findings was due to a different (and statistically significant) model formulation which also featured a non-linear relationship between external burrow temperature and actual weight (Figure 94), indicating individuals outside of the 10 – 11 kg weight range select burrows with slightly higher external temperatures. There was evidence for a relationship with habitat type and external burrow temperature in the selected model including sex and weight, however it was not (quite) significantly significant at the 5% level (p=0.0531).

Table 11: Mean, median, maximum, and minimum temperatures for internal and external burrow temperature

	Internal temperature (C°)	External Temperature (C°)
Mean	14.79	26.03
Median	14.80	24.50
Maximum	24.50	49.00
Minimum	9.10	7.10

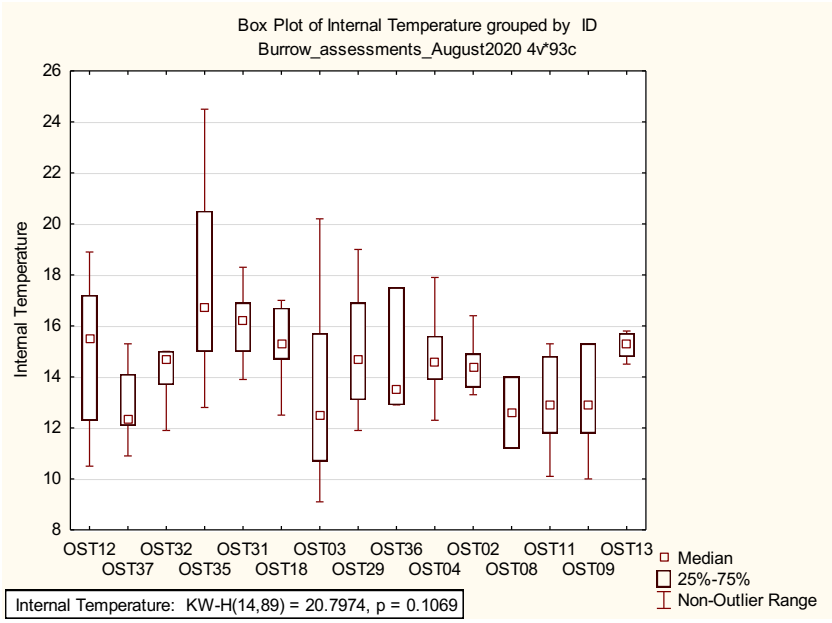

Figure 92: Box plot comparing internal burrow temperature between all individuals (p= 0.1069)

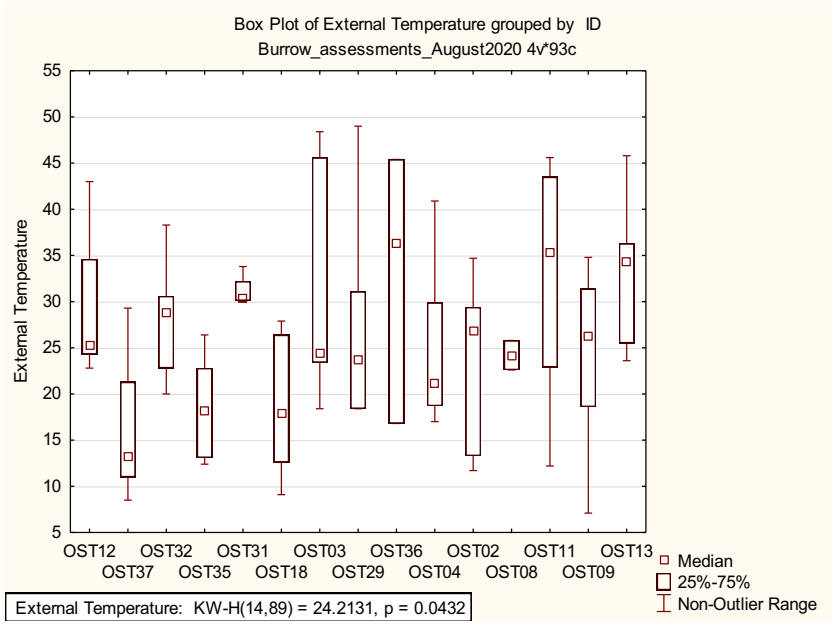

Figure 93: Box plot comparing external burrow temperature between all individuals (p= 0.0432)

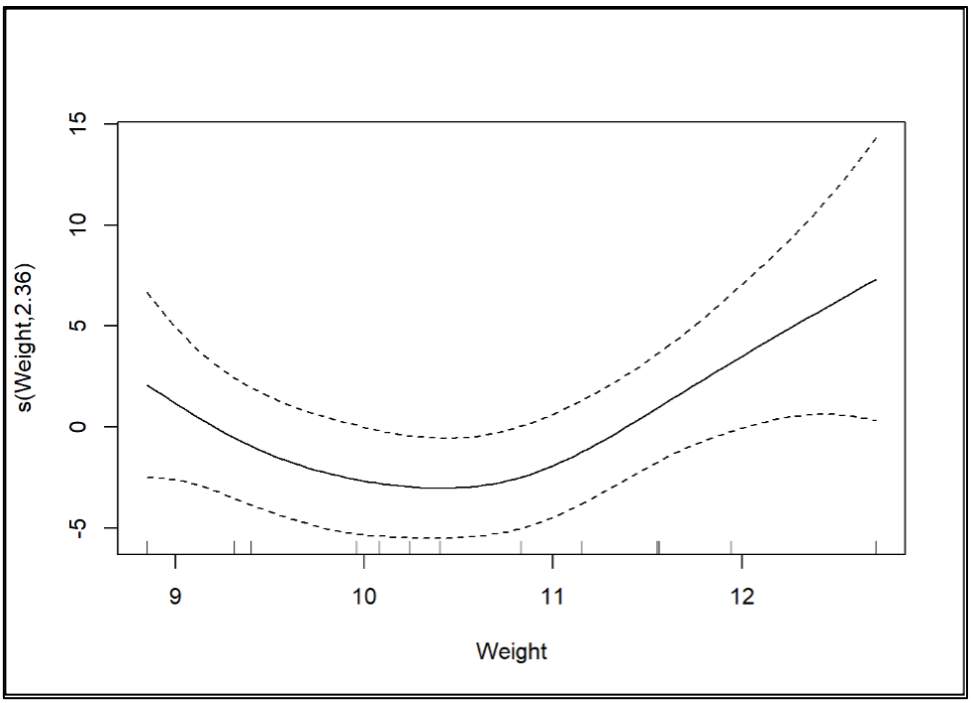

Figure 94: Non-linear relationship between external burrow temperature and actual weight

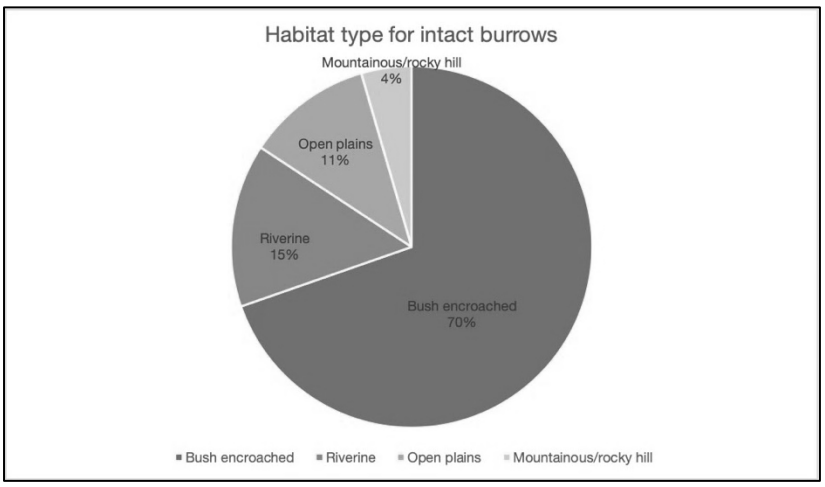

Figure 95: Percentage of habitat type for each burrow assessed

Chapter 4: Discussion

In line with the aim of this study, information on home range sizes and overlaps, feeding preference, and burrow type selection provides important guidance for areas suitable for post-trafficked pangolin release in the Namibian savanna biome.

4.1 Home range and distribution

4.1.1 Home range sizes

There are four well-documented studies on home range size of pangolins in southern Africa which showed comparable results to this study (Pietersen, 2013; Swart, 2013; Heath & Coulson, 1997a; and Van Aarde, 1990). Unlike the others, in addition to overall HR determinations, this study defined home range sizes for the growing and non-growing seasons to determine home range and core area sizes with different cover and food availability. The home range values recorded for the whole duration of this study were similar to studies by Pietersen (2013) and Swart (2013) in South Africa and Heath & Coulson (1997a) in Zimbabwe. When data from OST32 (male) , who had a considerably large range and was therefore an outlier, were not considered this study found adult home ranges in an arid climate with slightly less rainfall but also on the western extremes of the pangolin's range, in alignment with Pietersen (2013). In Zimbabwe, (Heath and Coulson, 1997a) and in Mpumalanga, South Africa (Swart, 2013), the upper limits of MCP home range sizes were similar to those in this study; however the lower limits were highly variable across all studies. This could be due to the inclusion of juvenile or sub-adult home ranges. In Limpopo (Van Aarde, 1990), MCP home ranges were much smaller than this study and other study sites. Swart (2013) found larger home ranges in the wet season which is consistent with home range sizes in this study being larger in the growing season, even though this was not statistically significant. However, some variation was observed across habitat and rainfall, suggesting further research is needed into the influence of rainfall on home range size in order to determine possible densities of pangolins in similar habitat.

Female core areas were consistently similar across the growing and non-growing seasons when compared to the overall spatial data; however male core areas varied across seasons. It was

expected to see more seasonally variation, however it is possible the limited non-growing season data set restricted the findings of this study. These results suggest that females habits don't change much across seasons, however males change the ways in which they utilize their territory. This finding could be related to changes in the male's spatial habits as they seek out females for mating. It has been observed that males and females will spend many days in the same burrow for a reproductive event (Skinner & Chimimba, 2005; Pietersen et al., 2020).

The significantly larger home range of OST32 could suggest there are floater males who are more transient than others, a trait which is also observed in various carnivore species, specifically cheetahs, where floater males don't have a home range (Melzheimer et al*.,* 2018). This would not be surprising given that the pangolin is in the same clade (Ferae) as carnivores (Gaudin et al*.,* 2009; Gaubert et al., 2020; Gaudin et al., 2020) and whom utilize scent-marking as a territorial behaviour (Kost, 2008). However, it is doubtful that this is the case for the large home range as OST32 regularly would come back to visit the same females in a circular movement pattern, which was observed in at least three consecutive loops over the span of two months.

This was the first study to use the CReSS model, taking physical boundaries into account, which can contribute to the variation in home ranges compared to other studies only utilizing less advanced models such as MCP. When calculating home ranges where there are definite physical barriers, it is important to implement methods like this otherwise home ranges can be greatly overestimated. However the variation, these results are likely to be the most representative of true home ranges as the CReSS model considers the local topography more completely (Scott-Hayward et al., 2013).

4.1.2 Social dynamics derivation from spatial data

Three previous studies have reported on the social dynamics of pangolins with opposing findings. Pietersen (2013) noted that pangolins potentially live in monogamous pairs, whereas Heath and Coulson (1997) and Swart (2013) recorded a polygamous mating structure with one male's home range almost entirely overlapping the home ranges of multiple females. This polygamous type of overlap is another similarity with many solitary carnivore species including leopards, tigers,

jaguars, cougars, bobcats, and wildcats (Rubenstein and Wrangham, 1986). The findings of this study recorded four males moving through their respective home ranges which fully overlapped with multiple females. In some areas, gaps of female data points were observed, which likely demonstrates the home range of an untagged female as this study found minimal female-female home range overlap. Pietersen et al. (2014) suggests this overlap could be demonstrative of transient males; however this study has monitored four males demonstrating a polygynous mating system from July 2018 – November 2020 with minimal shift in their home ranges over the study period. Respectively each male has been found to spend multiple days in the same burrow with two to five different females overlapping with their range and re-visits them throughout the year.

Male and female home range overlap was observed during both the growing and non-growing seasons, however same sex overlap was relatively minor. Consistent with the findings by Pietersen (2013), Heath and Coulson (1997) conclude that overlap most likely represents mating occurrences. However, contrarily, this study observed three males visiting three females with offspring believed to be offspring of their own on multiple occasions from birth to a few months old, suggesting that father pangolins may spend more time with females and their offspring than previously thought (Pietersen et al., 2020). One mating attempt was observed during a period at which the female had a young pup. Consistent with this behaviour, Sweeney (1974) documented a pregnant female with dependent juvenile suggesting the birth of two pups in one year. However, this is not believed to be the case at this study site, as for the duration of this study females were only observed to give birth during the months from October – January.

Some speculation can be made about the area with the highest individual overlap. Firstly, this area has seen a high number of pangolins tagged or identified within 1 km^2, with five adults- OST03, OST09, OST11, OST12, and OST003 - and three juveniles - OST17, OST21, and OST006. This area has a high density of suitable burrows with one notable complex which all previously mentioned tagged individuals have been observed to utilize. The complex consists of at least two structures connected by at least 10 active entrances. Sun-aged pangolin scales were found scattered across this site, suggesting the long-term utilization of this system by pangolins.

Additionally, there have often been observations of males and females sharing burrows here at the same time, as well as mothers with offspring. OST09 was observed in a territorial fight with OST11 that even could be heard underground and that began at one of the main entrances, meanwhile the offspring (OST006) of OST11 was trying to find its mother. OST09 has been located sharing the burrow with two different males in near succession and the same has been observed for OST03. It is possible these burrows are an ideal location for reproduction and birth and rearing of pups, and are therefore in high demand. Another possibility remains that this area has been highly frequented as it is conveniently located in the center of the reserve where a large number of individuals were being monitored (see Figure 7). Of the 36 tagged individuals, 16 were located either crossing the road in front of the research team or in the near vicinity of an already tagged pangolin. This suggests that more time and effort was put into this area and it is very possible the rest of the reserve would demonstrate similar overlap. Home ranges seem to fit together like a puzzle, therefore the empty gaps may represent areas where pangolins have not yet been tagged. This would make sense as most of the gaps are at the outer extremes of the reserve where little time was spent by the research team and is also less frequented by guides of the reserve.

4.2 Prey Preference

4.2.1 Pitfalls

Pitfall trapping was useful in determining a baseline of ant and termite species which are present on the reserve. Swart et al. (1999) and Pietersen (2013) conducted pitfall surveys to understand the prey preference of pangolins. This study found a much smaller variety of species of available ants and termite species compared to Pietersen (2013), who found 53 species and Swart (1999), who found a total of 55 species, but this study found a similar number of genera to both studies where Pietersen (2013) found 22 genera and Swart (1999) found 25 genera. Due to limited data on ant and termite species within Namibia, this study was only able to identify some specimen at the genus level. Not all prey species were captured in abundance, especially for the most preferred prey, it is possible some species such as *Trinervitermes* sp. are less likely to fall into pitfall traps due to their behaviour and activity in proximity to nests. Additionally, it is possible some larger species were able to climb out of the pitfall traps reducing the trapping incidences.

These factors make the estimation of abundance difficult, which is why the study considered presence.

4.2.2 Foraging samples

Similarly to Richer (1997), Skinner & Chimimba (2005), and Pietersen (2013), this study recorded *Anoplolepis custodiens* to be the most preferred prey despite not being the most commonly available. This study found a total of six preferred species, four ant species and two termite species. Compared to other studies this is low; Swart, Richardson, & Ferguson (1999) found 20 species (15 ant 5 termite) in South Africa, Jacobsen (1991) found 16 (13 ant and 3 termite) in South Africa, and Richer (1997) found seven species (6 ant and 1 termite). These studies had a much higher number of prey selected which could be due to the different climate and higher rainfall. The only other study in an arid environment had similar results to this one, with 4 ant species and 1 termite species (Pietersen et al., 2014). Comparatively, Pietersen et al. (2014) found three of the same species consumed in this study, *Anoplolepis* sp., *Crematogaster* sp., and *Trinervitermes* sp. Similarly to this study, Swart (1999) found six of the 20 species to make up 97% of a pangolin's diet, whereas this study found 6 species make up 100% of their diet. Additionally, Swart (1990) found *A. custodiens* comprises 77% of pangolin's diet yet only made up 5% of the trapped ants. This study found *A.* sp. cumulatively comprises 77% of their diet, *A. custodiens* at 47% and *A. steingroeveri* at 30%. Swart (1999) does not include *A. steingroeveri* in his publication, therefore it is possible both *A*. sp. were present. Comparatively, Pietersen et al. (2016) identifies *A. steingroeveri* as the most commonly preyed upon species, however does not include *A. custodiens.*

4.3 Burrow selection

Burrow type selection yielded similar findings to other studies in southern Africa with a preference towards those dug by aardvark (Pietersen, 2013; Swart, 2013). Larger burrows were used by males more than females, and therefore the availability of large burrows on a potential release site for trafficked male pangolins needs to be considered. Pangolins seem to be rather specific in using burrows at the base of termite mounds in thickly bushed areas. This might be to avoid predation, since aardvarks dig deeper holes at termite mounds to get to the bottom of

nests. During the rainy season, a large number of the pangolins' chosen burrows were also seen to collapse, with the highest number of collapsed burrows being selected by males. While burrow height varied significantly across all individuals, burrow width was only significantly different when comparing selection by males versus females as aggregates. Internal burrow temperatures were similar across individuals ranging from 9.1 C to 24.5 C while external burrow temperatures had a very high variance from 49 C to 7.1 C. The majority of burrows were over 1 meter deep and occurred in a bush-encroached area.

Chapter 5: Conclusion and recommendations

5.1. Conclusion

The overall aim of this study was to gain a better understanding of Temminck's pangolin ecology in order to inform conservation planning and anticipate the needs of trafficked pangolins released into the wild. The study addressed the issues of habitat preference, prey preference, burrow selection, and mating habits.

Pangolins were distributed across the reserve including on top of the mountain ranges demonstrating there was no major habitat preference. Average home range and core area sizes for females were much smaller than those for males and the variability in these values across time also demonstrates some flexibility in movement across seasons, which might be due to a shift in social dynamics. Pangolins are territorial towards same-sex individuals and males and females have different spatial requirements. Males have larger spatial requirements than females and utilize a home range and core area about two to four times larger than that of females. For example, the largest space utilized by a male was nearly 4000 hectares or 40 km^2, and up to 2000 hectares or 20 km^2 for a female. No released pangolins successfully settled into this area, demonstrating there was no available space for them to establish a new home range.

The study demonstrates that pangolins have a polygynous mating structure with one male territory overlapping multiple females through whose territories he rotates. However, these

findings also demonstrated there is more same-sex overlap in males than previously observed, including different males visiting the same female within days of one another.

On a 20,000 hectare area of similar habitat and prey and burrow availability, there are likely 15 male and 60 females. This density was surprising given the limited sightings and is likely only relatable to other fenced reserves without anthropogenic mortalities (especially caused by electrical fencing). Densities likely vary in other habitat where prey and burrow availability is different.

Pangolins consume considerably more ants than termites as a part of their diet. They demonstrate similar prey preference to much of southern Africa, identifying *Anoplolepis* sp., *Crematogaster* sp., and *Trinervitermes* sp. as a key part of their diet in central Namibia. These findings also highlight that there is variance amongst pangolins' diet across regions and habitat. Drought has a negative impact on the survival of pangolins and shifts their diet: less-observed species foraged were during the dry winter months in a drought year. The preferred prey, *Anoplolepis* sp. hibernates underground during droughts, causing the pangolins to select what is available. Preliminary research within Namibia demonstrates prey preference is variable across different habitats and this is important when selecting release sites for confiscated pangolins. Further investigating regional preferences and identifying preferred species by pangolins in rehabilitation could also help determine the origin from where the pangolin came.

Pangolins exhibit selection with specific burrow characteristics and features. As previously found, pangolins prefer burrows under termite mounds, which are most often dug by aardvarks. Areas with healthy aardvark populations are beneficial to pangolins because of the availability of preferred burrows. This study also found that over half of their selected burrows were either under a tree or shrub which measured over 1 meter. Additionally, pangolins in this area seem to prefer burrows in bush encroached areas. This is not surprising as the above factors contribute to more stable burrow temperatures and conditions which are important for pangolins who are not efficient at regulating their body temperature.

Results from this study can be utilized to advise conservation management planning and guidelines on the release of live confiscated pangolins. As the ecology of pangolins is variable across habitats which are highly diverse in the Temminck's pangolin's range, special care must be taken to understand the origin of confiscated pangolins and the ecology from where they originate.

5.2. Recommendations

This study has generated results which provide insight in creating recommendations for future work. The recommendations are:

I. **Care must be taken to consider the specific characteristics of central Namibia when deciding where to release trafficked pangolins.** Home range sizes and prey preference were different for central Namibia than other regions with similar rainfall but different habitat. This information is very useful for the rehabilitation and release of trafficked pangolins. Further research on resident pangolins is necessary in different regions and habitats to provide an idea of the origin of a trafficked individual. As pangolin are observed to select very specific prey species, the diet of a seized pangolin can be utilized in hypothesizing the origin. This information is vital in determining a suitable release site with these particular prey species and in turn provides information for law enforcement on the region where the animal originated. This research project should be replicated in the major habitats across Namibia and other range countries to understand variance in ecology and the population.

II. **In addition to understanding this area, it is important to consider the characteristics of the areas from which the trafficked pangolin are taken.** This study demonstrated small home range sizes and considerable overlap amongst individuals in a reserve free from anthropogenic mortalities. Research to understand the home range sizes and dynamics in other habitats, land uses, and areas under pressure from trafficking should be included. This information would be valuable to apply in assessing the population of pangolins and stronghold areas across Namibia.

III. **Male and female pangolins have different spatial needs which need to be taken into consideration when determining release sites.** Pangolins should be released into areas with no electrical fencing and only permeable fencing to allow for dispersal and movement. Areas with a low density of resident pangolin are ideal for release sites to reduce conflict and stress on both the resident and released pangolins.

IV. **Pangolins are territorial and research into the impact on resident pangolins from releases needs to be investigated.** Release sites should not be repeated to avoid continued conflict and stress on resident pangolins. Both resident and released pangolins should be monitored with GPS transmitters in areas where releases are occurring to understand their response and potential disruption from releases. GPS transmitters are essential for trafficked-released pangolins to monitor dispersal from the release site.

V. **A guide on pre-assessing potential release sites in the savanna can be developed.** This should include information on habitat and prey availability, number of suitable burrows, and the amount of area needed for normal social behaviour.

VI. **A great deal of further research is needed.** Other behaviours observed for the duration of this study both expand upon and vary from the limited research reported here, demonstrating a need to continue long-term research on the species. This insight can provide valuable information on areas of importance, such as reproductive success.

VII. **Conducting long-term research on one population would be of high value**. Very little data has been gathered on the growth, dispersal, and longevity of pangolins in southern Africa. This information is highly valuable for a better understanding of the species and their needs.

REFERENCES

Addison, P., & Samways, M. J. (2000). A survey of ants (Hymenoptera: Formicidae) that forage in vineyards in the Western Cape Province, South Africa. *African Entomology*, 8, 251–260. https://journals.co.za/doi/10.10520/AJA10213589_336

Addison, P., & Samways, M. (2006). Surrogate habitats demonstrate the invasion potential of the African pugnacious ant. *Biodiversity and Conservation,* 15(1), 411-428. doi:10.1007/s10531-005-5399-4

Baiyewu, A.O., Boakye, M.K., Kotze, A., Dalton, D.L. & Jansen, R. (2018). Ethnozoological survey of traditional uses of Temminck's ground pangolin (*Smutsia temminckii*) in South Africa*. Society & Animals,* 26(3), 306-425. https://doi.org/10.1163/15685306-12341515

Barnard, P. (1998). Overview of Namibia and its biological diversity - 1.1 Geographical features. In Barnard, P., *Biological Diversity in Namibia: A Country Study*, pp. 15-28. Namibian National Biodiversity Task Force.

Beck, A. (2008). *Electric fence induced mortality in South Africa*. MSc Thesis. University of the Witwatersrand, Pretoria, South Africa.

Boakye, M.K., Pietersen, D.W., Kotze, A., Dalton, D.L. & Jansen, R. (2014). Ethnomedicinal use of African pangolins by traditional medical practitioners in Sierra Leone. *Journal of Ethnobiology and Ethnomedicine,* 10, 76. https://doi.org/10.1186/1746-4269-10-76

Boakye, M. K., Pietersen, D. W., Kotzé, A., Dalton, D. L., & Jansen, R. (2015). Knowledge and uses of African pangolins as a source of traditional medicine in Ghana. *PLoS ONE*, 10(1), 1–14. https://doi.org/10.1371/journal.pone.0117199

Boakye, M.K., Kotze, A., Dalton, D.L. & Jansen, R. (2016). Unravelling the pangolin bushmeat commodity chain and the extent of trade in Ghana. *Human Ecology,* 44(2), 257-264. https://doi.org/10.1007/s10745-016-9813-1

Boakye, M.K. (2018). Influence of ethnicity on cultural use of pangolins in Ghana and its implications on their conservation. *Ethnobiology and Conservation*, 7(13), 1-18. https://doi.org/10.15451/ec2018-10-7.13-1-18

Bräutigam, A., Howes, J., Humphreys, T. and Hutton, J. (1994). Recent information on the status and utilization of African pangolins. *TRAFFIC Bulletin,* 15, 15-22.

Cardinale, B. J., Duffy, J. E., Gonzalez, A., Hooper, D. U., Perrings, C., Venail, P., Naeem, S. (2012). Biodiversity loss and its impact on humanity*. Nature,* 486(7401), 59–67. https://doi.org/10.1038/nature11148

Challender, D.W.S., Hywood, L. (2012). African pangolins under increased pressure from poaching and intercontinental trade. *TRAFFIC Bulletin,* 24(2), 53-55.

Challender, D.W.S., Waterman, C., & Baillie, J.E.M. (2014). Scaling up pangolin conservation. *IUCN SSC Pangolin Specialist Group Conservation Action Plan.* Zoological Society of London, London, UK.

Challender, D., Willcox, D.H.A., Panjang, E., Lim, N., Nash, H., Heinrich, S. & Chong, J. (2019). *Manis javanica*. *The IUCN Red List of Threatened Species* 2019: e.T12763A123584856. https://dx.doi.org/10.2305/IUCN.UK.2019-3.RLTS.T12763A123584856.en. Downloaded on 20 December 2020.

Challender, D., Wu, S., Kaspal, P., Khatiwada, A., Ghose, A., Ching-Min Sun, N., Mohapatra, R.K. & Laxmi Suwal, T. (2019). *Manis pentadactyla* (errata version published in 2020). *The IUCN Red List of Threatened Species* 2019: e.T12764A168392151. https://dx.doi.org/10.2305/IUCN.UK.2019-3.RLTS.T12764A168392151.en. Downloaded on 20 December 2020.

Chao, J.-T., Li, H.-F., & Lin, C.-C. (2020). The role of pangolins in ecosystems. In Challender, D.W.S., Nash, H.C., and Waterman, C., *Pangolins: Science, Society, and Conservation* pp. 43–48. Academic Press. https://10.1016/b978-0-12-815507-3.00003-4

Cunningham, A.B. and Zondi, A.S. (1991). *Use of animal parts for the commercial trade in traditional medicines*. Institute of Natural Resources, University of Natal, Pietermaritzburg, South Africa.

D'Cruze, N., Singh, B., Mookerjee, A., Harrington, L.A. & Macdonald, D.W. (2018) A socio-economic survey of pangolin hunting in Assam, Northeast India. *Nature Conservation-Bulgaria*, 30, 83-105. https://doi.org/10.3897/natureconservation.30.27379

Dyer, C. (2014). New names for the African Acacia species in Vachellia and Senegalia. *Southern Forests: a Journal of Forest Science,* 76(4), iii–iii. https://doi.org/10.2989/20702620.2014.980090

Gaubert, P., Antunes, A., Meng, H., Miao, L., Peigné, S., Justy, F., Nijokou, F., Dufour, S., Danquah, E., Alahakoon, J., Verheyen, E., Stanley, W.E., O'Brien, S.J., Johnson, W.E., and Luo, S. (2018). The complete phylogeny of pangolins: scaling up resources for the molecular tracing of the most trafficked mammals on Earth. *Journal of Heredity,* 109(4), 347 – 359. https://doi.org/10.1093/jhered/esx097

Gaubert, P., Wible, J. R., Heighton, S. P., & Gaudin, T. J. (2020). Phylogeny and systematics. In Challender, D.W.S., Nash, H.C., and Waterman, C. (Eds.), *Pangolins: Science, Society, and Conservation* pp. 25–39. Academic Press. https://doi.org/10.1016/b978-0-12-815507-3.00002-2

Gaudin, Timothy J., Robert J. Emry, and John R. Wible. (2009). The Phylogeny of Living and Extinct Pangolins (Mammalia, Pholidota) and Associated Taxa: A Morphology Based Analysis. *Journal of Mammalian Evolution,* 16(4), 235–305. https://doi.org/ 10.1007/s10914-009-9119-9

Gaudin, T. J., Gaubert, P., Billet, G., Hautier, L., Ferreira-Cardoso, S., & Wible, J. R. (2020). Evolution and morphology. In Challender, D.W.S., Nash, H.C., and Waterman, C. (Eds.)*, Pangolins: Science, Society, and Conservation* pp. 5–23. Academic Press. https://doi.org/10.1016/b978-0-12-815507-3.00001-0

Global Administrative Areas. 2018. GADM database of Global Administrative Areas. [online] URL: www.gadm.org

Hastie, T.J. & Tibshirani, R.J. (1990) *Generalized Additive Models.* Chapman and Hall/CRC

Heath M.E., & Coulson, I.M. (1997a). Home range size and distribution in a wild population of Cape pangolins, *Manis temminckii* in north-west Zimbabwe. *African Journal of Ecology*, 35(2*),* 94-109

Heath M.E., & Coulson, I.M. (1997b). Preliminary studies on relocation of Cape pangolins *Manis temminckii. South African Journal of Wildlife Research,* 27(2*)*, 51–56

Heath, M.E. & Coulson, I.M. (1998). Measurements of length and mass in a wild population of Cape pangolins (*Manis temminckii*) in north-west Zimbabwe*. African Journal of Ecology,* 36, 267–270. http://dx.doi.org/10.1046/j.1365-2028.1998.00129.x

Heinrich, S., Wittmann, T.A., Prowse, T.A.A., Ross, J.V., Delean, S., Shepherd, C.R. & Cassey, P. (2016) Where did all the pangolins go? International CITES trade in pangolin species. *Global Ecology and Conservation*, 8, 241-253. https://doi.org/10.1016/j.gecco.2016.09.007

Heinrich, S., Wittman, T.A., Ross, J.V., Shepherd, C.R., Challender, D.W.S., & Cassey, P. (2017). Global Trafficking of Pangolins: A comprehensive summary of seizures and tracking routes from 2010–2015. *TRAFFIC*, Southeast Asia Regional Office, Petaling Jaya, Selangor, Malaysia.

Hornor, F., Thorne, D., Shaver, A. (2020). Tipping the Scales - Exposing the growing trade of African Pangolins into China's Traditional Medicine Industry. http://the-eis.com/elibrary/sites/default/files/downloads/literature/Exposing%20the%20growing%20trade%20of%C2%A0African%20Pangolins%20into%20Chinas%C2%A0Traditional%20Medicine%20Industry.pdf

Hua, L., Gong, S., Wang, F., Li, W., Ge, Y., Li, X., & Hou, F. (2015). Captive breeding of pangolins: current status, problems and future prospects. *ZooKeys*, 507, 99–114. https://doi.org/10.3897/zookeys.507.6970

Ingram, D.J., Coad, L., Abernethy, K.A., Maisels, F., Stokes, E.J., Bobo, K.S., Breuer, T., Gandiwa, E., Ghiurghi, A., Greengrass, E., Holmern, T., Kamgaing, T.O.W., Obiang, A.M.N., Poulsen, J.R., Schleicher, J., Nielsen, M.R., Solly, H., Vath, C.L., Waltert, M., Whitham, C.E.L., Wilkie, D.S. & Scharlemann, J.P.W. (2018). Assessing Africa-wide pangolin exploitation by scaling local data. *Conservation Letters,* 11(2), 9. https://doi.org/10.1111/conl.12389

Ingram, D.J., Shirley, M.H., Pietersen, D., Godwill Ichu, I., Sodeinde, O., Moumbolou, C., Hoffmann, M., Gudehus, M. & Challender, D. (2019). *Phataginus tetradactyla*. *The IUCN Red List of Threatened Species* 2019: e.T12766A123586126. https://dx.doi.org/10.2305/IUCN.UK.2019-3.RLTS.T12766A123586126.en. Downloaded on 20 December 2020

Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. (2019). *UN Report: Nature's Dangerous Decline 'Unprecedented'; Species Extinction Rates 'Accelerating' – United Nations Sustainable Development*. United Nations. https://www.un.org/sustainabledevelopment/blog/2019/05/nature-decline-unprecedented-report/

Jacobsen, N.H.G., Newberry, R.E., De Wet, M.J., Viljoen, P.C. & Pietersen, E. (1991). A contribution of the ecology of the Steppe pangolin *Manis temminckii* in the Transvaal. *Z. Säugtier. 56*(2), 94– 100

Karawita, H., Perera, P., Gunawardane, P., & Dayawansa, N. (2018). Habitat preference and den characterization of Indian Pangolin (*Manis crassicaudata*) in a tropical lowland forested landscape of southwest Sri Lanka. *PloS ONE*, 13(11), 1-15. https://doi.org/10.1371/journal.pone.0206082

Kruskal-Wallis H Test using SPSS Statistics. (n.d.). https://statistics.laerd.com/spss-tutorials/kruskal-wallis-h-test-using-spss-statistics.php. Last accessed 30 June 2021

Lim, N.T.L. (2007). *Autecology of the Sunda Pangolin (Manis javanica) in Singapore*. M.Sc. Thesis. National University of Singapore, Singapore

Mahmood, T., Jabeen, K., Hussain, I., & Kayani, A.R. (2013). Plant species association, burrow characteristics, and the diet of the Indian pangolin, *Manis crassicaudata*, in the Potohar Plateau, Pakistan. *Pakistan Journal of Zoology*, 45(6*),* 1533-1539

Mahmood, T., Challender, D., Khatiwada, A., Andleeb, S., Perera, P., Trageser, S., Ghose, A. & Mohapatra, R. (2019). *Manis crassicaudata*. *The IUCN Red List of Threatened Species* 2019: e.T12761A123583998. https://dx.doi.org/10.2305/IUCN.UK.2019-3.RLTS.T12761A123583998.en. Downloaded on 20 December 2020

Melzheimer, J., Streif, S., Wasiolka, B., Fischer, M., Thalwitzer, S., Heinrich, S. K., Wachter, B. (2018). Queuing, takeovers, and becoming a fat cat: Long-term data reveal two distinct male spatial tactics at different life-history stages in Namibian cheetahs. *Ecosphere,* 9(6), 1-17. https://doi.org/10.1002/ecs2.2308

Meyer, F. (2020). *Survival and distribution of Temminck's pangolin (Smutsia temminckii) retrieved from the illegal wildlife trade in South Africa*. M.Sc. Thesis. University of Venda, Thohoyandou, South Africa

Millspaugh, J.J., Kesler, D.C., Kays, R.W., Gitzen, R.A., Schulz, J.H., Rota, C.T., Bodinof, C.M., Belant, J.L., & Keller, B.J. (2012). Wildlife Radiotelemetry and Remote Monitoring. In N.J. Silvy (Ed.), *The Wildlife Techniques Manual* (pp 258-283). Baltimore, The John Hopkins University Press

Ministry of Environment, Forestry, and Tourism. (2019). Combatting Wildlife Crime in Namibia - Annual Report 2019. http://the-eis.com/elibrary/sites/default/files/downloads/literature/MET_Combatting%20Wildlife%20Crime%20in%20Namibia%20Annual%20Report%202019.pdf

Ministry of Environment, Forestry, and Tourism. (2021). Combatting Wildlife Crime in Namibia - Annual Report 2020. http://the-eis.com/elibrary/sites/default/files/downloads/literature/Combatting%20Wildlife%20Crime%20in%20Namibia_Annual%20Report%202020.pdf

Morin, D. J., Challender, D. W. S., Ichu, I. G., Ingram, D. J., Nash, H. C., Panaino, W., Panjang, E., Sun, N.C., Willcox, D. (2020). Developing robust ecological monitoring methodologies for pangolin conservation. *Pangolins,* 545–558. https://doi.org/10.1016/B978-0-12-815507-3.00035-6

Namibian Chamber of Environment. (2018). Illegal trade in pangolins in Namibia: the impact of an informer-reward scheme. Report, Windhoek, Namibia

Nebe, B. & Rankin, P. (n.d.) Pangolin Research Mundulea. http://pangolins-namibia.blogspot.com/ Last accessed 30 June 2021

Nixon, S., Pietersen, D., Challender, D., Hoffmann, M., Godwill Ichu, I., Bruce, T., Ingram, D.J., Matthews, N. & Shirley, M.H. (2019). *Smutsia gigantea*. *The IUCN Red List of Threatened Species* 2019: e.T12762A123584478. https://dx.doi.org/10.2305/IUCN.UK.2019-3.RLTS.T12762A123584478.en. Downloaded on 20 December 2020

Pietersen, D.W., 2013. *Behavioural Ecology and Conservation Biology of Ground Pangolins (Smutsia temminckii) in the Kalahari Desert*. M.Sc. Thesis, University of Pretoria, Pretoria, South Africa

Pietersen, D.W., McKechnie, A.E., & Jansen, R. (2014a). A review of the anthropogenic threats faced by Temminck's ground pangolin, *Smutsia temminckii*, in southern Africa. *South African Journal of Wildlife Research,* 44, 167–178. https://doi.org/10.3957/056.044.0209

Pietersen, D.W., McKechnie, A.E., & Jansen, R. (2014b). Home range, habitat selection, and activity patterns of an arid-zone population of Temminck's ground pangolins, S*mutsia temminckii*. *African Zoology,* 49, 265–276. https://doi.org/10.1080/15627020.2014.11407642

Pietersen, D., Waterman, C., Hywood, L., Rankin, P., & Soewu, D. (2014). *Smutsia temminckii*. *The IUCN Red List of Threatened Species 2014: e.T12765A45222717*. http:// dx.doi.org/10.2305/IUCN.UK.2014-2.RLTS.T12765A45222717.en

Pietersen D, Jansen R, Swart J, & Kotze A. (2016). A conservation assessment of *Smutsia temminckii.* In Child MF, Roxburgh L, Do Linh San E, Raimondo D, Davies-Mostert HT (Eds.). *The Red List of Mammals of South Africa, Swaziland and Lesotho*. South African National Biodiversity Institute and Endangered Wildlife Trust, South Africa

Pietersen, D.W., Symes, C.T., Woodborne, S., McKechnie, A.E., & Jansen, R. (2016). Diet and prey selectivity of the specialist myrmecophage, Temminck's ground pangolin*. Journal of Zoology* 298, 198–208. https://doi.org/10.1111/jzo.12302

Pietersen, D., Jansen, R. & Connelly, E. (2019). *Smutsia temminckii*. *The IUCN Red List of Threatened Species* 2019: e.T12765A123585768*.* https://dx.doi.org/10.2305/IUCN.UK.2019-3.RLTS.T12765A123585768.en. Downloaded on 20 December 2020

Pietersen, D., Moumbolou, C., Ingram, D.J., Soewu, D., Jansen, R., Sodeinde, O., Keboy Mov Linkey Iflankoy, C., Challender, D. & Shirley, M.H. (2019). *Phataginus tricuspis*. *The IUCN Red List of Threatened Species* 2019: e.T12767A123586469. https://dx.doi.org/10.2305/IUCN.UK.2019-3.RLTS.T12767A123586469.en. Downloaded on 20 December 2020

Pietersen, D. W., & Challender, D. W. S. (2020). Research needs for pangolins. In Challender, D.W.S., Nash, H.C., and Waterman, C., *Pangolins: Science, Society, and Conservation* pp. 537–543*.* Academic Press. https://doi.org/10.1016/B978-0-12-815507-3.00034-4

Pietersen, D. W., Jansen, R., Swart, J., Panaino, W., Kotze, A., Rankin, P., & Nebe, B. (2020). Temminck's pangolin (*Smutsia temminckii*). In Challender, D.W.S., Nash, H.C., and Waterman, C. (Eds.), *Pangolins: Science, Society, and Conservation* pp. 175–193. Academic Press. https://doi.org/10.1016/B978-0-12-815507-3.00011-3

Prediger, K.A. (2021). Namibian Pangolin Working Group: collaboration for conservation success and World Pangolin Day. http://conservationnamibia.com/blog/b2021-namibian-pangolin-conservation.php

R Core Team (2021). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/. Last accessed on 15 July 2021

Richer, R.A., Coulson, I.M., & Heath, M.E. (1997). Foraging behaviour and ecology of the Cape pangolin (*Manis temminckii*) in north-western Zimbabwe*. African Journal of Ecology,* 35, 361–369. http://dx.doi.org/10.1111/j.1365-2028.1997.101-89101.x

Rodgers, M., Bilton, M.C., & Hauptfleisch, M.L. (2017). Responses and feedbacks of burrowing mammals under differently managed rangelands. *Namibian Journal of Environment,* 1, 40-51

Rubenstein, D.I. and Wrangham, R.W. (1986). *Ecological Aspects of Social Evolution Birds and Mammals*, pp 429-452. Princeton University Press, Princeton

Scott-Hayward, L.A.S., Oedekoven, C., Mackenzie, M., Walker, C. & Rexstad, E. (2013). MRSea Package (version 0.1.5): Statistical Modelling of Bird and Cetacean Distributions in Offshore Renewables Development Areas. (Report No. CR/2012/05). Report by University of St Andrews. Report for Marine Scotland Science

Scott-Hayward, L.A.S., Mackenzie, M.L., Donovan, C.R., Walker, C.G., & Ashe, E. (2013). Complex region spatial smoother (CReSS). *Journal of Computational and Graphical Statistics,* 23(2), 340-360. https://doi.org/10.1080/10618600.2012.762920

Setlalekgomo, M.R. (2014) Ethnozoological survey of the indigenous knowledge on the use of pangolins (*Manis* sp.) in traditional medicine in Lentsweletau Extended Area in Botswana. *Journal of Animal Science Advances*, 4(6), 883-890. https://doi.org/1.5455/jasa.20140526093512

Shepherd, C. R., Connelly, E., Hywood, L. and Cassey, P. (2016). Taking a stand against illegal wildlife trade: the Zimbabwean approach to pangolin conservation. *Oryx,* 51 (2), 1–6. https://doi.org/10.1017/S0030605316000119

Schoppe, S., Katsis, L. & Lagrada, L. (2019). *Manis culionensis*. *The IUCN Red List of Threatened Species* 2019: e.T136497A123586862. https://dx.doi.org/10.2305/IUCN.UK.2019-3.RLTS.T136497A123586862.en. Downloaded on 20 December 2020

Skinner, J.D., Chimimba, C.T. (2005). *The Mammals of the Southern African Sub-region*. Cambridge University Press

Smith, D. (2019). Pangolin research at Tswalu. https://tswalu.com/pangolin-research-at-tswalu/. Last accessed on 15 June 2021.

Soewu, D.A. & Ayodele, I.A. (2009) Utilisation of pangolin (*Manis* sp.) in traditional Yorubic medicine in Ijebu province, Ogun State, Nigeria. *Journal of Ethnobiology and Ethnomedicine*, 5, 11. https://doi.org/10.1186/1746-4269-5-39

Sun, N.C.M., Arora, B., Lin, J.S., Lin, W.C., Chi, M.J., Chen, C.C. & Pei, K.J.C. (2019) Mortality and morbidity in wild Taiwanese pangolin (*Manis pentadactyla pentadactyla*). *PLoS One*, 14(2), 1 https://doi.org/10.1371/journal.pone.0198230

Swart, J.M. (1996). *Foraging behaviour of the Cape pangolin Manis temminckii in the Sabie Sand Wildtuin.* M.Sc. Thesis. University of Pretoria, Pretoria, South Africa.

Swart, J.M., Richardson, P.R.K., Ferguson, J.W.H. (1999). Ecological factors affecting the feeding behavior of pangolins (*Manis temminckii*). *Journal of Zoology*, 247(3), 281–292. https://doi.org/10.1111/j.1469-7998.1999.tb00992.x

Swart, J.M. 2013. Smutsia temminckii Ground Pangolin. In: Kingdon, J., Hoffmann, M (Eds.), Mammals of Africa, vol V, Carnivores, Pangolins, Equids, Rhinoceroses. Bloomsbury Publishing, pp. 400-405

van Aarde, R.J., Richardson, P.R.K, Pietersen, E. (1990). *Report on the Behavioural Ecology of the Cape Pangolin (Manis temminckii)*. Mammal Research Institute, University of Pretoria, Internal Report

Wang, B., Yang, W., Sherman, V.R. & Meyers, M.A. (2016) Pangolin armor: Overlapping, structure, and mechanical properties of the keratinous scales. *Acta Biomaterialia*, 41, 60-74. https://doi.org/10.1016/j.actbio.2016.05.028

Weyer, N.M. (2019). *Physiological flexibility of free-living aardvarks (Orycteropus after) in response to environmental fluctuations*. PhD Thesis, University of Witwatersrand, Johannesburg, South Africa

Willcox, D., Nash, H.C., Trageser, S., Kim, H.J., Hywood, L., Connelly, E., Ichu Ichu, G., Kambale Nyumu, J., Mousset Moumbolou, C.L., Ingram, D.J. & Challender, D.W.S. (2019) Evaluating methods for detecting and monitoring pangolin (Pholidata: Manidae) populations. *Global Ecology and Conservation,* 17, 1-12. https://doi.org/10.1016/j.gecco.2019.e00539

Wood, S.N. (2011*)* Fast stable restricted maximum likelihood and marginal likelihood estimation of semiparametric generalized linear models. *Journal of the Royal Statistical Society (B),*73(1) , 3-36. https://doi.org/10.1111/j.1467-9868.2010.00749.x

Wood, S.N. (2017). *Generalized Additive Models: An Introduction with R*. 2nd ed. CRC Press

Wu, S.B., Liu, N.F., Ma, G.Z., Xu, Z.R., Chen, H. (2003). Habitat Selection by Chinese pangolin (*Manis pentadactyla*) in winter in Dawuling Natural Reserve. *Mammalia,* 67(4), 493-502. https://doi.org/10.1515/mamm-2003-0403

APPENDICES

Appendix 1: Raw data for pangolins identified at the study site

Table 12: Morphometric data for all tagged pangolins			
ID	Sex	Weight (kg)	Circumference (cm)
OST01	F	3.8	68
OST02	M	10.08	95
OST03	F	11.15	98
OST04	F	9.4	94.5
OST05	M	Unknown	Unknown
OST06*	M	10.15	100
OST07	M	7.9	Unknown
OST08	F	9.96	95
OST09	F	10.24	96
OST10	M	9.82	93
OST11	F	11.55	98
OST12	M	12.71	140
OST13	M	8.85	Unknown
OST14*	M	7.8	Unknown
OST15	F	3.05	63.6
OST16	F	5.15	79
OST17	M	4.5	74
OST18	F	10.83	102.5
OST19	M	5.37	73
OST20	M	3.8	67
OST21	M	5.77	74

OST22*	M	6.9	90
OST23	M	7.5	85.5
OST24	M	4.28	73
OST25	F	5.41	69
OST26	M	4.5	72.5
OST27	F	9.41	91
OST28	M	8.34	89.5
OST29	F	11.56	Unknown
OST30	M	5.70	84.7
OST31	F	8.85	91
OST32	M	11.94	104
OST33	M	6.93	95.1
OST34*	F	Unknown	Unknown
OST35	M	10.40	97
OST36	F	13.45	103
OST37	M	9.31	Unknown
OST38	F	3.74	65
OST39	M	4.10	65.5
OST40	M	3.70	Unknown

*Trafficked-released pangolin

Table 13: Morphometric data for untagged pangolins						
Untagged ID	Date of Initial sighting	Time	Sex	Weight (kg)	Circumference (cm)	Notes
OST001*	01/10/18	20:20	M	NA	NA	OST12
OST002*	11/10/18	22:58	F	NA	NA	OST11
OST003	15/10/18	21:15	M	NA	NA	NA
OST004	18/05/19	18:15	Unknown	2.91	70.5	NA
OST005	20/05/19	9:45	Unknown	3.98	68.7	NA
OST006	21/05/19	21:45	M	4.77	Unknown	NA
OST007	14/06/19	19:15	M	8.5	Unknown	NA
OST008	10/07/19	12:15	Unknown	5.1	79	NA
OST009	12/07/19	18:15	Unknown	NA	NA	NA
OST010	16/08/19	NA	M	5.1	76.1	Deceased : PM: Malnutrition: Starvation

*Tagged at a later point

Appendix 2: Home range analysis for all seasons combined

Table 14: MCP, 95KD, and 50KD home range data for entire tagging period						
ID	Sex	Weight	N	MCP (km^2)	95KD (km^2)	50KD (km^2)
OST02	M	6-10 kg	430	21.29	20.53	4.23
OST03	F	>10 kg	864	12.64	8.54	2.17
OST04	F	6-10 kg	406	4.85	3.18	1.04
OST08	F	6-10 kg	443	16.04	41.53	6.91
OST09	F	6-10 kg	661	10.24	7.00	1.05
OST11	F	>10 kg	873	21.17	11.38	3.42
OST12	M	>10 kg	532	26.24	21.17	4.23
OST13	F	6-10 kg	98	9.09	13.73	2.34
OST18	F	>10 kg	450	4.24	5.04	1.15
OST29	F	>10 kg	310	5.85	9.36	1.39
OST31	F	6-10 kg	331	6.73	9.75	1.62
OST32	M	>10 kg	483	35.74	38.77	6.21
OST35	M	>10 kg	433	12.20	15.43	2.87
OST36	F	>10 kg	246	5.80	1.62	0.58

Appendix 3: MCP and CReSS home ranges for growing and non-growing seasons

Table 15: MCP and CReSS (HR and CA) home range data for the growing and non-growing season						
Growing				CReSS ($km^{2)}$		
ID	Sex	Weight	N	HR	CA	MCP (km^2)
OST02	M	6-10 kg	534	17.00	6.45	-
OST03	F	>10 kg	302	6.08	2.37	-
OST04	F	6-10 kg	502	2.79	1.01	5.34
OST08	F	6-10 kg	280	5.90	1.89	5.1
OST09	F	6-10 kg	342	5.11	1.55	4.76
OST11	F	>10 kg	373	10.07	3.72	11.41
OST12	M	>10 kg	449	17.13	6.17	16.08
OST13	F	6-10 kg	63	6.52	2.32	4.32
OST18	F	>10 kg	262	2.45	0.90	2.29
OST29	F	>10 kg	444	4.93	1.55	-
OST31	F	6-10 kg	419	3.75	1.42	-
OST32	M	>10 kg	543	33.98	11.77	-
OST35	M	>10 kg	589	10.07	3.72	-
OST36	F	>10 kg	362	6.80	1.74	-
Non-growing						
ID	Sex	Weight	N	HR	CA	MCP
OST03	F	>10 kg	485	6.15	1.77	5.49
OST08	F	6-10 kg	30	3.42	0.92	2.28
OST09	F	6-10 kg	222	3.36	1.09	3.38
OST10	M	>10 kg	116	5.95	1.52	-
OST11	F	>10 kg	447	6.65	2.61	7.15
OST12	M	>10 kg	71	6.69	2.10	4.88
OST13	F	6-10 kg	26	8.17	3.23	4.85
OST18	F	>10 kg	187	2.86	0.86	2.14

Appendix 4: Post-hoc tables comparing p values for CReSS individual home range and core area sizes

Table 16: Post-hoc table with p values for CReSS home range sizes for all individuals

HR	OST02*	OST03	OST04	OST08	OST09	OST11	OST12*	OST13	OST18	OST29	OST31	OST32*	OST35*	OST36	OST10*
OST02*		0.02346	0.013817	0.013647	0.011693	0.055764	0.219222	0.037573	0.006689	0.027648	0.018792	0.005911	0.155623	0.051707	0.038836
OST03	0.02346		0.407304	0.650999	0.560874	0.48971	0.10193	0.701527	0.298304	0.762561	0.550566	0.000151	0.329255	0.861044	0.966331
OST04	0.013817	0.407304		0.635254	0.713028	0.183285	0.046243	0.266428	0.972449	0.638228	0.831845	0.000184	0.138563	0.387858	0.49168
OST08	0.013647	0.650999	0.635254		0.894132	0.268681	0.050788	0.412223	0.535823	0.944939	0.816277	0.000109	0.19463	0.588214	0.742397
OST09	0.011693	0.560874	0.713028	0.894132		0.222311	0.041476	0.346223	0.623734	0.859042	0.901308	0.0001	0.165809	0.518353	0.663118
OST11	0.055764	0.48971	0.183285	0.268681	0.222311		0.286894	0.751375	0.106399	0.393413	0.261205	0.000255	0.664027	0.691567	0.543214
OST12*	0.219222	0.10193	0.046243	0.050788	0.041476	0.286894		0.181844	0.019802	0.106697	0.067282	0.00063	0.6406	0.217608	0.158109
OST13	0.037573	0.701527	0.266428	0.412223	0.346223	0.751375	0.181844		0.171628	0.542401	0.372301	0.0002	0.49346	0.889191	0.722448
OST18	0.006689	0.298304	0.972449	0.535823	0.623734	0.106399	0.019802	0.171628		0.56545	0.780004	0.000072	0.090051	0.308176	0.411337
OST29	0.027648	0.762561	0.638228	0.944939	0.859042	0.393413	0.106697	0.542401	0.56545		0.79427	0.000285	0.276508	0.680586	0.821546
OST31	0.018792	0.550566	0.831845	0.816277	0.901308	0.261205	0.067282	0.372301	0.780004	0.79427		0.000223	0.19007	0.506371	0.629001
OST32*	0.005911	0.000151	0.000184	0.000109	0.0001	0.000255	0.00063	0.0002	0.000072	0.000285	0.000223		0.000917	0.000428	0.000355
OST35*	0.155623	0.329255	0.138563	0.19463	0.165809	0.664027	0.6406	0.49346	0.090051	0.276508	0.19007	0.000917		0.477271	0.375693
OST36	0.051707	0.861044	0.387858	0.588214	0.518353	0.691567	0.217608	0.889191	0.308176	0.680586	0.506371	0.000428	0.477271		0.850818
OST10*	0.038836	0.966331	0.49168	0.742397	0.663118	0.543214	0.158109	0.722448	0.411337	0.821546	0.629001	0.000355	0.375693	0.850818	

* denotes male

Table 17: Post-hoc table with p values for CReSS core area sizes for all individuals

CA	OST 02*	OST03	OST04	OST08	OST09	OST11	OST12*	OST13	OST18	OST29	OST31	OST32*	OST35*	OST36	OST10*
OST02*		0.020464	0.014916	0.010919	0.010097	0.060406	0.159036	0.040884	0.006786	0.023355	0.020941	0.01646	0.151543	0.027423	0.022773
OST03	0.020464		0.493926	0.59653	0.551592	0.391617	0.128794	0.575128	0.354161	0.733764	0.671479	0.000303	0.298368	0.828666	0.719176
OST04	0.014916	0.493926		0.795758	0.83887	0.185799	0.070943	0.268608	0.931958	0.759498	0.815926	0.000388	0.15414	0.67986	0.772396
OST08	0.010919	0.59653	0.795758		0.945484	0.1857	0.056957	0.290909	0.674773	0.924135	0.992137	0.000201	0.159036	0.826121	0.93979
OST09	0.010097	0.551592	0.83887	0.945484		0.167866	0.05131	0.264425	0.724565	0.879999	0.947628	0.000191	0.14631	0.783215	0.895533
OST11	0.060406	0.391617	0.185799	0.1857	0.167866		0.445272	0.754557	0.098458	0.307946	0.273598	0.000626	0.716757	0.364319	0.299721
OST12*	0.159036	0.128794	0.070943	0.056957	0.05131	0.445272		0.294164	0.030029	0.121842	0.107037	0.001256	0.785718	0.147032	0.11826
OST13	0.040884	0.575128	0.268608	0.290909	0.264425	0.754557	0.294164		0.158122	0.43185	0.38699	0.00048	0.540509	0.503825	0.421179
OST18	0.006786	0.354161	0.931958	0.674773	0.724565	0.098458	0.030029	0.158122		0.662123	0.724025	0.000148	0.094452	0.576619	0.676181
OST29	0.023355	0.733764	0.759498	0.924135	0.879999	0.307946	0.121842	0.43185	0.662123		0.941052	0.000529	0.241547	0.913955	0.986382
OST31	0.020941	0.671479	0.815926	0.992137	0.947628	0.273598	0.107037	0.38699	0.724025	0.941052		0.00049	0.217217	0.855713	0.954635
OST32*	0.01646	0.000303	0.000388	0.000201	0.000191	0.000626	0.001256	0.00048	0.000148	0.000529	0.00049		0.002093	0.000592	0.00052
OST35*	0.151543	0.298368	0.15414	0.159036	0.14631	0.716757	0.785718	0.540509	0.094452	0.241547	0.217217	0.002093		0.281298	0.235732
OST36	0.027423	0.828666	0.67986	0.826121	0.783215	0.364319	0.147032	0.503825	0.576619	0.913955	0.855713	0.000592	0.281298		0.90045
OST10*	0.022773	0.719176	0.772396	0.93979	0.895533	0.299721	0.11826	0.421179	0.676181	0.986382	0.954635	0.00052	0.235732	0.900450	

*denotes male

Appendix 5: Individual CReSS home range and core area overlap for the growing season

Table 18: Individual home range cell overlap and area for the growing season			
IDs	Cells overlapping (100m x 100m)	Sexes	Area (km^2)
OST08, OST35	343	F,M	3.43
OST11, OST12	286	F, M	2.86
OST29, OST32, OST36	259	F, M, F	2.59
OST31, OST35	220	F, M	2.2
OST03, OST12	218	F, M	2.18
OST04, OST32	216	F, M	2.16
OST29, OST32	192	F, M	1.92
OST03, OST09, OST12	189	F, F, M	1.89
OST02, OST18	174	M, F	1.74
OST02, OST11, OST12, OST13	161	M, F, M, F	1.61
OST32, OST36	158	M, F	1.58
OST02, OST13	144	M, F	1.44
OST02, OST08, OST35	113	M, F, M	1.13
OST02, OST11, OST12	97	M, F, M	0.97
OST02, OST12, OST13	85	M, M, F	0.85
OST12, OST32	84	M, M	0.84
OST03, OST09, OST11, OST12	80	F, F, F, M	0.8
OST08, OST31, OST35	78	F, F, M	0.78
OST09, OST12	69	F, M	0.69
OST02, OST32	62	M, M	0.62
OST02, OST18, OST35	51	M, F, M	0.51
OST13, OST32	51	F, M	0.51
OST02, OST12, OST13, OST32	50	M, M, F, M	0.5
OST09, OST12, OST32	49	F, M, M	0.49
OST02, OST13, OST32	45	M, F, M	0.45
OST03, OST11, OST12	45	F, F, M	0.45
OST02, OST35	44	M, M	0.44
OST04, OST29, OST32, OST36	42	F, F, M, M	0.42
OST02, OST09, OST11, OST12, OST13	32	M, F, F, M, F	0.32
OST09, OST12, OST13, OST32	25	F, M, F, M	0.25
OST12, OST13, OST32	22	M, F, M	0.22
OST02, OST12	21	M, M	0.21

OST04, OST32, OST36	21	F, M, F	0.21
OST02, OST08, OST18	20	M, F, F	0.2
OST02, OST03, OST11, OST12	16	M, F, F, M	0.16
OST09, OST11, OST12, OST13	12	F, F, M, F	0.12
OST03, OST09, OST11, OST12, OST32	9	F, F, F, M, M	0.09
OST09, OST32	9	F, M	0.09
OST03, OST32	8	F, M	0.08
OST09, OST11, OST12	8	F, F, M	0.08
OST09, OST11, OST12, OST13, OST32	8	F, F, M, F, M	0.08
OST02, OST08, OST31, OST35	7	M, F, F, M	0.07
OST02, OST09, OST12, OST13, OST32	7	M, F, M, F, M	0.07
OST03, OST09, OST11, OST12, OST13, OST32	4	F, F, F, M, F, M	0.04
OST02, OST08	3	M, F	0.03
OST02, OST09, OST11, OST12	3	M, F, M, M	0.03
OST03, OST09, OST12, OST32	3	M, F, F, M, F	0.03
OST02, OST03, OST11, OST12, OST13	2	M, F, F, M, F	0.02
OST02, OST31, OST35	2	M, F, M	0.02
OST03, OST09, OST11, OST12, OST13	2	F, F, F, M, F	0.02
OST02, OST09, OST11, OST12, OST13, OST32	1	M, F, F, M, F, M	0.01
OST02, OST09, OST12, OST13	1	M, F, M, F	0.01
OST02, OST12, OST32	1	M, M, M	0.01

Table 19: Raw data for home range overlap per sex and combination types with size of overlap for the growing season															
Number of Individual overlap and cases of overlap															
Number of individuals	2	3	4	5	6										
Cases of overlap	18	16	10	7	2										
Types of overlap with size of overlap and mean and median for each type of overlap															
Overlap type	M-F	M-M	F-F	F-F-F	M-F-F	M-M-F	M-M-M	M-F-F-F	M-M-F-F	M-M-M-F	M-F-F-F-F	M-M-F-F-F	M-M-M-F-F	M-M-F-F-F-F	M-M-M-F-F-F-F
Cases	14	4	0	0	7	8	1	2	6	2	1	5	1	1	1
Size of overlap (km^2)	3.43	0.84			2.59	1.44	0.01	0.80	1.61	0.50	0.02	0.32	0.07	0.04	0.01
	2.86	0.62			1.89	1.13		0.12	0.42	0.03		0.09			
	2.20	0.44			0.78	0.97			0.25			0.08			
	2.18	0.21			0.45	0.51			0.16			0.03			
	2.16				0.21	0.50			0.07			0.02			
	1.92				0.20	0.49			0.01						
	1.74				0.08	0.22									
	1.58					0.02									
	1.44														
	0.69														
	0.51														
	0.09														
	0.08														
	0.03														
Mean	1.49	0.53			0.89	0.66		0.46	0.42	0.27		0.11			
Median	1.66	0.53			0.45	0.51		0.46	0.21	0.27		0.08			

Table 20: Individual core area cell overlap and area for the growing season

IDs	Cells overlapping (100m x 100m)	Sexes	Area (km^2)
OST29, OST32, OST36	131	F, M, F	1.31
OST31, OST35	120	F, M	1.2
OST09, OST12	107	F, M	1.07
OST08, OST35	102	F, M	1.02
OST02, OST18	90	M, F	0.9
OST04, OST32	72	F, M	0.72
OST11, OST12	69	F, M	0.69
OST03, OST12	61	F, M	0.61
OST02, OST12, OST13	55	M, M, F	0.55
OST02, OST13	42	M, F	0.42
OST02, OST11, OST12, OST13	41	M, F, M, F	0.41
OST03, OST09, OST12	41	F, F, M	0.41
OST12, OST13	40	M, F	0.4
OST32, OST36	36	M, F	0.36
OST02, OST11, OST12	20	M, F, M	0.2
OST29, OST32	20	F, M	0.2
OST04, OST29, OST32, OST36	4	F, F, M, F	0.04
OST02, OST11	3	M, F	0.03
OST04, OST32, OST36	3	F, M, F	0.03
OST02, OST35	2	M, M	0.02
OST11, OST12, OST13	2	F, M, F	0.02
OST08, OST31, OST35	1	F, F, M	0.01
OST09, OST12, OST13	1	F, M, F	0.01

Table 21: Raw data for core area overlap per sex and combination types with size of overlap for the growing season								
Number of Individual overlap and cases of overlap								
Number of individuals	2	3	4					
Cases of overlap	13	8	2					
Types of overlap with size of overlap and mean and median for each type of overlap								
Overlap type	M-F	M-M	F-F	F-F-F	M-F-F	M-M-F	M-F-F-F	M-M-F-F
Cases	12	1	0	0	6	2	1	1
Size of overlap (km^2)	1.20	0.02			1.31	0.55	0.04	0.41
	1.07				0.41	0.20		
	1.02				0.03			
	0.90				0.02			
	0.72				0.01			
	0.69				0.01			
	0.61							
	0.42							
	0.40							
	0.36							
	0.20							
	0.03							
Mean	0.64				0.30	0.38		
Median	0.65				0.03	0.38		

Appendix 6: Individual CReSS home range and core area overlap for the non-growing season

Table 22: Individual home range cell overlap and area for the non-growing season

IDs	Cells overlapping (100 m x 100 m)	Sexes	Area (km^2)
OST12, OST13	122	M, F	1.22
OST03, OST09, OST12	96	F, F, M	0.96
OST03, OST09	84	F, F	0.84
OST11, OST12	73	F, M	0.73
OST11, OST13	71	F, F	0.71
OST10, OST11, OST13	62	M, F, F	0.62
OST03, OST09, OST11, OST12	56	F, F, F, M	0.56
OST10, OST11	54	M, F	0.54
OST10, OST11, OST12, OST13	50	M, F, M, F	0.5
OST03, OST09, OST13	47	F, F, F	0.47
OST10, OST12, OST13	26	M, M, F	0.26
OST11, OST12, OST13	26	F, M, F	0.26
OST10, OST11, OST12	21	M, F, M	0.21
OST09, OST13	18	F, F	0.18
OST03, OST12	16	F, F	0.16
OST03, OST13	13	F, F	0.13
OST09, OST12	10	F, M	0.1
OST03, OST12, OST13	8	F, M, F	0.08
OST09, OST10, OST11, OST12	6	F, M, F, M	0.06
OST09, OST11, OST12, OST13	6	F, F, M, F	0.06
OST03, OST11, OST12, OST13	5	F, F, M, F	0.05
OST03, OST09, OST11, OST12, OST13	4	F, F, F, M, F	0.04
OST09, OST10, OST11, OST12, OST13	4	F, F, F, M, F	0.04
OST10, OST13	3	M, F	0.03
OST09, OST11, OST12	2	F, F, M	0.02

Table 23: Raw data for home range overlap per sex and combination types with size of overlap for the non-growing season									
Number of Individual overlap and cases of overlap									
Number of individuals	2	3	4	5					
Cases of overlap	10	8	5	2					
Types of overlap with size of overlap and mean and median for each type of overlap									
Overlap type	M-F	M-M	F-F	F-F-F	M-F-F	M-M-F	M-F-F-F	M-M-F-F	M-F-F-F-F
Cases	5	0	5	1	5	2	3	2	2
Size of overlap (km^2)	1.22		0.84	0.47	0.96	0.26	0.56	0.50	0.04
	0.73		0.71		0.62	0.21	0.06	0.06	0.04
	0.54		0.18		0.26		0.05		
	0.10		0.16		0.08				
	0.03		0.13		0.02				
Average	0.52		0.40		0.39	0.24	0.22	0.28	0.04
Median	0.53		0.29		0.26	0.24	0.06	0.28	0.04

Table 24: Individual core area cell overlap and area for the non-growing season			
IDs	Cells overlapping (100m x 100m)	Sexes	Area (km^2)
OST09, OST12	37	F, M	0.37
OST11, OST13	26	F, F	0.26
OST09, OST11, OST12	16	F, F, M	0.16
OST03, OST09	12	F, F	0.12
OST09, OST13	11	F, F	0.11
OST09, OST11	1	F, F	0.01
OST12, OST13	1	M, F	0.01

Table 25: Raw data for core area overlap per sex and combination types with size of overlap for the non-growing season					
Number of Individual overlap and cases of overlap					
Number of individuals	2	3			
Cases of overlap	6	1			
Types of overlap with size of overlap and mean and median for each type of overlap					
Overlap type	M-F	M-M	F-F	F-F-F	M-F-F
Cases	2	0	4	0	1
Size of overlap (km^2)	0.37		0.26		0.16
	0.01		0.12		
			0.11		
			0.01		
Average	0.19		0.08		
Median	0.19		0.11		

Appendix 7: Ant and termite species found in pitfall traps

Table 26: Ant and termite taxonomy and species collected from pitfall trapping	
ANTS	
Formicidae- 4 subfamilies, 20 genera, 24 species minimum	
Formicinae- 5 genera, 9 species minimum	Specimen collected
Anoplolepis custodiens	2
Anoplolepis steingroeveri	254
Camponotus (black spp)	84
Camponotus (red spp)	258
Camponotus cf. maculatus	437
Camponotus cf. mayri	52
Camponotus fulvopilosus	120
Lepisiota	391
Tapinolepis	297
Total	1895
Myrmicinae- 7 genera, 7 species minimum	
Crematogaster spp	38
Meranoplus	176
Messor denticornis	124
Monomorium spp	5492
Ocymyrmex	3618
Pheidole	4995
Tetramorium	3395
Total	17838
Ponerinae - 7 genera, 7 species minimum	
Anochetus	2
Bothroponera	77
Brachyponera	126
Megaponera	100
Odontomachus	364
Ophthalmopone	1235
Plectroctena	5

Total	1909
Pseudomyrmecinae - 1 genus, 1 species minimum	
Tetraponera	1
Total	1
Termites	
Hodotermitidae- 1 genera, 1 species	
Hodotermes spp	1184
Termitidae, 2 genera, 2 species	
Macrotermitinae- 1 genera, 1 species	
Macrotermes spp	235
Nasutitermitinae- 1 genera, 1 species	
Trinervitermes spp	7

Appendix 8: Foraging data

Table 27: Raw foraging sample data with species and foraging type (when noted)		
Date	Species	Foraging type
28/02/19	*Trinervitermes* sp.	
28/02/19	*Trinervitermes* sp.	
28/02/19	*Trinervitermes* sp.	
04/03/19	*Trinervitermes* sp.	
10/03/19	*Crematogaster* sp.	
10/03/19	*Crematogaster* sp.	
14/03/19	*Trinervitermes* sp.	Nest-no digging
25/03/19	*Trinervitermes* sp.	
25/03/19	*Trinervitermes* sp.	
26/03/19	*Anoplolepis custodiens*	
26/03/19	*Anoplolepis custodiens*	
27/03/19	*Anoplolepis custodiens*	
01/04/19	*Anoplolepis steingroeveri*	
01/04/19	*Anoplolepis steingroeveri*	
01/04/19	*Anoplolepis steingroeveri*	
01/04/19	*Anoplolepis steingroeveri*	
02/04/19	*Trinervitermes* sp.	
08/04/19	*Anoplolepis steingroeveri*	
09/04/19	*Anoplolepis steingroeveri*	
11/04/19	*Anoplolepis steingroeveri*	
11/04/19	*Anoplolepis steingroeveri*	
11/04/19	*Anoplolepis steingroeveri*	
11/04/19	*Anoplolepis steingroeveri*	
13/04/19	*Trinervitermes* sp.	Digging
15/04/19	*Trinervitermes* sp.	
15/04/19	*Anoplolepis steingroeveri*	
16/04/19	*Anoplolepis custodiens*	Surface active individuals
16/04/19	*Anoplolepis custodiens*	Nest-no digging
17/04/19	*Anoplolepis custodiens*	Nest-no digging
19/04/19	*Anoplolepis custodiens*	
23/04/19	*Anoplolepis custodiens*	
23/04/19	*Anoplolepis custodiens*	
29/04/19	*Anoplolepis steingroeveri*	

07/05/19	*Trinervitermes* sp.	
07/05/19	*Trinervitermes* sp.	
09/05/19	No sample collected	Digging
09/05/19	No sample collected	Nest-no digging
15/05/19	*Anoplolepis steingroeveri*	Nest-no digging
15/05/19	No sample collected	Nest-no digging
16/05/19	No sample collected	Digging
22/05/19	*Anoplolepis steingroeveri*	
22/05/19	No sample collected	Digging
26/05/19	*Anoplolepis custodiens*	
02/06/19	No sample collected	Digging
04/06/19	No sample collected	Digging
06/06/19	No sample collected	Nest-no digging
11/06/19	*Anoplolepis custodiens*	
14/06/19	*Trinervitermes* sp.	Digging
16/06/19	No sample collected	Digging
17/06/19	No sample collected	Surface active individuals
19/06/19	No sample collected	Digging
21/06/19	*Trinervitermes*	
24/06/19	*Trinervitermes* sp.	
25/06/19	*Trinervitermes* sp.	
05/07/19	*Anoplolepis custodiens*	
10/07/19	No sample collected	Nest-no digging
10/07/19	No sample collected	Nest-no digging
14/07/19	*Anoplolepis custodiens*	Digging
14/07/19	*Anoplolepis custodiens*	Nest-no digging
10/08/19	*Anoplolepis custodiens*	
05/09/19	*Anoplolepis custodiens*	
10/09/19	*Trinervitermes* sp.	
22/09/19	Crematogaster sp.	
22/09/19	*Trinervitermes*	
23/09/19	No sample collected	Digging
25/09/19	*Trinervitermes* sp.	
27/09/19	*Trinervitermes* sp.	
27/09/19	No sample collected	Digging
01/10/19	No sample collected	Nest-no digging
01/10/19	No sample collected	Nest-no digging
02/10/19	No sample collected	Clawing wood

03/10/19	No sample collected	Clawing wood
07/10/19	*Anoplolepis custodiens*	
07/10/19	No sample collected	Digging
09/10/19	*Trinervitermes* sp.	
10/10/19	*Trinervitermes* sp.	
13/10/19	*Anoplolepis custodiens*	Digging
15/10/19	*Anoplolepis steingroeveri*	
15/10/19	*Anoplolepis custodiens*	Nest-no digging
16/10/19	*Anoplolepis steingroeveri*	
16/10/19	No sample collected	Digging
17/10/19	*Trinervitermes* sp.	
17/10/19	*Trinervitermes sp.*	Digging
17/10/19	*Anoplolepis custodiens*	
21/10/19	*Trinervitermes* sp.	
29/10/19	*Anoplolepis steingroeveri*	
29/10/19	*Trinervitermes sp.*	
04/11/19	*Anoplolepis steingroeveri*	
04/11/19	*Anoplolepis steingroeveri*	
04/11/19	*Anoplolepis steingroeveri*	
04/11/19	*Anoplolepis steingroeveri*	
09/11/19	*Anoplolepis custodiens*	
09/12/19	*Crematogaster sp.*	
16/12/19	*Anoplolepis steingroeveri*	
09/01/20	*Anoplolepis custodiens*	
15/01/20	*Anoplolepis custodiens*	
15/01/20	*Anoplolepis custodiens*	
15/01/20	*Anoplolepis custodiens*	
16/01/20	*Anoplolepis custodiens*	
23/01/20	*Anoplolepis steingroeveri*	
23/01/20	*Anoplolepis custodiens*	
25/01/20	*Trinervitermes* sp.	
25/01/20	*Anoplolepis steingroeveri*	
27/01/20	*Anoplolepis custodiens*	
28/01/20	*Anoplolepis custodiens*	
06/02/20	*Anoplolepis custodiens*	
06/02/20	*Anoplolepis custodiens*	
11/02/20	*Anoplolepis custodiens*	

19/02/20	*Anoplolepis custodiens*	
24/02/20	*Anoplolepis steingroeveri*	
24/02/20	*Anoplolepis custodiens*	
24/02/20	*Anoplolepis steingroeveri*	
24/02/20	*Anoplolepis steingroeveri*	
24/02/20	*Anoplolepis steingroeveri*	
24/02/20	*Anoplolepis steingroeveri*	
25/02/20	*Anoplolepis custodiens*	
26/02/20	*Anoplolepis custodiens*	
02/03/20	*Anoplolepis custodiens*	
02/03/20	*Anoplolepis custodiens*	
04/03/20	*Anoplolepis custodiens*	
04/03/20	*Anoplolepis custodiens*	
04/03/20	*Anoplolepis custodiens*	
05/03/20	*Crematogaster sp.*	
05/03/20	*Anoplolepis steingroeveri*	
06/03/20	*Anoplolepis custodiens*	
06/03/20	*Anoplolepis steingroeveri*	
07/03/20	*Anoplolepis custodiens*	
07/03/20	*Anoplolepis custodiens*	
07/03/20	*Anoplolepis steingroeveri*	
08/03/20	*Anoplolepis steingroeveri*	
09/03/20	*Anoplolepis custodiens*	
09/03/20	*Anoplolepis steingroeveri*	
12/03/20	*Anoplolepis custodiens*	
12/03/20	*Anoplolepis custodiens*	
12/03/20	*Anoplolepis custodiens*	
12/03/20	*Anoplolepis custodiens*	
13/03/20	*Anoplolepis steingroeveri*	Digging
18/03/20	*Anoplolepis custodiens*	Digging
22/03/20	*Anoplolepis custodiens*	Nest-no digging
23/03/20	*Anoplolepis custodiens*	Nest-no digging
23/03/20	*Anoplolepis custodiens*	Digging
23/03/20	*Anoplolepis custodiens*	Surface active individuals
23/03/20	*Anoplolepis custodiens*	Nest-no digging
24/03/20	*Anoplolepis custodiens*	Nest-no digging
24/03/20	*Anoplolepis custodiens*	Surface active individuals

27/03/20	*Anoplolepis steingroeveri*	Surface active individuals
27/03/20	*Anoplolepis steingroeveri*	Digging
29/03/20	*Anoplolepis custodiens*	Digging
07/04/20	*Anoplolepis custodiens*	Surface active individuals
07/04/20	*Anoplolepis steingroeveri*	Surface active individuals
07/04/20	*Anoplolepis steingroeveri*	Surface active individuals
07/04/20	*Anoplolepis steingroeveri*	Digging
07/04/20	*Anoplolepis steingroeveri*	Digging
08/04/20	*Anoplolepis custodiens*	Digging
08/04/20	*Anoplolepis custodiens*	Digging
08/04/20	*Anoplolepis steingroeveri*	Digging
08/04/20	*Anoplolepis custodiens*	Digging
08/04/20	*Anoplolepis custodiens*	Digging
08/04/20	*Anoplolepis steingroeveri*	Nest-no digging
11/04/20	*Anoplolepis steingroeveri*	Digging
11/04/20	*Anoplolepis custodiens*	Digging
13/04/20	*Anoplolepis steingroeveri*	Digging
15/04/20	*Anoplolepis custodiens*	Nest-no digging
15/04/20	*Anoplolepis custodiens*	Digging
15/04/20	*Anoplolepis custodiens*	Digging
16/04/20	*Crematogaster* sp.	Nest-no digging
20/04/20	*Anoplolepis custodiens*	Digging
20/04/20	*Anoplolepis custodiens*	Digging
20/04/20	*Anoplolepis custodiens*	Digging
06/05/20	*Anoplolepis custodiens*	Digging
13/07/20	*Anoplolepis custodiens*	Nest-no digging
15/07/20	*Anoplolepis custodiens*	Digging
15/07/20	*Anoplolepis custodiens*	Digging
NO DATE	*Macrotermes* sp.	Digging
NO DATE	*Anoplolepis steingroeveri*	
NO DATE	*Anoplolepis steingroeveri*	
NO DATE	*Anoplolepis steingroeveri*	

Appendix 9: Mapped burrow sites for each individual

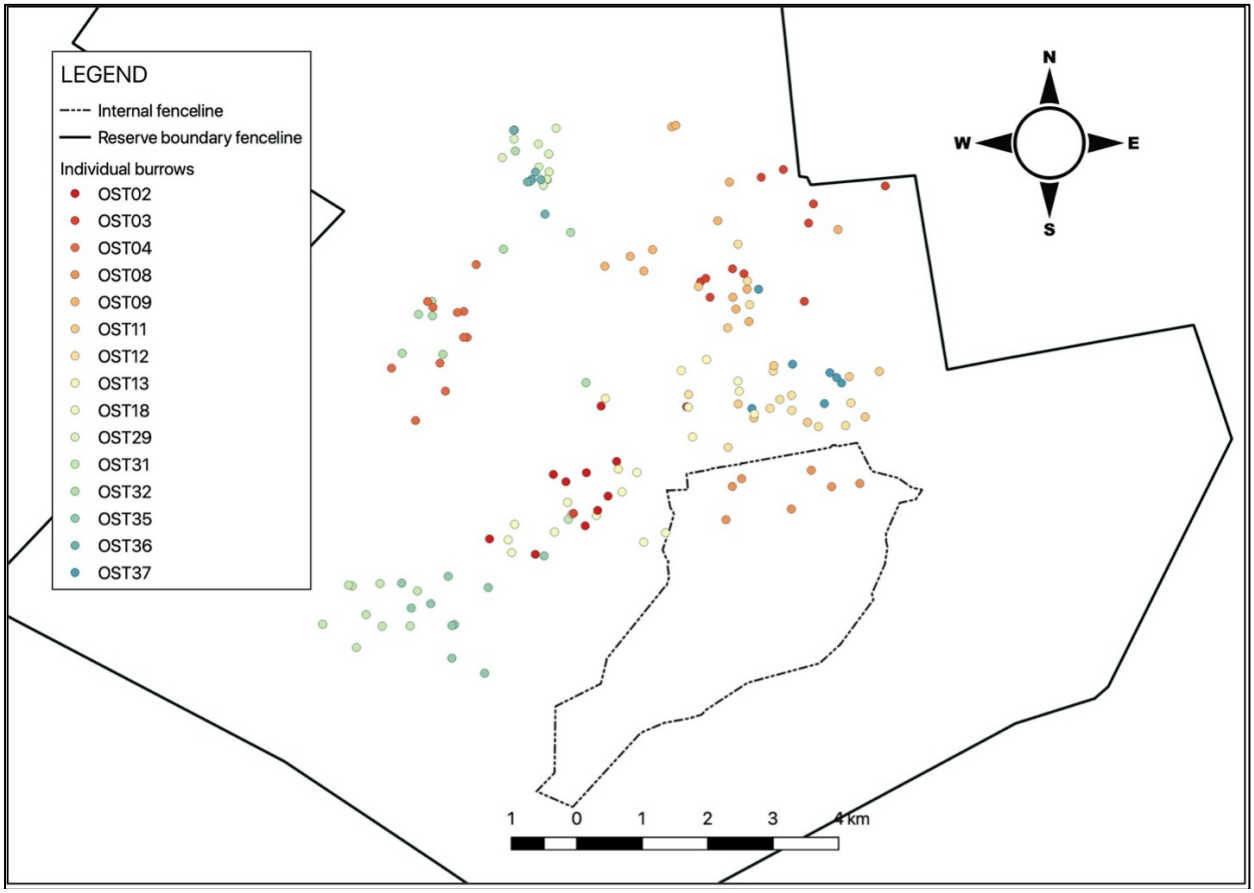

Figure 96: Map of 151 randomly selected burrows which were assessed for each individual

Appendix 10: Burrow measurements and details

Table 28: Burrow width, height, internal and external temperature, and habitat type for each individual

ID	Sex	Weight	Weight Category	Coll-apsed (C)	Width (cm)	Height (cm)	Internal Temper-ature (C°)	External Temper-ature (C°)	Habitat type
OST12	Male	12.71	>10 kg		20	64	10.5	25.2	Bush encroached
OST12	Male	12.71	>10 kg		40	32	15.5	34.6	Bush encroached
OST12	Male	12.71	>10 kg		40	39	12.3	25.3	Riverine
OST12	Male	12.71	>10 kg		28	26	18.9	53	Bush encroached
OST12	Male	12.71	>10 kg		34	60	15.6	24.5	Bush encroached
OST12	Male	12.71	>10 kg		58	59	14.9	22.8	Bush encroached
OST12	Male	12.71	>10 kg		19.5	31	17.2	24.3	Bush encroached
OST12	Male	12.71	>10 kg	C					
OST12	Male	12.71	>10 kg	C					
OST12	Male	12.71	>10 kg	C					
OST11	Male	11.71	>10 kg	C					
OST12	Male	12.71	>10 kg	C					
OST12	Male	12.71	>10 kg	C					
OST37	Male	9.31	6-10 kg		35	46	15.3	29.3	Bush encroached
OST37	Male	9.31	6-10 kg		24	26	12.4	13.2	Bush encroached
OST37	Male	9.31	6-10 kg		33	30	14.1	21.3	Bush encroached
OST37	Male	9.31	6-10 kg		29	24	10.9	11	Bush encroached
OST37	Male	9.31	6-10 kg		38	39	12.3	8.5	Bush encroached
OST37	Male	9.31	6-10 kg		34.5	27	12.1	13.4	Bush encroached
OST37	Male	9.31	6-10 kg	C					
OST32	Male	11.94	>10 kg		40	40	14.7	22.8	Bush encroached
OST32	Male	11.94	>10 kg		43	49	17.6	38.3	Bush encroached
OST32	Male	11.94	>10 kg		40	43	15	28.8	Riverine
OST32	Male	11.94	>10 kg		45	54	11.9	20	Bush encroached
OST32	Male	11.94	>10 kg		34	42	13.7	30.6	Bush encroached
OST32	Male	11.94	>10 kg	C					
OST32	Male	11.94	>10 kg	C					
OST32	Male	11.94	>10 kg	C					
OST32	Male	11.94	>10 kg	C					

OST32	Male	11.94	>10 kg	C					
OST35	Male	10.40	>10 kg		31	35	24.5	22.2	Bush encroached
OST35	Male	10.40	>10 kg		23	21	12.8	13.1	Bush encroached
OST35	Male	10.40	>10 kg		27	48	16.7	26.4	Bush encroached
OST35	Male	10.40	>10 kg		33	25	20.5	22.8	Mountainous/ rocky
OST35	Male	10.40	>10 kg		50	32	19.8	18.2	Mountainous/ rocky
OST35	Male	10.40	>10 kg		33	45	16.4	16.3	Bush encroached
OST35	Male	10.40	>10 kg		38	39	15	12.4	Bush encroached
OST35	Male	10.40	>10 kg	C					
OST35	Male	10.40	>10 kg	C					
OST35	Male	10.40	>10 kg	C					
OST31	Female	8.85	6-10 kg		19	34	13.9	33.8	Bush encroached
OST31	Female	8.85	6-10 kg		28	29	16.9	32.2	Bush encroached
OST31	Female	8.85	6-10 kg		20	31	16.2	30	Bush encroached
OST31	Female	8.85	6-10 kg		42	42	15	30.4	Bush encroached
OST31	Female	8.85	6-10 kg		20	32	18.3	30.1	Bush encroached
OST31	Female	8.85	6-10 kg	C					
OST31	Female	8.85	6-10 kg	C					
OST31	Female	8.85	6-10 kg	C					
OST31	Female	8.85	6-10 kg	C					
OST31	Female	8.85	6-10 kg	C					
OST31	Female	8.85	6-10 kg	C					
OST18	Female	10.83	>10 kg		37	23	14.7	26.4	Riverine
OST18	Female	10.83	>10 kg		43	27	12.5	17.9	Bush encroached
OST18	Female	10.83	>10 kg		24	30	15.4	12.6	Bush encroached
OST18	Female	10.83	>10 kg		19	24	14.8	17.1	Riverine
OST18	Female	10.83	>10 kg		26	17	16.7	9.1	Bush encroached
OST18	Female	10.83	>10 kg		20	17	17	12.3	Mountainous/rocky
OST18	Female	10.83	>10 kg		51	49	14.2	27.9	Bush encroached
OST18	Female	10.83	>10 kg		38	37	15.3	22.8	Riverine
OST18	Female	10.83	>10 kg		40	32	17	47.7	Riverine
OST18	Female	10.83	>10 kg	C					
OST18	Female	10.83	>10 kg	C					
OST03	Female	11.15	>10 kg		32	31	15.7	48.4	Riverine
OST03	Female	11.15	>10 kg		30	24	9.1	5.6	Bush encroached
OST03	Female	11.15	>10 kg		24	26	13.1	23.4	Open plains

OST03	Female	11.15	>10 kg		37	28	20.2	38.1	Riverine
OST03	Female	11.15	>10 kg		30	36	12.1	24.4	Open plains
OST03	Female	11.15	>10 kg		33	47	12.5	23.7	Bush encroached
OST03	Female	11.15	>10 kg		39	33	10.7	18.4	Open plains
OST03	Female	11.15	>10 kg	C					
OST03	Female	11.15	>10 kg	C					
OST03	Female	11.15	>10 kg	C					
OST03	Female	11.15	>10 kg	C					
OST03	Female	11.15	>10 kg	C					
OST29	Female	11.56	>10 kg		25	40	19	49	Bush encroached
OST29	Female	11.56	>10 kg		74	40	15.2	31.1	Bush encroached
OST29	Female	11.56	>10 kg		47	38	11.9	18.4	Bush encroached
OST29	Female	11.56	>10 kg		24	29	14.7	23.7	Bush encroached
OST29	Female	11.56	>10 kg		20	23	13.5	24.5	Bush encroached
OST29	Female	11.56	>10 kg		40	28	16.9	18.6	Bush encroached
OST29	Female	11.56	>10 kg		25	28	13.1	18.4	Open plains
OST29	Female	11.56	>10 kg	C					
OST29	Female	11.56	>10 kg	C					
OST29	Female	11.56	>10 kg	C					
OST36	Female	11.56	>10 kg		38	30	13.5	55.4	Riverine
OST36	Female	11.56	>10 kg		30	25	17.5	36.3	Open plains
OST36	Female	11.56	>10 kg		43	38	12.9	16.8	Open plains
OST36	Female	11.56	>10 kg	C					
OST36	Female	11.56	>10 kg	C					
OST36	Female	11.56	>10 kg	C					
OST36	Female	11.56	>10 kg	C					
OST04	Female	9.40	6-10 kg		15	17	15.6	40.9	Bush encroached
OST04	Female	9.40	6-10 kg		40	37	13.9	29.9	Bush encroached
OST04	Female	9.40	6-10 kg		43	25	17.9	17	Bush encroached
OST04	Female	9.40	6-10 kg		33	32	14.6	18.7	Bush encroached
OST04	Female	9.40	6-10 kg		39	34	12.3	21.1	Riverine
OST04	Female	9.40	6-10 kg	C					
OST04	Female	9.40	6-10 kg	C					
OST04	Female	9.40	6-10 kg	C					
OST04	Female	9.40	6-10 kg	C					
OST04	Female	9.40	6-10 kg	C					
OST04	Female	9.40	6-10 kg	C					
OST02	Male	10.08	>10 kg		45	50	13.6	11.7	Bush encroached

OST02	Male	10.08	>10 kg		45	65	13.3	13.3	Mountainous/rocky
OST02	Male	10.08	>10 kg		39	33	14.9	29.4	Open plains
OST02	Male	10.08	>10 kg		40	37	16.4	26.8	Open plains
OST02	Male	10.08	>10 kg		25	30	14.4	34.7	Bush encroached
OST02	Male	10.08	>10 kg	C					
OST02	Male	10.08	>10 kg	C					
OST02	Male	10.08	>10 kg	C					
OST02	Male	10.08	>10 kg	C					
OST02	Male	10.08	>10 kg	C					
OST02	Male	10.08	>10 kg	C					
OST02	Male	10.08	>10 kg	C					
OST08	Female	9.96	6-10 kg		72	42	14	25.8	Open plains
OST08	Female	9.96	6-10 kg		19	25	11.2	22.6	Open plains
OST08	Female	9.96	6-10 kg	C					
OST08	Female	9.96	6-10 kg	C					
OST08	Female	9.96	6-10 kg	C					
OST08	Female	9.96	6-10 kg	C					
OST08	Female	9.96	6-10 kg	C					
OST11	Female	11.55	>10 kg		37	34	11.8	22.9	Riverine
OST11	Female	11.55	>10 kg		43	39	14.8	45.6	Bush encroached
OST11	Female	11.55	>10 kg		45	29	15.3	43.5	Bush encroached
OST11	Female	11.55	>10 kg		38	43	10.1	12.2	Bush encroached
OST11	Female	11.55	>10 kg		25	33.5	12.9	35.3	Bush encroached
OST11	Female	11.55	>10 kg	C					
OST11	Female	11.55	>10 kg	C					
OST11	Female	11.55	>10 kg	C					
OST11	Female	11.55	>10 kg	C					
OST09	Female	10.24	>10 kg		32	25	10	7.1	Bush encroached
OST09	Female	10.24	>10 kg		40	40	20.8	26.3	Bush encroached
OST09	Female	10.24	>10 kg		21	35	15.3	28.6	Bush encroached
OST09	Female	10.24	>10 kg		20	20	12.2	19.9	Bush encroached
OST09	Female	10.24	>10 kg		16	40	14.4	34.8	Bush encroached
OST09	Female	10.24	>10 kg		32	34	11.5	31.4	Bush encroached
OST09	Female	10.24	>10 kg		19	27	12.9	18.6	Bush encroached
OST09	Female	10.24	>10 kg		29	26	11.8	12.3	Bush encroached
OST09	Female	10.24	>10 kg		40	33	23.1	31.8	Bush encroached
OST09	Female	10.24	>10 kg	C					
OST09	Female	10.24	>10 kg	C					

OST09	Female	10.24	>10 kg	C					
OST09	Female	10.24	>10 kg	C					
OST13	Female	8.85	6-10 kg		25	20	14.8	23.6	Bush encroached
OST13	Female	8.85	6-10 kg		48	36	15.7	34.4	Bush encroached
OST13	Female	8.85	6-10 kg		44	39	15.3	25.5	Riverine
OST13	Female	8.85	6-10 kg		23	31	15.2	45.8	Bush encroached
OST13	Female	8.85	6-10 kg		25	44	15.8	36.3	Riverine
OST13	Female	8.85	6-10 kg		20	23	15.7	35.4	Bush encroached
OST13	Female	8.85	6-10 kg		19	20	14.5	30.7	Bush encroached
OST13	Female	8.85	6-10 kg	C					

Appendix 11: Statistical fit for selective models of burrow height and external temperature

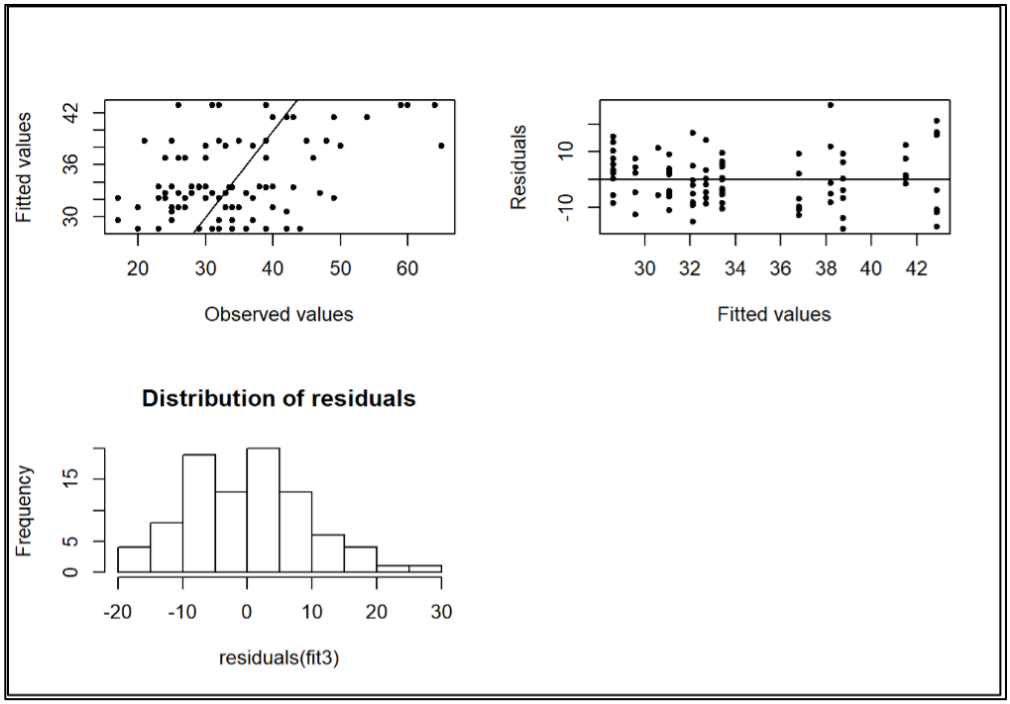

Figure 97: : Statistical fit for the standardized model for burrow height with sex and individual weight

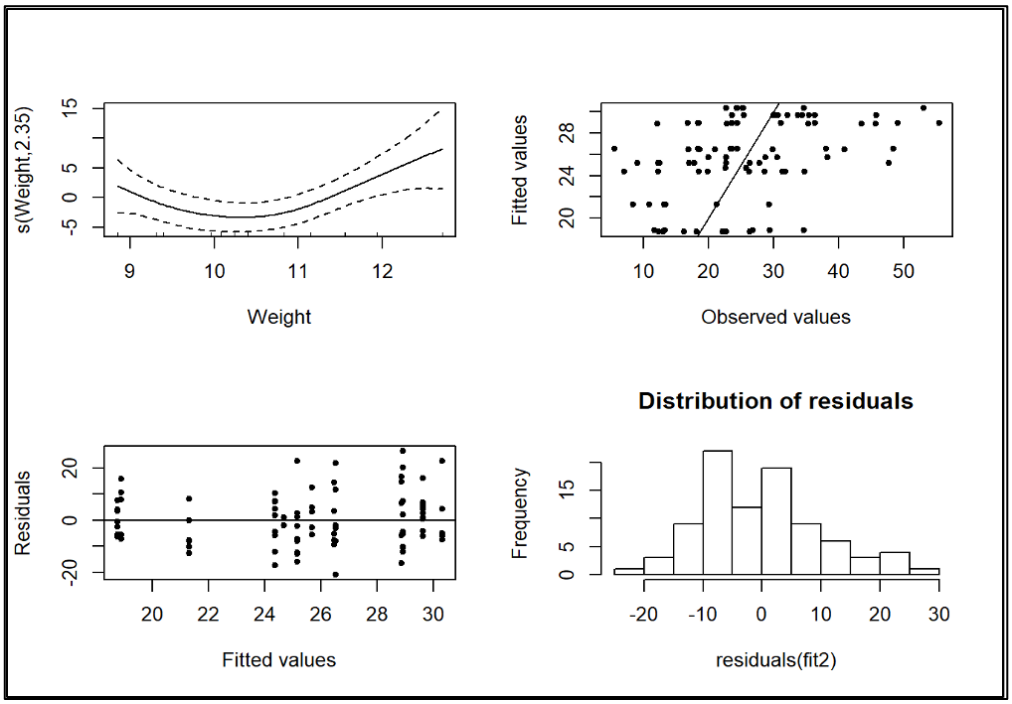

Figure 98: Statistical fit for the standardized model for burrow external temperature with sex and individual weight

Appendix 12: Details of burrow characteristics

Table 29: Number of burrows assessed per individual with the number of characteristics

Individual ID	Total burrows assessed	Total intact burrows	Total Under termite mound	Total under a Tree (over 1m)	Total under Shrub (under 1 m)	Total deeper than 1 m	Total shallower than 1 m	Total with multiple entrances	Total burrow complexes	Total Caves
OST02	12	5	2	3	1	3	2			
OST03	12	7	4	2	1	6	1			
OST04	11	5	1	3	1	4	1			
OST08	7	2	1	1	1		2			
OST09	13	9	6	4	3	8	1			
OST11	9	5	3	3	1	5				
OST12	13	7	6	3	1	6	1	1		
OST13	8	7	6	4	2	4	3			
OST18	11	9	6	4		5	4			
OST29	10	7	7	5	1	6	1			
OST31	11	5	5	1	1	4	1			
OST32	10	5	2	1		5				
OST35	10	7	2	3	2	5	2			2
OST36	7	3	1		1	3				
OST37	7	6	3	5	1	6			1	
Grand Total	151	89	55	42	17	70	19	1	1	2