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A study on the individual preferences in the prey selection of Temminck's Ground Pangolins (*Smutsia temminckii*) in the bushveld of Limpopo

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Due to a high demand for their scales and meat for use in traditional medicine, the fabrication of leather products, and the consumption as bushmeat, pangolins have become the most trafficked animals in the world. On the IUCN Red List, they are classified as threatened, and their population continues to decline because of poaching and habitat destruction.

In addition, attempts at in situ conservation of these animals are challenging as their mortality rates are high and captive breeding programmes are rarely successful, due to these animals' high susceptibility to stress-related disorders, insufficient knowledge about their husbandry requirements, and their specialised myrmecophagous diet, which is difficult to provide in captivity.

Pangolins feed exclusively on ants and termites, and studies about their foraging behaviour and feeding preferences are still limited.

To investigate whether there are individual preferences in the selection of their prey, the feeding behaviour of three Temminck's Ground Pangolins (*Smutsia temminckii*), living at the Umoya Khulula Wildlife Rehabilitation Centre in the Limpopo Province of South Africa, was observed. For this purpose, faecal samples were collected over the course of six weeks, dirt material was separated from the exoskeletons of digested ants and termites, and the proportions of the diet constituted by each of the 7 species of ants and 2 species of termites found in this region, were calculated.

This paper describes the methods developed to process the faecal samples to obtain the ant and termite exoskeletons and analyses whether differences can be found in the composition of the diet of the three pangolins that could hint at individual preferences in the selection of their food.

The results show that there seem to be no significant preferences in the prey selection of these three pangolins, although the distribution of ants and termites across the faecal samples differs. The temperature does not affect the dietary composition in this study.

The collected data, together with further studies, could be useful for improving husbandry practices of Temminck's Ground Pangolins and increasing the success rate of rehabilitation and release programmes.

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Chapter 1 – Introduction

The name pangolin is derived from the Malayan word "pengguling", which means "something that rolls up." They are mammals belonging to the order Pholidota, and eight pangolin species are currently recognised (Choo et al., 2016), of which four stem from Asia (*Manis pentadactyla*, *Manis crassicaudata*, *Manis javanica*, and *Manis culionensis*) and four from Africa (*Smutsia gigantea*, *Smutsia temminckii*, *Phataginus tetradactyla*, and *Phataginus tricuspis*). Pangolins are considered the most heavily trafficked mammals in the world, and all eight species are listed under Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (Heighton and Gaubert, 2021). This work focusses on *Smutsia temminckii* (Smuts, 1832), the Temminck's ground pangolin, hereafter simply referred to as pangolin.

1.1 Temminck's Ground Pangolin

Temminck's pangolin is a medium-sized species, weighing on average between 9 and 10 kg and reaching a body length of up to 140 cm, with males tending to be larger and heavier than females (Pietersen et al., 2020). The dorsal and lateral surfaces of the body, the limbs, the tail, and the forehead are protected by hard, plate-like keratin scales, whereas the rest of the head, the ventral surface of the body, and the inside of the limbs are covered by soft skin and sparse, short hairs (Pietersen, McKechnie, and Jansen, 2014; Pietersen et al., 2020). When feeling threatened, the pangolin has the ability to roll into a tight ball to protect its vulnerable belly and head from predators or other attackers with nearly impenetrable armour (Pietersen, McKechnie, and Jansen, 2014).

S. temminckii is the only bipedal species of pangolin and tends to walk on its hindlimbs while the forelimbs are held up against the chest and the tail is held off the ground to keep balance. This allows it to stand erect on the hind legs while sniffing the air to survey the surrounding area and makes it a competent climber (Pietersen et al., 2020; Pietersen, McKechnie, and Jansen, 2014).

Temminck's Ground Pangolin is the most widely distributed African pangolin species. It can be found in eastern and southern Africa, from South Sudan and southern Chad to the northern, western, and eastern provinces of South Africa (Northern Cape, North West Province, Limpopo, Mpumalanga, Kwazulu-Natal), although their exact range of distribution is difficult to determine, due to their elusive behaviour and low population densities (Pietersen et al., 2021). The species inhabits savannah and dryland habitats, including mopane vegetation, Combretum, mixed marula, Miombo woodland, Vachellia and Senegalia thornveld grassland, and Baikiaea woodland, gallery forest, and duneveld grassland (Sabashau et al., 2024; Pietersen et al., 2020). It is absent, however, from closed-canopy forests and true deserts, as well as from regions with altitudes over 1700 m above sea level (Pietersen et al., 2020).

According to Pietersen et al. (2020), the home ranges of pangolins can vary with both age and locality. In some areas, such as the Kalahari region in South Africa, a male's home range overlaps with that of a single female, which would suggest a monogamous mating system, and male and female home ranges are of similar sizes, whereas in Zimbabwe males tend to have larger home ranges that overlap with those of multiple females, suggesting a polygynous mating system (Pieterse et al., 2020). Within these home ranges, *S. temminckii* tends to spend several consecutive days in a particular burrow before moving on to another one. Burrows are seldom dug by the pangolins themselves and instead are often deserted homes of other animals, such as aardvarks (*Orycteropus afer*), springhares (*Pedetes capensis*), Cape porcupines (*Hystrix africaeaustralis*), or warthogs (*Phacochoerus* spp.) (Pietersen et al., 2020). These shelters are extremely important to pangolins as they are poor temperature regulators (Chao, Li, and Lin, 2020), and the availability of suitable refuges may greatly affect the distribution of pangolins in a specific region (Pietersen et al., 2020).

Pangolins are predominantly nocturnal mammals (Pietersen et al., 2021), and they are solitary, except during the mating season, which lasts from May to July (Hua et al., 2015). They have an exceptionally well-developed olfactory system, and their social interactions are based on scent (Chao, Li, and Lin, 2020).

Due to their nocturnal behaviour and secretive nature, it is nearly impossible to accurately estimate the total population size of Temminck's ground pangolins, but it is believed to be decreasing (Pietersen, McKechnie, and Jansen, 2014). Although the species is widely distributed across the African continent, it is listed as vulnerable on the IUCN Red List of Threatened Species, and the population is predicted to further decrease by 30-40% over the next three generations due to a variety of conservation threats, including habitat degradation, mining, poaching, trafficking, exploitation for traditional medicines, talismans, and, as a source of protein, accidental electrocution on electrified fences and road mortalities (Pietersen, McKechnie, and Jansen, 2014; Pietersen et al., 2021; Sabashau et al., 2024).

1.2 Major threats to pangolins

Pangolins have several natural predators, which include African lions (*Panthera leo*), leopards (*Panthera pardus*), spotted hyaenas (*Crocuta crocuta*), and honey badgers (*Mellivora capensis*) (Pietersen et al., 2020), yet the conservation threats reducing the population size are predominantly of anthropogenic nature (Sabashau et al., 2024; Pietersen, McKechnie, and Jansen, 2014).

Pangolins have been labelled as “the most heavily trafficked wild mammals on earth,” and according to recent estimates, around 895,000 pangolins were trafficked globally between August 2000 and July 2019, although the actual numbers are likely to be even higher (Heighton and Gaubert, 2021). The main reason for this is the use of their scales, as well as foetuses, blood, bones, and claws in Asian and African traditional medicine, as they are believed to have healing properties (Heinrich et al., 2016; Pietersen et al., 2020), as well as the use for cultural rituals, talismans, traditional dresses, and ornamentations (Pietersen, McKechnie, and Jansen, 2014; Pietersen et al., 2020). Furthermore, pangolin meat is considered a delicacy in some countries, as well as a symbol of status (Heinrich et al., 2016; Hua et al., 2015), while they are also consumed as a local source of protein in their native home countries (Heinrich et al., 2016). The high economic value of pangolins has led to a rapid exhaustion of wild populations due to poaching and illegal trade (Hua et al., 2015), and the export of African pangolins to Asian markets is still increasing due to the decline in Asian pangolin populations, which are now unable to meet the high demand, especially in China and Vietnam (Pietersen, McKechnie, and Jansen, 2014; Heinrich et al., 2016). Most countries in southern Africa have national legislation protecting pangolins, but enforcement is often lacking (Pietersen, McKechnie, and Jansen, 2014).

Besides overexploitation, accidental electrocution on electric fences poses the second main threat to Temminck’s ground pangolins (Pietersen et al., 2020; Stracquadanio et al., 2024). Fencing is frequently used for wildlife management and to protect private land, livestock farms, and game reserves (Stracquadanio et al., 2024), and electrocutions are particularly prevalent in South Africa and Namibia (Pietersen et al., 2020). Since *S. temminckii* walks on its hind legs, its unprotected belly is exposed to low-level electric wires, and upon receiving an electric shock, the pangolin curls into a ball, often wrapping itself around the electric wire (Pietersen et al., 2020). The individual may die either due to continuous electrical pulses, which can cause epidermal burns and internal injuries, or succumb to exposure and/or starvation after remaining trapped on the fence (Pietersen, McKechnie, and Jansen, 2014; Pietersen et al., 2020). Pietersen, McKechnie, and Jansen (2014) suggest that mortality rates may be as high as 0.09 individuals/km/yr, although it is difficult to determine exact numbers as there are no regular fence controls in many of the large conservation areas and there is a possibility of scavengers removing carcasses from fences before they are discovered by monitoring teams. In a different study, Pietersen et al. (2016A) state that an estimated 377-1,028 pangolins are killed by electric fences per year, which equals 2-13% of the population, not taking into account electrified livestock fences.

Another threat to pangolins, particularly in regions where farming with small livestock is common, is gin traps in which the pangolins are accidentally caught (Pietersen et al., 2016A; Pietersen, McKechnie, and Jansen, 2014). When the animal steps on a central pressure plate, two spring-loaded metal jaws snap together and trap the animal (Pietersen, McKechnie, and Jansen, 2014). These traps are normally used to reduce damage caused by predators (Pietersen, McKechnie, and Jansen, 2014), and if the accidentally caught pangolin is found in time, it can usually be released unharmed. However, the gin traps tend to be checked rather infrequently, and the trapped animal may die of exposure or succumb to its injuries (Pietersen et al., 2016A).

Other possible threats to Temminck's ground pangolin include death due to traffic collisions on roads and railways (Pietersen et al., 2020; Pietersen, McKechnie, and Jansen, 2014), habitat loss because of land transformation for subsistence and crop agriculture (Pietersen et al., 2020), poisoning by agriculture pesticides (Pietersen, McKechnie, and Jansen, 2014; Swart, 1996), and pet trade (Pietersen et al., 2016A). Pangolins are particularly vulnerable to threats like habitat destruction, poaching, and overexploitation because females usually only bear a single offspring per year (Heinrich et al., 2016).

1.3 Challenges of husbandry practices of pangolins in captivity

Pangolins are widely regarded as understudied, and there are still many gaps in the research about pangolin biology and ecology, trade networks, genetics, husbandry, and veterinary health, as well as the impacts of climate change on the species (Heighton and Gaubert, 2021), which makes it difficult to determine a proper husbandry regime.

Prior to the 1970s, pangolins were quite commonly found in zoos, but nowadays they are rarely exhibited anymore as they are difficult to maintain for long periods, especially due to dietary problems (Yang et al., 2007). Pangolins feed exclusively on ants and termites (Swart, 1996), which can be nearly impossible to provide in sufficient quantities in a captive setting (Yang et al., 2007), and it is difficult to replace the natural diet with artificial food (Hua et al., 2015).

Since pangolins have a slow metabolism and little hair to keep them warm, it is important to maintain a suitable temperature in the enclosure (Hua et al., 2015), which is approximately 15 to 18°C (Yang et al., 2007). If the temperatures drop below this range, the animal may start to shiver, and if it catches a cold, it will be susceptible to pneumonia, which may result in its death (Hua et al., 2015).

Another major cause of captive pangolin mortality is stress. They are mostly nocturnal and generally shy animals, preferring to spend the majority of the time in concealment, except when they come out to forage. It is therefore possible that pangolins in captivity are continuously under great stress, which may lead to the development of gastric ulcers and death (Hua et al., 2015). Choo et al., (2022) suggest that pangolins are particularly susceptible to stress-induced immunosuppression due to a reduced number of heat shock protein (HSP) gene family members. The poor adaptability to a captive environment combined with a weak immune system causes pangolins to easily become sick, and the most common causes of death include gastrointestinal disease, pneumonia, skin disease, and parasites. Most pangolins die within only six months in captivity (Hua et al., 2015). This is not only a problem in zoos but also reduces the success rate of reintroductions of confiscated pangolins from rescue centres into the wild. In general, the number of centres able to provide adequate care for these animals is insufficient, and many veterinarians may also not be sufficiently trained to treat them (Choo et al., 2022). Considering the rapid decline in wild pangolin populations, captive breeding is starting to play an important part in both *in-situ* and *ex-situ* conservation of the species. However, due to the difficulties in maintaining these animals in captivity and their specialised behaviours, as well as a lack of research regarding pangolins' reproductive traits, the success of captive breeding programs is limited, and further studies are needed to improve the application of artificial reproductive technology (Hua et al., 2015).

1.4 Feeding ecology of pangolins

Smutsia temminckii are obligate myrmecophages, which means that they feed exclusively on ants and termites (Swart, 1996), and they are important predators of these invertebrates, as a single pangolin can consume millions of ants and termites per year (Pietersen et al., 2016A). Pangolins have a variety of morphological adaptations that allow them to detect and gain access to concealed galleries and nests of ants and termites (Swart, Richardson, and Ferguson, 1999). They possess acute olfactory senses, enabling them to locate prey even beneath the soil surface (Pietersen et al., 2020). Furthermore, they have muscular forelimbs and strong claws, which they can use to tear open ant nests or dead trees or remove cartilaginous material from termite mounds (Pietersen et al., 2020), but they do not usually dig deep into the ground and instead feed on ants and termites close to the soil surface (Swart, Richardson, and Ferguson, 1999). Pangolins also have a long vermiform tongue (Swart, 1996), which they can insert deep into nest chambers to capture ants hidden there (Pietersen et al., 2020). They produce large amounts of sticky saliva, further aiding the entrapment of their prey, and the muscular pyloric region of their stomach helps them digest their specialised diet (Swart, 1996).

When foraging, pangolins seem to locate their prey by following a haphazard zigzag path (Swart, 1996), while holding their nose close to the ground and continuously sniffing to locate their prey (Pietersen et al., 2020). Temminck's pangolins are mainly nocturnal, although some research suggests that juveniles and sub-adults are diurnal or crepuscular foragers to avoid nocturnal predators. The distances covered in search of prey can vary depending on habitat and prey availability, and an adult pangolin may cover up to 3791 m per night (Pietersen et al., 2020). According to Swart, Richardson, and Ferguson (1999), most of the pangolin's active time is spent foraging for ants and termites, but only 15.7% of this time is spent actually feeding, and individual feeding bouts on average only last 40 seconds. Active time is also correlated with feeding intensity, and when the feeding intensity is higher, the duration of activity is shorter (Swart, 1996). The reason for the shortness of the feeding bouts may be to prevent the annihilation of an ant or termite colony so that the same nest can be revisited at a later time (Pietersen et al., 2020).

Swart (1996) recorded ants and termites from 25 different genera and a total of 55 species in the Sabi Sand Wildtuin in South Africa, of which Formicidae were represented by 20 genera and 50 species, while five genera and 5 species of termites were caught in pitfalls. Of these, the most common species obtained was *Pheidole* sp., which accounted for 27% of the total pitfall catches (Swart, Richardson, and Ferguson, 1999). Despite this abundance of different ant and termite species, only 15 of them were preyed on by pangolins (Swart, Richardson, and Ferguson, 1999), while another study states that in Sudan, Temminck's pangolins feed on only two out of 22 available ant species (Chao, Li, and Lin, 2020). In total, there seem to be 30 ant and 10 termite species that are preyed upon by *S. temminckii*, while other species are ignored (Pietersen et al., 2020). This selectivity for certain prey species may at least be partially due to a preference for larger species (>0.5 cm) (Swart, Richardson, and Ferguson, 1999). This is supported by the fact that in the Sabi Sand Wildtuin, six species of ants >5 mm in length made up 97% of the entire diet, including *Anoplolepsis custodies*, *Myrmicaria natalensis*, *Camponotus cinctellus*, *Polyrhachis schistacaea*, *Hodotermes mossambicus*, and *Camponotus* sp. -*maculatus*- group (Swart, Richardson, and Ferguson, 1999; Pietersen et al., 2020). Another factor influencing the selectivity may be the closeness of nest galleries to the soil surface, which makes them more easily accessible to the pangolins (Swart, Richardson, and Ferguson, 1999). Overall, according to Swart (1996), Swart, Richardson, and Ferguson (1999), and Pietersen et al. (2020), *A. custodiens* appears to be the most important prey species of Temminck's pangolin in southern Africa, accounting for 77% of the total diet even though it only formed 5% of the ants that were trapped in the Sabi Sand Wildtuin. It is necessary to distinguish between prey abundance and prey availability, as the most abundant species may be difficult to access if they live deep below the soil surface or if the nests are constructed with a hard outer crust that pangolins are not able to penetrate. Nonetheless, ant abundance is one of the two main factors determining the number of feeding bouts on an individual ant species, with the other one being ant size (Swart, Richardson, and Ferguson, 1999).

Another factor to take into consideration is prey defence. When a pangolin starts feeding on an ant or termite colony, there will be defence mechanisms that cause a decrease in the prey value. This leads to limited predation and results in feeding bouts of shorter duration. Such defence mechanisms may, for example, include swarming and biting, as well as spraying formic acid (Swart, Richardson, and Ferguson, 1999).

Ant communities are seasonally dynamic, and above-ground activity is higher during the summer than during the winter, as well as higher during the day than at night, which can affect their availability and abundance as prey (Chao, Li, and Lin, 2020; Swart, Richardson, and Ferguson, 1999). Swart, Richardson, and Ferguson (1999), for example, report that the above-ground abundance of *Anoplolepis custodiens* is low during the winter and then gradually increases in early summer, reaching its peak in February, followed by a steep decrease at the end of summer. This phenomenon is correlated to the daily minimum temperatures and may also be linked to rainfall. A low above-ground level of activity suggests higher densities of ants in the underground galleries, where they are more easily accessible to pangolins. Other factors influencing the composition of ant communities include humidity, light, food availability, and predation (Chao, Li, and Lin, 2020), as well as the local vegetation, as plants can act as important food sources and nesting sites (Swart, 1996). Swart (1996) found grassland savanna clearings to have a particularly high overall ant species diversity and describes them as the "ideal habitat type for ants."

The distribution and abundance of ants and termites, especially *A. custodiens*, probably affect the distribution of Temminck's pangolin in southern Africa (Swart, Richardson, and Ferguson, 1999). Vice versa, by preying on ants and termites, pangolins likely also influence local ant and termite abundance and community structure. Most ant species feed on small arthropods, plant tissue, or the detritus of animal bodies and act as decomposers in the ecosystem. Termites, on the other hand, are specialised in scavenging dead plant tissue and forage from a variety of food sources, including wood, leaf litter, humus, algae, and fungi, and they are even able to digest cellulose and hemicellulose. This causes them to play a crucial part in energy and material recycling in ecosystems. Besides this, ants and termites are also known to be able to become pests and can cause substantial crop damage. Pangolins therefore have the potential to control ant and termite populations and to regulate local ecosystem function (Chao, Li, and Lin, 2020).

1.5 Project aims

Due to the limited number of studies available on Temminck's ground pangolins, the rapid decline in population size due to the various threats faced by this species, and the many difficulties limiting the success of attempts at keeping and breeding them in captivity, it becomes exceedingly important to perform further research aimed at improving rehabilitation and conservation measures and saving these unique animals from extinction. The objective of this project is to better understand pangolin prey selectivity and determine whether there are individual preferences in prey selection besides the selectivity for certain species of ants and termites by *Smutsia temminckii* in general. The results could be useful in modifying the composition and mode in which diet is presented to pangolins in captivity to increase the success of dietary husbandry.

To achieve this, the faecal samples of three pangolins living at the Umoya Khulula Wildlife Rehabilitation Centre in the Limpopo Province in South Africa were examined over the course of six weeks. Dirt material was separated from the exoskeleton of digested ants and termites, the different species of prey were determined, and the individuals belonging to each species were counted. Finally, the proportions of the diet composed by each of the species were calculated. This report will describe the materials and methods used during sample collection, sample processing, and statistical analysis and lay out the results that were obtained, including the different ant and termite species found and variations in the diet of the three pangolins. Finally, the results will be analysed, the project evaluated, and the limitations of the study examined.

1.6 Research question

The research question guiding this project is: Are there any individual preferences in the prey selection of Temminck's Ground Pangolins (*Smutsia temminckii*) in the bushveld of Limpopo?

Chapter 2 – Materials and Methods

This project was constructed in close collaboration with and overseen by Emma De Jager, who is a co-owner and the rehabilitation manager of the Umoya Khulula Wildlife Rehabilitation Centre. She has been working in wildlife rehabilitation for over 15 years and is a member of the IUCN SSC Pangolin Specialist Group, which is a network of experts from around the world, including field biologists, social scientists, zoologists, veterinarians, ecologists, and geneticists, who are all actively involved in pangolin research and conservation.

2.1 Sample Collection

The study was carried out at the Umoya Khulula Wildlife Rehabilitation Centre (UKWRC), located near the town of Tzaneen in the Limpopo Province of South Africa.

To determine which species of ants they have eaten, the faecal samples of three different pangolins were collected over a range of 6 weeks, from April 7th to May 18th 2024. The pangolins' names are Orion, Sweet Pea, and Tamu, and they had all been confiscated from the illegal wildlife trade. Their admittance dates, admittance weight and sex, as well as the specific collection dates of the samples used in the study, are listed in Table 1.1. At UKWRC, pangolins are housed in individual rooms, which are temperature-regulated and each contain a large wooden box with blankets to sleep in and a bowl of water. To guarantee the safety of these threatened animals from poachers, each room has two doors that are both locked whenever the pangolin is inside, and during the night there is an additional alarm that is set off when someone tries to enter the building. The staff at UKWRC have found that none of the Temminck's pangolins they have cared for over the years have fed out of a bowl. To ensure that they still have a sufficient dietary intake, the pangolins are taken on walks by designated staff members once or twice a day. This gives the animals the possibility to express their natural foraging behaviour and search for ant and termite nests themselves, and it has proven to be a successful method for feeding the pangolins at UKWRC. Young individuals who are not as experienced in foraging yet or underweight pangolins may occasionally be tube-fed in addition, to guarantee that they still receive all the required nutrients. The walks are usually carried out in the morning and late afternoon or evening when it is neither too hot nor too cold for the pangolins, and each walk lasts several hours. The exact duration of each walk depends on the individual pangolin, its feeding motivation, and its efficiency. If the pangolin struggles to find nests of ants and termites, the walk is likely to last for a longer period of time to ensure that the animal can still eat enough. Before and after each walk, the pangolins are weighed to keep track of their food intake and to be able to observe long-term weight gains or losses.

The region of South Africa in which UKWRC is situated is characterised by the Southern African bushveld, a subtropical grassland ecoregion (Rutherford, Mucina, and Powrie, 2006), and the centre itself is located on farmland, consisting of open fields, mango groves, and forests. Ant and termite nests are abundant throughout the entire property, and the species of ants and termites that can be found are listed in Table 1.2.

The faecal samples of the three pangolins were collected either during the walks or from their rooms, where the pangolins spend the rest of their time, primarily to sleep. For the collection, volunteers working at UKWRC who were responsible for cleaning the pangolin rooms each day would clean up the faeces using dustpans and brushes and then put each sample into a separate zip-lock bag. The bags were then labelled with the name of the pangolin corresponding to the faecal sample and the date of collection and then stored in a freezer to preserve the samples for later processing.

Finally, the temperature on the days before each sample collection was recorded (Table 1.3), which corresponds to the temperature on the day the insects in each sample were ingested. The purpose of this was to allow testing for any significant effects of temperature on the dietary composition of the three pangolins.

Animal ID	Admittance Date	Sex	Admittance Weight (kg)	Collection Date	Weight before morning walk (kg)	Weight after morning walk (kg)	Weight before evening walk (kg)	Weight after evening walk (kg)
Orion	12.04.2024	M	8.54	14.04.2024	8.36	8.54		
Orion	12.04.2024	M	8.54	19.04.2024	7.96	8.14		
Orion	12.04.2024	M	8.54	24.04.2024	7.78	7.94		
Sweet Pea	13.10.2023	F	2.74	08.04.2024	4.08	4.10	3.98	4.10
Sweet Pea	13.10.2023	F	2.74	28.04.2024				
Sweet Pea	13.10.2023	F	2.74	17.05.2024	3.80	3.98		
Tamu	24.04.2024	M	6.60	27.04.2024	6.68	6.72		
Tamu	24.04.2024	M	6.60	03.05.2024	6.42	6.76		
Tamu	24.04.2024	M	6.60	11.05.2024	6.46	6.24	6.16	6.36

Table 1.1: Names of the pangolins, the date each one of them was admitted to UKWRC, their sex, their weight at the time of admittance, the dates of the sample collections and the pangolin weights before and after each of their walks

Species	English name	Family	Subfamily
Anoplolepis custodiens (Smith, F., 1858)	Common Pugnacious Ant	Formicidae	Formicinae
Myrmicaria natalensis (Smith, F., 1858)	Natal Droptail Ant	Formicidae	Myrmicinae
Polyrhachis spinicola (Forel, 1894)	Common Spiny Sugar Ant	Formicidae	Formicinae
Camponotus niveosetosus (Mayr, 1862)	Hairy Sugar Ant	Formicidae	Formicinae
Camponotus cuneiscapus (Forel, 1910)	Orange Sugar Ant	Formicidae	Formicinae
Lepisiota capensis (Mayr, 1862)	Common Small Black Ant	Formicidae	Formicinae
Crematogaster peringueyi (Emery, 1895)	Black Cocktail Ant	Formicidae	Myrmicinae
Macrotermes natalensis (Haviland, 1898)	Natal fungus-growing termite	Termitidae	
Hodotermes mossambicus (Hagen, 1853)	Harvester termite	Hodotermitidae	

Table 1.2: Species of ants and termites found on the property of the Umoya Khulula Wildlife Rehabilitation Centre

Collection Date	Average Temperature on the day before (in °C)
08.04.2024	19.55
14.04.2024	15.72
19.04.2024	18.67
24.04.2024	22.89
27.04.2024	20.72
28.04.2024	18.28
03.05.2024	20.67
11.05.2024	18.89
17.05.2024	16.55

Table 1.3: Dates of collection of the samples used in the study and the average temperature on the days before the collection

2.2 Sample Processing

To begin with the processing, the faecal samples were removed from the freezer and thawed in a bucket. Once the samples were completely unfrozen, they were weighed on kitchen scales and then emptied from the zip-lock bags into a fine sieve over a plastic container.

Ant and termite exoskeletons contain a high percentage of chitin, which is resistant to digestion in most digestive systems. Therefore, the exoskeletons are not fully digested in the gastrointestinal tract of pangolins, and since the heads of ants and mandibles of termites are the most solid parts, they remain mostly intact in the faeces (Sun et al., 2020). As pangolins ingest some dirt material like sand, small stones, and plant pieces when they are feeding on ants and termites, the first processing step consisted of separating the ant heads and termite mandibles from the rest of the faeces. For this purpose, small amounts of water were added to the faecal sample to facilitate the passage of sand through the sieve and into the plastic container, and to further help this process, a spoon was used to carefully push dirt material through the holes of the sieve without damaging the exoskeletons. The exact amount of water added to each sample was measured in a measuring cup and recorded. Since the heads and mandibles were bigger than the holes of the sieve, they would remain inside the sieve.

Once all the water and smaller dirt particles had passed into the plastic container, small stones, pieces of plants, and any other substances remaining in the sieve were picked out with tweezers to separate them from the ant heads and termite mandibles and added into the plastic container with the dirt material. The water and dirt material in the plastic container were then weighed, the weight of the plastic container and water were subtracted from the total amount, and the weight of the dirt material was recorded (Table 2.1). Afterwards, the water and dirt material were disposed of, and the remaining exoskeletons were transferred into a clean plastic container, weighed, and then moved into a clean zip-lock bag and frozen again to be counted later. The weight of the plastic container was again subtracted from the total weight, and the weight of the exoskeletons was recorded (Table 2.1) to be evaluated in a different project relating to the feeding efficiency of pangolins in which the proportions of ant and termite remains and ingested dirt material of the total feed intake are compared.

Three exoskeleton samples from three different dates within the six-week study period were chosen per pangolin and thawed again at a later date for the separation into the different ant and termite species. The contents of a single zip-lock bag were emptied into a clean plastic container, and the ant heads and termite mandibles were then sorted according to the descriptions found in Table 2.2 into separate containers with the use of tweezers. Finally, the heads and mandibles in each container were counted, and the obtained numbers were written down.

Pangolin	**Collection Date**	**Faecal Sample Weight (in g)**	**Dirt Material Weight (in g)**	**Exoskeleton Weight (in g)**	**Error**
Orion	14.04.2024	93	62	22	9
Orion	19.04.2024	15	3	6	6
Orion	24.04.2024	89	62	12	15
Sweet Pea	08.04.2024	13	0	8	5
Sweet Pea	28.04.2024	52	26	9	17
Sweet Pea	17.05.2024	120	88	22	10
Tamu	27.04.2024	51	26	9	16
Tamu	03.05.2024	100	72	16	12
Tamu	11.05.2024	44	27	7	10

Table 2.1: Weights of the original faecal samples containing exoskeletons and dirt material, weight of dirt material and weight of exoskeletons of each sample as well as the amount of weight that was lost throughout the processing (error)

Ant and termite species	Description of heads and mandibles
Common Pugnacious Ant (*Anoplolepis custodiens*)	Medium size, red-brown to dark-brown
Natal Droptail Ant (*Myrmicaria natalensis*)	Large size, red-brown or dark red
Common Spiny Sugar Ant (*Polyrhachis spinicola*)	Black colour, medium size, shiny mandibles, scattered dots
Hairy Sugar Ant (*Camponotus niveosetosus*)	Small size, black or dark grey with stiff white bristles
Orange Sugar Ant (*Camponotus cuneiscapus*)	Medium size, yellow-orange colour, dark eyes
Common Small Black Ant (*Lepisiota capensis*)	Small, shiny black colour
Black Cocktail Ant (*Crematogaster peringueyi*)	Medium-size, jet black
Natal fungus-growing Termite (*Macrotermes natalensis*)	Large orange-red head and large black mandibles without serrated inner edges
Harvester termite (*Hodotermes mossambicus*)	Yellowish or dark-coloured head and dark mandibles with serrated inner edges

Table 2.2: Different ant and termite species found around UKWRC and description of their heads and mandibles according to which they were distinguished and sorted

2.3 Statistical Analysis

To see if any individual pangolin had a significant effect on the distribution of ant species found in the faecal samples, and therefore to check for any feeding preferences of the three pangolins, an ANOVA (Analysis of Variance) test was performed. At the same time, it was used to see if there are any differences in the overall ant-type presence among all the faecal samples. An ANOVA test can be used when mean measurements of more than two groups – in this case, three pangolins – need to be compared. The requirements for an ANOVA are a continuous measurement variable, normally distributed data within each group, independent samples, and homogenous variances. To make the distribution of the data more normal, the number of observations (N) was converted to the logarithm of the number of distributions (log(N)). As the effect of temperature on the feeding preference of the pangolins was also of interest, temperature was used as a covariate. At the base of each of the tests are two hypotheses, a null hypothesis (H_0) and an alternative hypothesis (H_A).

1. $H_{0(1)}$ (null hypothesis): The means of the values for all pangolins are equal (no preference)
   $H_{A(1)}$ (alternative hypothesis): The means of the values for all pangolins are not equal (i.e., at least two differ) (there is a preference)
2. $H_{0(2)}$ (null hypothesis): The distribution of ant types is equal for all faecal samples
   $H_{A(2)}$ (alternative hypothesis): The distribution of ant types is not equal for all faecal samples

To investigate the accuracy of the results of the ANOVA, a non-parametric alternative was used, the Kruskal-Wallis test. This test can be used to check for differences between several independent groups without a normal distribution and looks for differences between rank sums. All results are sorted according to size and ranked with the smallest number obtaining rank 1. The rank numbers from each group (in this case each pangolin) are then added together, and the added numbers result in a rank sum for each group. The rank sums are divided by the number of observations in each group to obtain the median rank sums, and then the variance of ranks is calculated. The final test variable H equals χ^2.

Two different Kruskal-Wallis tests were performed, one to test if "preference" for the different ant types is significantly different among the three pangolins (nine separate tests for each ant and termite species) and the second to test if the differences among the different ant types in faecal samples are significantly different.

3. $H_{0(3)}$ (null hypothesis): The samples of a specific ant/termite type have the same rank sum for each pangolin
   $H_{A(3)}$ (alternative hypothesis): The samples of a specific ant/termite type have different rank sums for at least two of the pangolins
4. $H_{0(4)}$ (null hypothesis): The rank sums of the different ant and termite species are the same across all faecal samples
   $H_{A(4)}$ (alternative hypothesis): The rank sums of the different ant and termite species differ across the faecal samples

Chapter 3 – Results

The numbers of specimens of each ant and termite species found in the faecal samples of the three pangolins are listed in Table 3.1, and the total numbers of each ant and termite species per pangolin are in Tables 3.2, 3.3, and 3.4. No hairy sugar ants (*Camponotus niveosetosus*) or harvester termites (*Hodotermes mossambicus*) were found in any of the samples.

Pangolin	Pugnacious Ant	Natal Droptail Ant	Spiny Sugar Ant	Hairy Sugar Ant	Orange Sugar Ant	Small Black Ant	Black Cocktail Ant	Macrotermes natalensis	Harvester Termite
Orion	29	58	49	0	0	196	157	0	0
Orion	54	2	24	0	1	2	145	0	0
Orion	86	6	15	0	59	183	28	4	0
Sweet Pea	205	32	28	0	25	0	56	1	0
Sweet Pea	854	61	68	0	98	0	48	2	0
Sweet Pea	163	11	76	0	115	104	22	21	0
Tamu	105	37	63	0	53	33	21	9	0
Tamu	309	5	60	0	133	264	32	22	0
Tamu	734	0	15	0	29	198	56	0	0

Table 3.1: Numbers of ants and termites found in each faecal sample

Pugnacious Ant	1222
Natal Droptail Ant	104
Spiny Sugar Ant	172
Hairy Sugar Ant	0
Orange Sugar Ant	238
Small Black Ant	104
Black Cocktail Ant	126
Macrotermes natalensis	24
Harvester Termite	0

Table 3.2: Total number of each ant and termite species found in the faecal samples of the pangolin Sweet Pea

Pugnacious Ant	169
Natal Droptail Ant	66
Spiny Sugar Ant	88
Hairy Sugar Ant	0
Orange Sugar Ant	60
Small Black Ant	381
Black Cocktail Ant	330
Macrotermes natalensis	4
Harvester Termite	0

Table 3.3: Total number of each ant and termite species found in the faecal samples of the pangolin Orion

Pugnacious Ant	1148
Natal Droptail Ant	42
Spiny Sugar Ant	138
Hairy Sugar Ant	0
Orange Sugar Ant	215
Small Black Ant	495
Black Cocktail Ant	109
Macrotermes natalensis	31
Harvester Termite	0

Table 3.4: Total number of each ant and termite species found in the faecal samples of the pangolin Tamu

The ANOVA test results (Table 3.5) indicate that there are no significant differences in preference among the pangolins ($p > 0.05$). Furthermore, the environmental temperature does not have a significant effect on the distribution of ant species across faecal samples. There are, however, differences in ant-type presence in the faecal samples ($p < 0.05$).

The first null hypothesis ($H_{0(1)}$) can therefore be accepted: the means of the values for all pangolins are equal, and there are no preferences in ant type. The second null hypothesis ($H_{0(2)}$), however, has to be rejected, and the alternative hypothesis ($H_{A(2)}$), that the distribution of ant types is not equal for all faecal samples, has to be accepted.

	Number of observations (N)		**Log(N)**	
Factors	F	p-value	F	p-value
Model	2.793	0.001	2.315	0.014
Intercept	1.205	0.277	6.359	0.017
Pangolin	1.166	0.319	2.323	0.113
Ant type	6.323	0.000	4.845	0.001
Animal*Ant type	1.396	0.180	0.733	0.710
Temperature (covariate)	0.305	0.583	0.296	0.590

Table 3.5: ANOVA test results

The first Kruskal Wallis test showed that there was no significant preference for any of the nine species of ants and termites among the three pangolins ($p > 0.05$) (Table 3.6). The null hypothesis ($H_{0(3)}$) can therefore be accepted: the samples of all ant and termite types have the same rank sum for each pangolin.

	Droptail	Spiny Sugar	Hairy Sugar	Large Pugnacious	Orange Sugar	Small Black	Black Cocktail	Harvester Termites	Macrotermes natalensis
H of Kruskal-Wallis	1.867	2.980	0.000	5.422	2.400	3.854	1.770	0.000	1.747
df	2	2	2	2	2	2	2	2	2
p-level	0.393	0.225	1.000	0.066	0.301	0.146	0.413	1.000	0.417

Table 3.6: Results of the Kruskal-Wallis test to see if the “preference” for the different ant types is significantly different among the three pangolins

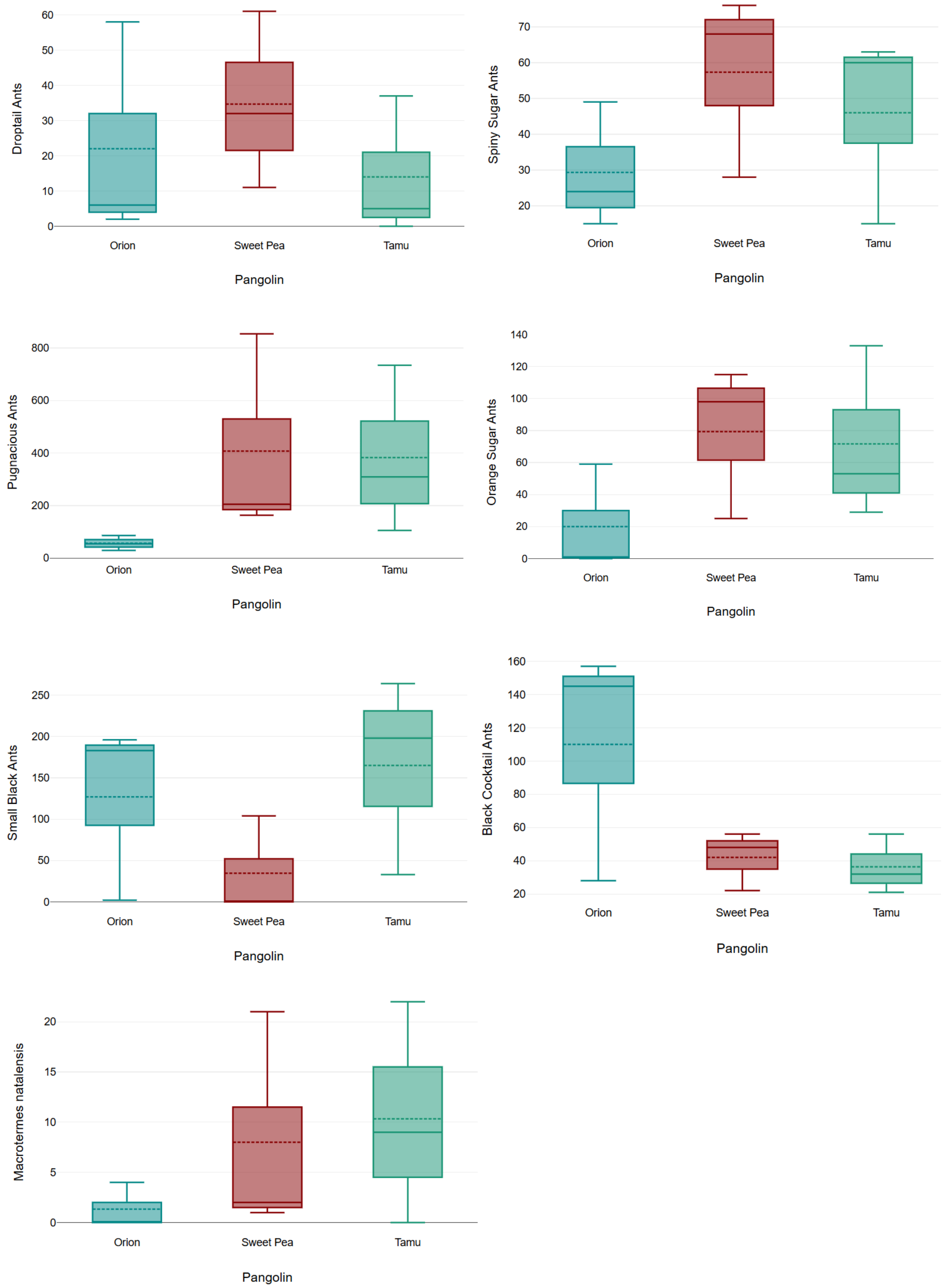


Figure 3.1: Distribution of the different ant and termite species found in the faecal samples across the three pangolins

Finally, the second Kruskal-Wallis test results (Table 3.7) show that the differences among the different ant types in the faecal samples overall are significant ($p < 0.05$). Here, the null hypothesis ($H_{0(4)}$) is rejected and the alternative hypothesis ($H_{A(4)}$) is accepted: the rank sums of the different ant and termite species differ across the faecal samples. The superscripts in Figure 3.2 also indicate that there are significant differences between the distributions of the different ant and termite species found in the samples, as there are different letters (a, b, and c).

This confirms the results that were obtained from the ANOVA test.

H of Kruskal-Wallis	51.211
df	8
P-level	0.000

Table 3.7: Results of the Kruskal-Wallis test to see if the differences among the different ant types in faecal samples are significantly different (p<0.05).

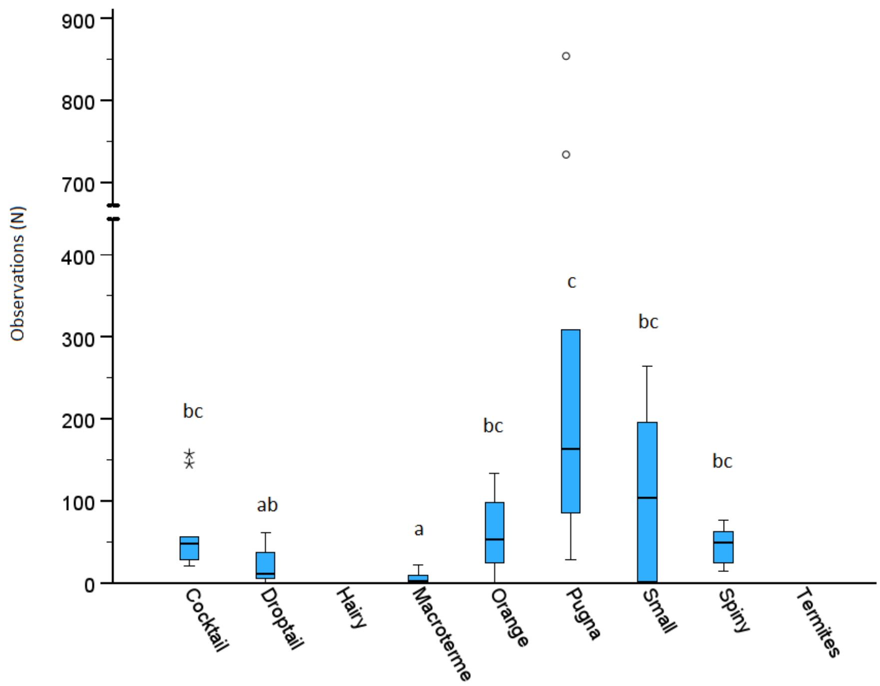


Figure 3.2: Number of ant and termite types observed in faecal samples of the three pangolins. The superscripts indicate that the distributions are significantly different (p<0.05).

Chapter 4 - Discussion

4.1 Analysis of Results

Even though the three pangolins in the study were of different ages, sexes and origins and had spent different amounts of time in captivity, there were no significant preferences in the selection of their prey. The distribution of ant and termite species across the faecal samples overall, however, differed significantly, and ants made up a greater proportion than termites of the diet of all three pangolins. Hairy sugar ants (*Camponotus niveosetosus*) and harvester termites (*Hodotermes mossambicus*) were not found in any of the samples. Furthermore, no significant effect of temperature on the diet was found, even though other studies reported that temperature affects ant activity and the mean monthly prey abundance of pangolins (Swart, Richardson, and Ferguson, 1999; Panaino et al., 2022).

It is unclear what caused the differences in ant and termite distributions across the samples in this study, but it is likely that environmental parameters other than the temperature, which were not investigated in this study, were contributing factors. Swart, Richardson, and Ferguson (1999), for example, speculate that rainfall can affect the above-ground presence of certain ant species, and Panaino et al. (2022) state that climate impacts the abundance of pangolin prey resources through the effects of rainfall on the grass cover in the southern Kalahari region of South Africa.

It is also possible that there are seasonal shifts in the diet of pangolins, although this is still not entirely clear and may depend on the habitat (Panaino et al., 2022). In general, there seems to be a higher activity of ants and termites in spring and summer than there is in autumn and winter (Swart, Richardson, and Ferguson, 1999), which causes a decreased prey abundance in autumn and winter. Pietersen et al. (2016B) also found seasonal variations in ant abundance, but this did not lead to significant seasonal variations in the diet of pangolins in the Kalahari. Panaino et al. (2022), on the other hand, reported a seasonal dietary shift in their study, which can be observed, for example, through an increase in the intake of termites in winter. In addition, they predicted that pangolins might expand their dietary niche or shift their dietary preferences in response to food scarcity, such as during the winter months, but found that pangolins do not exploit a wider variety of prey items even when prey is scarce, they merely increase the intake of ant and termite species, which are more available during this time. As this study was conducted from April to June, a period of transition between summer and winter, the season may also have affected the distribution of ants and termites in the samples.

Even though no harvester termites were found in any of the samples of the three pangolins at UKWRC, they have been reported in the diet of pangolins in other studies. Swart, Richardson, and Ferguson (1999) observed *H. mossambicus* to be the most common termite prey of pangolins in the Sabi Sand Wildtuin in Mpumalanga. A possible explanation would be a regional difference in the diet of *Smutsia* *temminckii*, but there could be other reasons as well. During the summer *H. mossambicus* are diurnal, but in winter they become predominantly nocturnal, which normally would make them more available as prey to pangolins during the winter (Swart, Richardson, and Ferguson, 1999). If their behaviour was already shifting towards a more nocturnal one during the study period, this may have reduced the chances of the pangolins at UKWRC to encounter individuals of this species, however, as the feeding walks always take place during the day. Furthermore, *H. mossambicus* are only preyed on when they are abundant at nest entrances because their nests are about 1.5 m below the soil surface, where they are difficult to reach for pangolins (Swart, Richardson, and Ferguson, 1999). *Anoplolepis* sp. in comparison, one of the major food sources of *S. temminckii*, occupy nests that are shallower than 300 mm in depth (Panaino et al., 2022).

Hairy sugar ants have not been reported in the diet of pangolins in other studies either. It is possible that they are simply not preyed on by pangolins, as it has been stated several times before that these animals are selective in their diet, and even though an ant species may be present and even abundant in an area, it is not necessarily consumed as part of the diet as well (Swart, Richardson, and Ferguson, 1999; Pietersen et al., 2016B). Swart, Richardson, and Ferguson (1999) emphasise the importance of the difference between abundance and availability and explain that the availability of an ant species as prey for a pangolin can be significantly reduced through nest structures and prey defence mechanisms. As members of the subfamily Formicinae, hairy sugar ants are able to produce and spray formic acid from a poison gland or inject it into their bite, which may reduce their attractiveness as a potential prey (Swart, Richardson, and Ferguson, 1999). Pietersen et al. (2016B) also mention that many species of ants are probably not eaten because chemical and mechanical defences or gallery structures make them unsuitable as prey.

Several other factors may have had an effect on the distribution of ants and termites in the faecal samples. The error that occurred during the sample processing, evident through the loss of several grammes of weight from the original sample as compared to separated ant and termite exoskeletons and dirt material, may have changed the precise numbers of ants and termites found in each sample as it is unclear what caused the lost weight and it is possible that some exoskeletons were lost as well. Furthermore, Sun et al. (2020) have expressed concern that there may be a general underestimation of termites in faecal samples of pangolins. This is due to the fact that termites have rather thin and flexible cuticles, a reduced pronotum, and slender legs, whereas ant cuticles are strong and tough. The digestibility of termites differs from that of ants because of these contrasts concerning the physical structure of exoskeletons and the degrees of hardness and thickness. They found that ant head capsules are better preserved in faeces compared to termite mandibles, with termites having a recovery rate of 0.34 ± 0.10 and ants of 0.65 ± 0.04. This means that about two-thirds of termite mandibles are lost during the digestion process, while only one-third of ant head capsules are lost. Finally, in addition to the low recovery rate, the small size and microscopic morphology of termite mandibles make it even more difficult to detect them (Sun et al., 2020).

In general, it is possible that ant head capsules and termite mandibles were missed, lost, or damaged throughout the different stages of the project.

4.2 Evaluation of the Project

Overall, there were no new findings in this study, except that there seem to be no individual preferences in the prey selection of Temminck's pangolins, which had previously only been mentioned by Pietersen et al. (2016B), who stated that they did not see any age- or sex-related differences in diet. Further studies over a longer period of time and involving more individual pangolins with different backgrounds would be useful to confirm this.

Several results of the project coincide with statements from previous studies. Pietersen et al. (2016B), Panaino et al. (2022), and Sun et al. (2020) also found that ants are more frequently consumed by pangolins than termites. *Anoplolepis custodiens* is often mentioned as the most important prey species of *Smutsia temminckii* (Swart, Richardson, and Ferguson, 1999; Pietersen et al., 2020; Swart, 1996), and also in this study, it was the species that was most often found in the samples. These studies also agreed that the precise composition of the diet varies. *Camponotus niveosetosus* was not found in the diet of pangolins in other studies either, but this might also be due to different study locations where these ants may not occur.

On the other hand, there were also some contradictions between the findings of this study and others. Swart, Richardson, and Ferguson (1999), Pietersen et al. (2016B), and Panaino et al. (2022) all determined that there was an effect of the temperature on the abundance of ant and termite species. This prompts the question if even though the abundance of termite and ant species changes, this does not significantly affect the composition of the diet of the pangolins or if the effect of the temperature could not be shown in this study due to the small sample size and limited duration of the study. A continuation of the research over several years and including different seasons would be necessary to get a better understanding of the effect of the temperature, especially since according to Panaino et al. (2022), very high temperatures during which insects retreat into their nests, had the most significant effect. Extreme temperatures and great variations in temperature were not recorded during this project, as it took place only during a single season, namely autumn. Results regarding the inclusion of Harvester termites in the diet of pangolins are inconsistent, which seems to be the case for the proportions of termites in pangolin diets in general, according to Sun et al. (2020). Swart, Richardson, and Ferguson (1999) identified *H. mossambicus* as the only termite species that made a significant contribution to the diet of Temminck's pangolins in the Sabi Sand Wildtuin, whereas Pietersen et al. (2016B) recorded the presence of *H. mossambicus* in pitfall traps in the Kalahari, but there they were not preyed on. These contradictions to other studies may at least partially be due to the limitations of this project.

Low incidences of some ant or termite species in the diet (such as *Macrotermes natalensis* in this study) could hint at an accidental ingestion when feeding on other preferred prey items (Panaino et al., 2022). Generally, low proportions of termites in pangolin faeces may result from diet preferences or different habitats, but the different levels of digestibility are also a concern and have to be taken into consideration (Sun et al., 2020).

The results of this study may be useful to rehabilitation centres like UKWRC because they show that it is possible to provide a sufficient and varied diet to pangolins living in captivity if some of the ant and termite species known to be eaten by *S. temminckii* are present on the property, and specific adjustments to accommodate individual preferences are not necessary.

4.3 Study Limitations

Several factors have limited the scope of the study and possibly the accuracy of the results. Since only three individual pangolins were involved in this study and the amount of time available for the sample collection and processing was short, only a very small number of samples could be obtained and used to investigate possible preferences in prey selection. As samples were only collected over six weeks from April to June, it was not possible to take seasonal shifts, pronounced changes in weather, or seasonal changes in ant and termite activity into consideration. More studies over several years and including a larger number of pangolins could solve this issue.

Another problem, which further adds to the need for a longer study period, was how long the processing of the individual faecal samples took. The separation of the exoskeletons from the dirt material required over an hour for each sample, and the counting of the ant head capsules and termite mandibles took at least a full day of work per sample. In the future, it would be of help for similar projects if a way could be found to improve these methods. This, however, would require more time to try out different possibilities. In addition, more professional equipment such as microscopes and laboratory scales, which were not available at UKWRC, could help to make the processes easier, faster, and more accurate and would likely reduce the error that occurred in this project.

Another limitation concerns the sample collection. During the walks, the pangolins often pass through patches of tall grass and thickets where they might defecate, and some samples are therefore likely to be missing. Even when the faeces are found during the walks or in the rooms of the pangolins, it is nearly impossible to collect them perfectly, and small proportions of each sample and the ants and termites contained in them are lost.

As mentioned previously, no information about the relative abundances of each ant and termite species in the area and on the property of UKWRC was available. How this may have affected the distribution of the insects in the faecal samples could consequently not be taken into consideration.

Finally, as this is a study conducted on pangolins living in captive conditions at the time, the results cannot automatically be assumed to apply to *S. temminckii* living in the wild as well. The three pangolins in the study could only feed during certain times of the day, even though the species has been found to be primarily nocturnal, and in free-living conditions, a majority of the foraging activity would occur during the night (Pietersen et al., 2021). The levels of activity of their prey items differ from day to night, and it is possible that the composition of faecal samples collected from pangolins that are feeding during the night would look different than the ones found in this study. Furthermore, the pangolins at UKWRC were restricted to the property of the rehabilitation centre and could not completely freely choose where to go to look for food. The staff members looking after the animals during the walks have to make sure that they do not get lost and cannot allow them to enter into areas where they would not be able to follow, such as thick undergrowth or small caves, and the pangolins are not able to access ant and termite nests that may be located at these sites.

Another factor that needs to be taken into consideration is stress. The pangolins in this study were all rescued from the illegal wildlife trade and were in poor condition when they first arrived at the centre. Pangolins in captivity have often been shown to be particularly susceptible to stress-related disorders, and it cannot be ruled out that this would not also affect the feeding behaviour in one way or another.

Chapter 5 – Conclusion

The study results show that there are no individual preferences in the prey selection of pangolins at the Umoya Khulula Wildlife Rehabilitation Centre, even though there were significant differences in the composition of faecal samples.

Additional, more expansive investigations are needed to confirm and explain these findings and to evaluate their application to pangolins living in other conditions or locations.

More studies overall on pangolin dietary habits in captive situations such as rescue centres, as well as in the wild, are needed to better understand the feeding ecology of these poorly studied animals and to enhance the success of conservation and rehabilitation efforts. More research on *Smutsia temminckii* and other species of pangolins combined with stronger conservation efforts and stricter protective legislation will be crucial to developing a more accurate assessment of the severity of the state their populations are in and to prevent the extinction of these unique animals.

The feeding methods employed at the Umoya Khulula Wildlife Rehabilitation Centre, which allow the pangolins to walk freely and forage for their food in the same manner as they would in the wild, have proven to be a successful way of supplying a varied and sufficient diet to these animals. This provides an effective and possibly preferable alternative to the artificial diets that are given to pangolins in many other facilities and could be an important factor in improving the rehabilitation efforts of other rescue centres.

Chapter 6 – Acknowledgements

I want to thank all of my professors, from whom I have learnt so much over the last three years of this degree. Special thanks go to Professor Negrisolo and Professor Gabai, who have provided guidance and assistance throughout this project whenever I needed it.

Furthermore, I want to thank the staff at the Umoya Khulula Wildlife Rehabilitation Centre who have taught me so much about pangolins and who were always kind and helpful, especially Emma De Jager, who made this project possible in the first place. Thank you also to all the other volunteers who were working with me at the centre for assisting with the sample collection and for helping out with other tasks when I was preoccupied with this project.

I also want to mention Sweet Pea, Orion, and Tamu, who have sadly passed away since the end of this study as a consequence of their horrific past. They will always be a reminder to me of why it is so important to protect the pangolins and fight the illegal wildlife trade.

Last but not least, I want to thank my parents, who have always supported me and encouraged me to follow my dreams, who have first inspired my love for Africa and animals and without whom I would not be where I am today.

Appendix

1. Photographs of the property on which the Umoya Khulula Wildlife Rehabilitation Centre is located, where the pangolins are walked and can feed on ants and termites, including open fields, mango groves and woods (Wieser, S. (2024), Umoya Khulula Wildlife Rehabilitation Centre):






2. Photographs of the ant species found on the property of the Umoya Khulula Wildlife Rehabilitation Centre obtained from www.antweb.org:

Common Pugnacious Ant (*Anoplolepis custodiens*) photographed by Michele Esposito (CASENT0785808)

Hairy Sugar Ant (*Camponotus niveosetosus*) photographed by Bradley Reynolds (CASENT0813054)

Natal Droptail Ant (*Myrmicaria natalensis*) photographed by Wade Lee (CASENT0923007)

Common Spiny Sugar Ant (*Polyrhachis spinicola*) photographed by Michele Esposito (CASENT0227574)

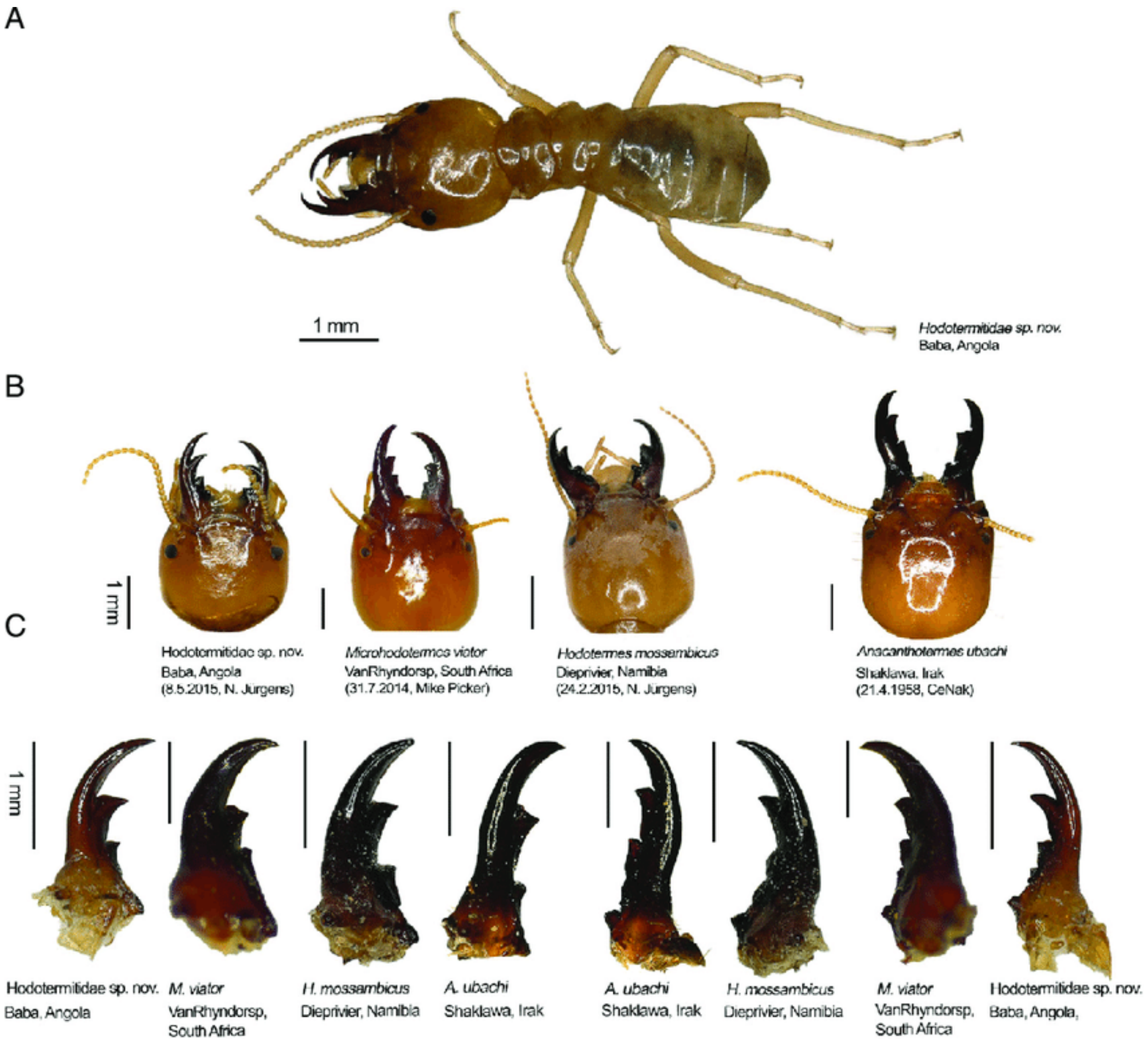
Orange Sugar Ant (*Camponotus cuneiscapus*) photographed by Michele Esposito (CASENT0822216)

Common Small Black Ant (*Lepisiota capensis*) photographed by Michele Esposito (CASENT026403

Black Cocktail Ant (*Crematogaster peringueyi*) photographed by Will Ericson (CASENT0904505)

3. Photograph of soldiers of the species *Macrotermes natalensis* (Musundire et al., 2021)

4. Comparison of mandibles and heads of *Hodotermitidae* sp., including *Hodotermes mossambicus* (Jürgens et al., 2020)



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