

**A survey on external (Ixodidae) and gastrointestinal parasites of small
ruminants on an arid communal rangeland in South Africa**

by

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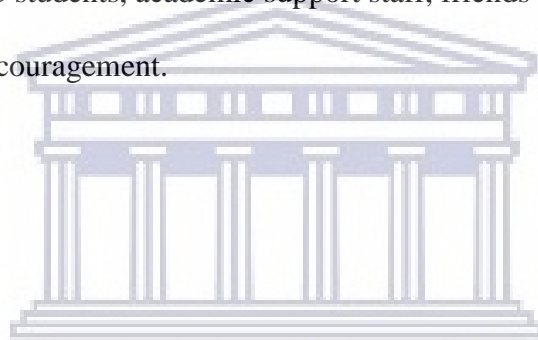
ABSTRACT

Parasites pose a major constraint on livestock farming. Its impacts are represented as transmission of disease to humans and economic costs for prevention and treatment as well as loss in terms of; livestock mortality and, lowered productivity. Although the impacts of parasitic loads can be decreased through proper management, extensive management systems are depended on external factors such as rainfall and forage availability, which, in its absence, promote malnutrition and therefore parasite susceptibility. The lack of proper nutrition with added stressors from an extensive management system (such as moving long distances for water, food, heat and being kept at proximity or high stocking densities) allows for an increase in parasite loads. Communal rangelands are known to be degraded, infrastructure and have low production as a result of bad or the lack of proper rangeland management. Therefore, we looked at parasite infection as the outcome of improper management, using factors such as stock genetics, stock health, kraal location and, grazing route as well as associating these to parasite species and abundances (prevalences). Thus, this study aimed to identify, quantify and determine internal and external parasite preferences for hosts and the environment using small ruminants in the Steinkopf communal rangeland. Parasites were identified through morphology, prevalence quantified for breed, sex, and age to pinpoint most affected hosts for treatment/prevention purposes. Next, we determined preferences for hosts based on host condition and the environment using generalised linear modelling, spatial data, and constrained redundancy analysis. Eleven herds were sampled, this included mixed-breed sheep (111), swakara sheep (56), and boer goats (58). Fifty-five faecal samples were taken from randomly selected animals to be used for gastrointestinal parasites analysis. Ticks were removed, stored in 70% ethanol and identified using dichotomous keys (Walker, 2003). Additional data gathered included body condition index, host species, sex and, age, altitude and stock-post position to gather spatial information. In

addition, eggs were identified to genus level and quantified as eggs per gram using the modified McMaster floatation technique. Nine livestock parasite genera were identified, *Trichuris* sp., *Ascaris* sp., *Monezia* sp., *Nematodirus* sp., *Aonecotheca* sp., *Paramphistimum* sp., *Bunostomum* sp., *Strongyle* sp., *Coccidia* oocysts. Of the identified species, the last two were the most abundant appearing in all samples suggesting heavy infections. Although gastrointestinal parasite prevalence differed slightly between hosts, no statistical differences were found ($p > 0.05$). Furthermore, we found poor body conditions, as well as smaller herds, harboured a higher diversity of gastrointestinal parasites per individual. Further results included a 56.4% prevalence of ticks, with both mixed-breed sheep, swakara, and goats equally infected. Three tick species were identified listed here from most to least abundant; *Rhipicephalus gertrudae*, *Hyalomma truncatum*, and *Rhipicephalus microplus*. Host health did not influence tick loads. Furthermore, the presence of invasive species *R. microplus* was found associated only with permanent stock-posts. Finally, correlating both gastrointestinal and external parasites to environmental variables, microclimates were well established, with parasite species associated with moisture, vegetation or old croplands. The methods of this study show how identifying and understanding parasite species of livestock can help to manage them, thereby recommending the importance of rotational grazing and continuous parasite management.

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DECLARATION

I, Saloshnie S. Govender, declare that “**A survey on external (Ixodidae) and gastrointestinal parasites of small ruminants on an arid communal rangeland in South Africa**” is my own work, that it has not been submitted before for any degree or assessment in any other university, and that all the sources I have used or quoted have been indicated and acknowledged by means of complete references.

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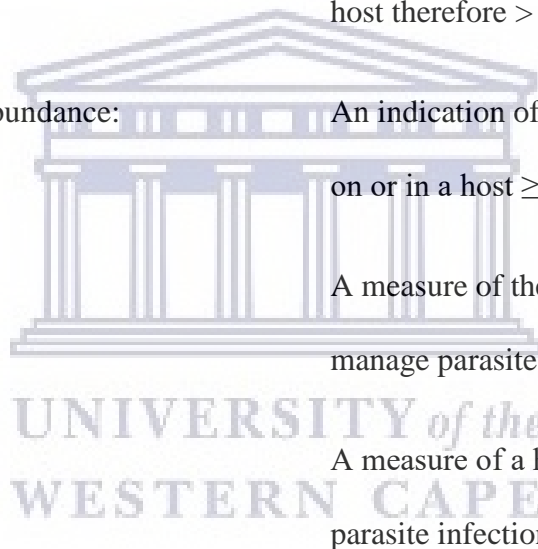
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Prevalence:	The proportion of infected (with parasites) hosts to all hosts examined during the period of this study.
Presence:	The occurrence of parasite species denoted as 1 for present and 0 for absent.
Intensity:	An indication of the number of conspecific parasites on or in an infected host therefore > 0 .
Parasite load or Parasite abundance:	An indication of the number of parasites on or in a host ≥ 0 .
Tolerance:	A measure of the ability of a host to manage parasite loads.
Resistance:	A measure of a hosts' ability to decrease parasite infection.
Kraal:	Widely known as a Corral, this is a temporary construct used to house and protect livestock during the night.



CHAPTER 1: GENERAL INTRODUCTION

1.1 The implication of increased livestock production

Worldwide, livestock production is one of the fastest growing subsectors in agriculture (Thornton, 2010). This is attributed to human population growth (that have protein requirements), increase in urbanisation causing the general shift towards livestock product consumption, and it is the most reasonable land use given the expansion of drier areas around the world due to climate change (Scollan et al., 2010; Meissner et al., 2013; Rojas et al., 2019). Globally, livestock products make up between 33% and 40% of agricultural gross domestic products (Scollan et al., 2010; Thornton, 2010). In South Africa (SA), livestock farming contributes to 44% of all agricultural outputs (KPMG Services (Pty) Ltd, 2012), and is set to increase due to continuous development (Thornton, 2010; Balmford et al., 2012).

With SA considered an arid to semi-arid country, an extensive livestock management system (such as transhumance and pastoralism) is well suited for areas that receive 700 mm and less annual rainfall such as the Northern Cape Province (Behnke et al., 1993; Kusiluka & Kambarage, 1996a; Hoffman et al., 2009). Worldwide, these drylands host a third of the world's population and half of its livestock (Boval et al., 2017). For instance, the Northern Cape province is the second highest producer of sheep with the majority of game farmed here too (Meissner et al., 2013).

This increase in livestock production has both direct and indirect impacts such as; an increase in disease and parasite susceptibility (Rust & Rust, 2013), prevalence (Thornton, 2010), and impacts the environment through climate change (Thornton, 2010), overgrazing (Hoffman et al., 2009) and, distribution of invasive species (Nyangiwe et al., 2013b). Parasites represent the main economic loss to livestock farming, one example by Minjauw (2005) shows in SA

the total loss caused by the tick-borne disease (in particular heartwater) is estimated at R 189.6 million annually.

1.2 Parasites and their diversity

Arguably parasites play an important role in ecosystem functioning, some view their existence as a refuge for system dynamics and overpopulation, others consider parasites an obvious adaptation of evolutionary cost versus benefits theory. The evolution of parasites has allowed them to extract their nutrients from a host organism (Price, 1977). Although many parasites we know feed on blood, many of them may even feed on skin debris and hair (Sasa, 1961). They are said to have evolved from this initial feeding behaviour to one more adapted to feeding directly on a hosts' blood supply – through the morphological adaptation of specialised mouthparts (Walker, 2003). This parasitic nature has evolved through several lineages throughout all domains of life due to this being one of the most advantageous means of acquiring nutrients at the expense of another organism (Poulin & Randhawa, 2015), thus they make up 50% of all known species (Poulin & Morand, 2000).

In the case of haemoparasites (blood parasites), they can be differentiated into two main types; ectoparasites and endoparasites (Price, 1977; Begon et al., 2006; Hendrix & Robinson, 2006). Furthermore, they may be multicellular, unicellular, and subcellular where they may be either obligate or facultative (Wall & Shearer, 2001). Obligate parasites are fully dependent on their hosts for survival and require a host to develop and reproduce, whereas facultative parasites may live with or without their hosts (Price, 1977; Wall & Shearer, 2001). Most haemoparasitic ectoparasites and endoparasites are obligate parasites requiring a blood meal to complete their lifecycles. Ectoparasites exist on the outer exterior of a host and include, mosquitos, ticks, and mites. Although some ectoparasites may bury themselves into

the epidermis of a host, they do spend most of their lives off the host (Wall & Shearer, 2001). Endoparasites or internal parasites may spend most of or all of their lives inside a host animal. These may be parasitic worms such as helminths (lungworms and tapeworms), protozoa, bacteria, or viruses (Wall & Shearer, 2001).

1.3 Ticks, their feeding strategies, and life cycles

Six main ectoparasites of known agricultural, veterinary, and medical importance, these include mites, ticks, adult flies, myiasis, fleas, and lice (Wall & Shearer, 2001). We acknowledge the broad subject matter, however, in this thesis, it will focus solely on ticks and their significance as livestock parasites.

Ticks belong to the class Arachnida, subclass Acari that includes three extant lineages of which Parasitiformes represent the order Ixodida. Ixodida then goes on to include three families; composed of the hard ticks (family Ixodidae) and, the soft ticks (the family Argasidae) and the only family with one known species, Nuttalliellidae. In comparison to other arthropods, ticks are a relatively small order with approximately 899 known species, and 52 tick species of domestic animals which are of veterinary importance in Africa (Walker, 2003; Elsheikha & Khan, 2011). Worldwide ticks are the most important vectors of disease to domestic and wild animals, and second to mosquitoes as vectors of zoonotic diseases (de la Fuente et al., 2008).

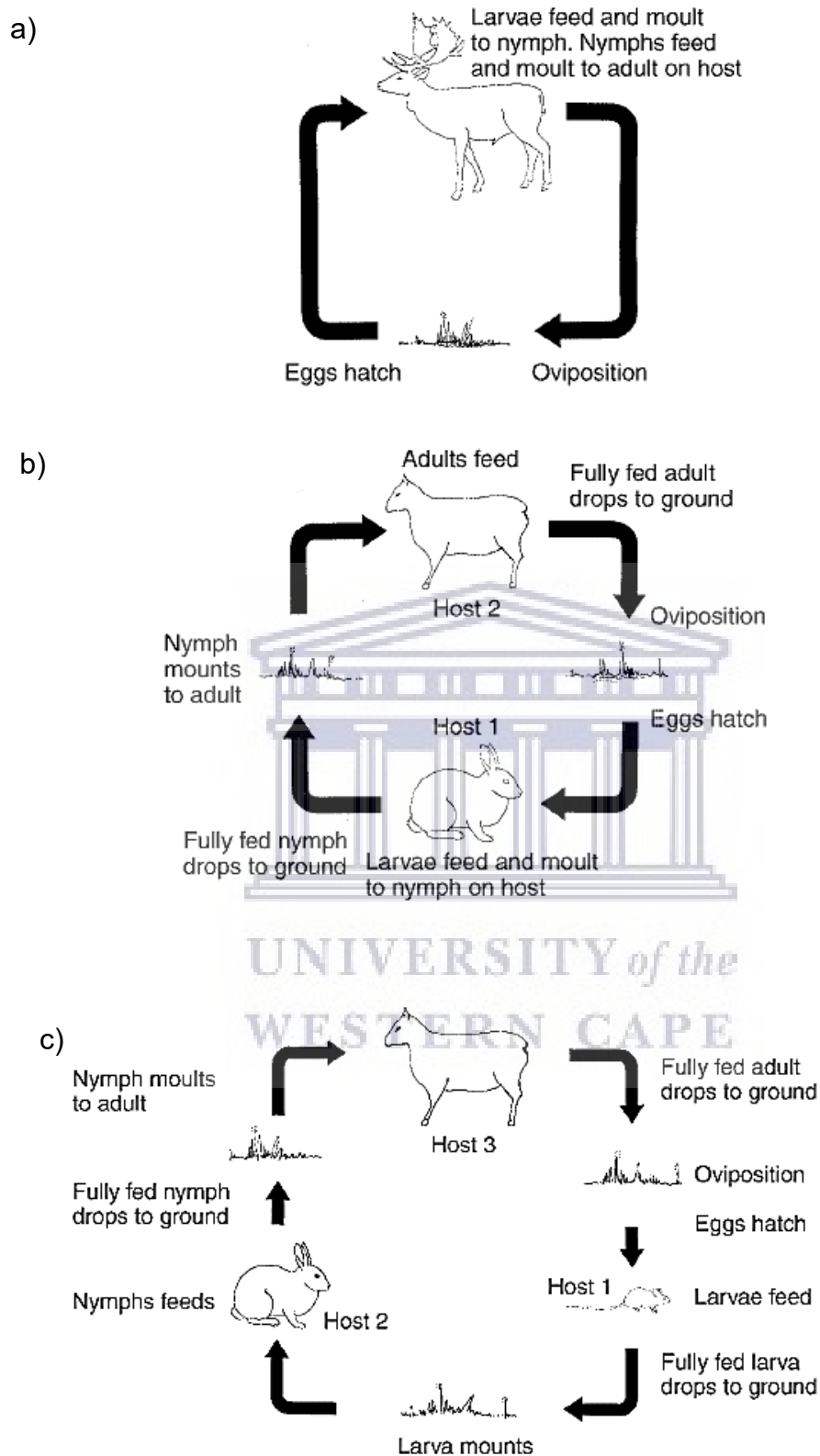


Figure 1.1: Life cycles of (a) one host (b) two and (c) three hosts feeding strategies of ticks

(Taken from Wall & Shearer, 2001).

The life cycles of ixodid ticks involve four instars (an instar refers to the process of forming stages) which are the egg, six-legged larva, eight-legged nymph and finally the eight-legged adult (Wall & Shearer, 2001). Blood meals are required for ixodid ticks to metamorphose to its next stage, however, this only accounts for 10% of its entire life spent on a host, and the remainder of its time is spent off the host (Ledger et al., 2019). Feeding strategies between ixodids and argasids differ. This is because of the marked differences in their morphology, which also determines the environments they inhabit, the species of animals they parasitize, their lifespan and, feeding strategies. For example (see Figure 1.1), one difference is a one to multiple host (generalised) feeding strategy of ixodids to an almost sole host (specialised) feeding strategy of argasids (Walker, 2003), some of which are obligate feeders and may die without a blood meal, for example, *Coxiella burnetii* (Costa et al., 2015).

1.4 Intestinal parasites, helminths, protozoa, and life cycles

Intestinal parasites may live in the digestive tract of a hosts' body, or migrate into the bloodstream, where they feed on blood or available nutrients (Hansen & Perry, 1994b). As mentioned before endoparasites include; helminths which are gastrointestinal parasites (GIPs) (such as lungworms and tapeworms), as well as protozoa, bacteria, or viruses. Due to the broad subject matter, in this thesis, it will focus on helminths and protozoa.

Helminths (which are parasitic worms) are responsible for the disease helminthiasis, which are grouped as - nematodes, cestodes and, trematodes. Nematodes are transmitted through the ingestion of their larval stage (L_3). There are four distinct larval stages (L_1 to L_4) each bringing about new a metamorphosis, with the third stage being the most infective of stages (L_3). Once ingested, adult worms may inhabit various places within a hosts' body, these may be the digestive tract, lungs (lungworms) as well as other organs and tissues such as the skin

(filarial nematodes) and eyes depending upon the species of roundworm (see Figure 1.2).

Cestodes most commonly inhabit the intestine and liver. Trematodes require a snail as an intermediary host and, are found within the liver, gastro-intestine (paramphistomes), pancreas, and the blood (schistosomes) of its host.

Lastly, most protozoa parasitize the intestine of their hosts and, may be transmitted through the ingestion of faecal matter (Hansen & Perry, 1994b). The lifecycle of parasitic protozoans includes an exogenous phase (occurs outside the host) where oocysts mature and an endogenous phase (occurs inside the host) where sexual or asexual reproduction occurs (Soulsby, 1982). Once passed in the faeces by an infected host, oocysts may become sporulated (and infectious) after 2 – 7 days depending on the species and environmental conditions (Soulsby, 1982). Some oocysts may survive up to a year in this external environment (Chartier & Paraud, 2012). Once ingested, they undergo a process of excystation, where sporozoites emerge from the cyst and attach to the lining of the small intestine and undergo asexual reproduction (large intestine with some species). This eventually results in the production of non-sporulated oocysts which are released with faecal matter (Foreyt, 1990).

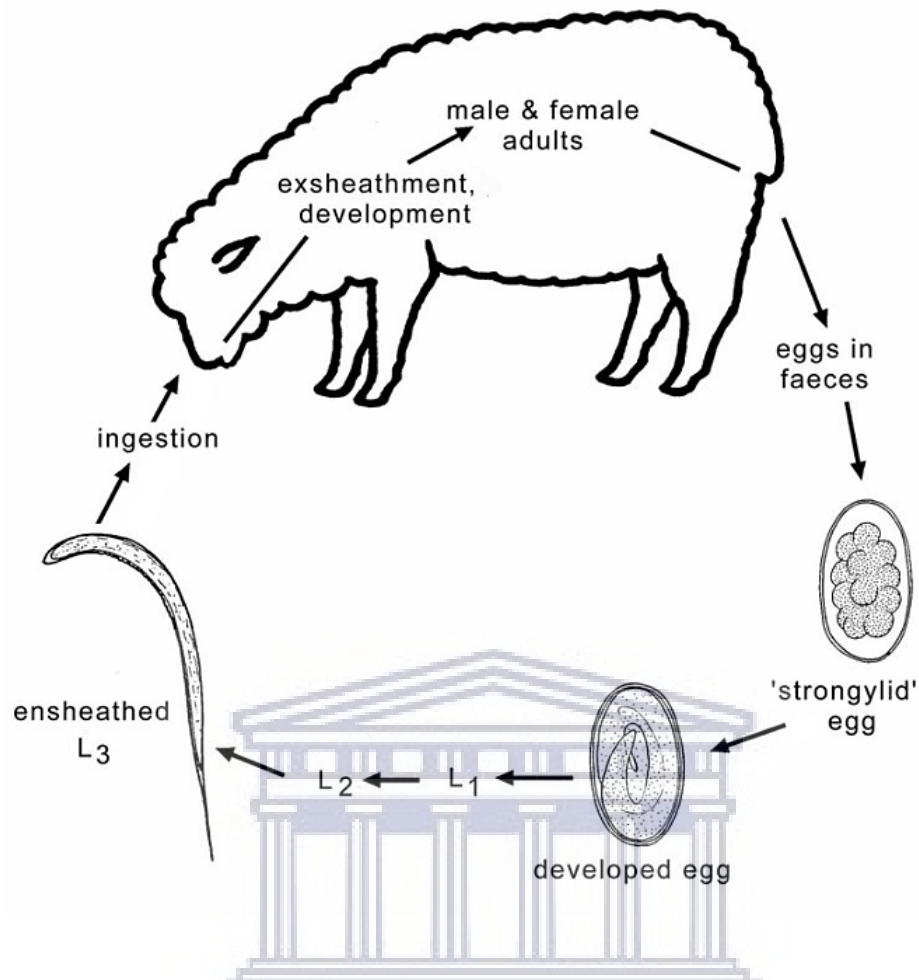


Figure 1.2: Generalised life cycle of gastrointestinal parasites using *Strongyle* egg as an example (Taken from Roeber et al., 2013).

1.5 The impacts of parasites on livestock farming

There are two distinct ways that parasites affect their host such as livestock. The first and most direct is through cutaneous effects causing inflammation and infection at the site of biting, this may lead to pruritus, self-wounding and “tick worry”, or the obstruction of organs when worm burdens are high (Wall & Shearer, 2001; Villarroel, 2013). The second way the parasites affect their hosts is through systematic effects, such as through the transmission of microorganisms (viruses, bacteria or protozoa) to hosts. This may then lead to further infections such as bacteraemia. This leads to increased parasite loads and poor health or

condition of the animal such as anaemia (Hansen & Perry, 1994b; Beinart & Brown, 2013; Villarroel, 2013). In certain cases, ticks may even induce the paralysis of a host (Wall & Shearer, 2001).

When compared to commercial livestock farms, communal rangelands are known for being rife with parasites and disease (Marufu et al., 2010; Nyangiwe et al., 2017). This is because they are generally resource-poor, have degraded rangelands and, low productivity (low nutrient intake) (Milton et al., 1994; Marufu et al., 2010; Nyangiwe et al., 2017). Degraded rangelands include soil degradation and fragmentation, which may be the effect of overgrazing. This causes disturbed and altered ecosystems which result in either increased (Mbora et al., 2009; Hussain et al., 2013) or decreased (Chasar et al., 2009; Evans et al., 2009) parasitism effects.

However, with commercial farming, the control and regulation of parasites are affordable and maintained in a closed system through the quarantine and treatment of infected individuals (Rust & Rust, 2013). In contrast, the control and regulation of parasites in pastoral systems is more challenging as herds form part of an open system and are always exposed to parasites. Thus, requiring herders to have forethought and knowledge for prevention such as high-risk area avoidance, signs, symptoms and, treatment (Blench, 2001; Torres-Acosta & Hoste, 2008; Thornton, 2010; Kumar et al., 2013; Rust & Rust, 2013).

Notably, pastoral systems are one of the major explanations for livestock disease being harder to eradicate in some areas as herds are inaccessible, as well as them constantly moving and interacting with other animals (Macpherson, 1995). Throughout the 1800s, the South African government has made strides and provisions to help curb parasitic effects on livestock, implementing regulatory dips since 1894 (Tamarkin, 2009). However, state funding has since ceased (Hlatshwayo & Mbatia, 2005), allowing for varying approaches to treatment

nonetheless, dipping and drenching livestock remains the most effective mechanism to treat parasite infection. But as parasites become more resistant to treatments (Le Jambre, 1978; Van Wyk et al., 1997; García-García et al., 2000; Van Wyk et al., 2001; Javed et al., 2011; de Koning, 2017), farmers may look to alternative methods such as; ethnobotany/ethnoveterinary as treatments for livestock (Blench, 2001), genetically selecting and breeding resistant breeds (Woolaston & Baker, 1996; Bishop & Morris, 2007), using easily obtainable alternatives such as diesel or car oil, biological control (Ridgway, 2013) and grazing management (Hoste et al., 2006; Javed et al., 2011).

In natural systems, parasites act to curb population growth and ecosystem carrying capacities (Minchella & Scott, 1991), thus every wild animal in some time or another hosts a parasite (Ledger et al., 2019). Most parasites show host specificity with preferences for a particular host (Sonenshine & Mather, 1994). For instance, Nyangiwe (2007) showed with game farming in the Eastern Cape Province, brown ear ticks had a preference for buffalo and Smith & Parker (2010) showed the consequence of wildlife and livestock in close proximity is a “ticking time-bomb” of disease outbreak. Wild animals being harder to treat for parasites (Beinart & Brown, 2013) and are known to act as reservoirs for disease (Gibbs et al., 1975; Simpson, 2002), prove the expansions of protected areas and game farming may have consequences for parasite re-emergence (Beinart & Brown, 2013). However, the loss of host biodiversity may also increase disease risk through host switching, especially apparent with generalist parasites (Salkeld et al., 2013), and habitat generalists which act as parasite vectors (Altizer et al., 2003).

1.6 Parasite spatial distribution in different rainfall regimes

Notably, parasites and disease are greatly influenced by environmental conditions, as these affect their regulation; distribution, transmission, development and host availability (Pavlovsky, 1966; Froeschke et al., 2010). According to Mas-Coma et al. (2008) climatic variables can affect parasite species richness and intensity, for example, the bulk of parasite development occurring after the rainy season (Patz et al., 2000). Rain or moisture, enable questing parasites to find hosts. Besides water, temperature also plays a large role in the development of parasites, as for most species high temperatures increase development rates (Kutz et al., 2005). However, like most living things, parasites cannot withstand extremely low or high temperatures (≤ -2 or ≥ 40 °C), such as free-living L₁ and L₃ nematodes (Forrester & Senger, 1963; Shostak & Samuel, 1984). Additionally, Bush and Holmes (1986) show that nematodes which are particularly sensitive, have specific temperature thresholds between 5 and 15 °C they then become inactive between 15 to 30 °C. As with most species, some ticks are adapted to arid environments however, they too have lethal temperature thresholds that stand at $-7 \leq 40$ °C (Süss et al., 2008). Consequently, Burtis et al. (2016) showed that years with hot and dry weather affected black-legged tick (*Ixodes scapularis*) development, thereby reducing Lyme disease incidences. As a result, we find that parasites thrive in areas with high rainfall, humidity and waterlogged areas making high humidity environments such as tropical regions infamous for parasitic infections and the spreading of disease (Dunn et al., 2010).

South Africa is diverse in terms of biological diversity and it has a natural climatic gradient, where rainfall and humidity increases from the west to the east together with altitude (Jury, 2013). This gradient affects vegetation distribution (Mucina & Rutherford, 2006), species diversity (Thuiller et al., 2006), livestock numbers (Meissner et al., 2013) and therefore parasites and disease (Froeschke et al., 2010). With rainfall, too much or too little has proven catastrophic in terms of parasite infection. Flooding, for example, creates a breeding ground

especially for waterborne (host to host) and vector-borne parasites (Okaka & Odhiambo, 2018). For instance, Diaz (2015) showed the association between rodent-borne infectious diseases and rainfall, resulted from the increased growth of wild grass seed production. In contrast, drought may decrease habitat, available hosts and, therefore abundance. But may result in unpredictable parasite adaptations such as migration (Trape et al., 1996) or even shifting temporal and seasonal patterns of activity (Brown et al., 2014). Globally as more climatic shifts occur, there are increasing incidences of parasite distribution shifts and, parasitic disease occurrence (Nyangiwe et al., 2013b). Consequently, the lack of rain in arid and semi-arid regions would mean livestock farming without the high risk of parasite infection and disease. Although the climate in Namaqualand has remained the same for over millions of years (Mans et al., 2011), Bourne et al. (2012) have predicted through climate modelling, an increase in summer rainfall and higher temperature. Furthermore, Weltzin et al. (2003) suggest any shift in precipitation in Namaqualand may lead to extreme rainfall events which are more drastic on the ecosystem than temperature and CO₂ rising.

However, through microhabitat selection by their hosts, parasites can survive in areas where they were previously thought incapable of doing so. Mountain ranges are an example of this in arid regions (Froeschke et al., 2010), the moisture (from mist/fog), together with high temperatures and the constant availability of hosts make these areas viable for parasites. These microhabitats protect immature stages and eggs (Scharsack et al., 2016). They include; riverine areas, areas of high elevation, areas with denser vegetation and, even soil, ultimately areas where contact with a host is guaranteed (Walker, 2003). When conditions are unfavourable ticks and mites have dormant phases in their life cycles to withstand unfavourable environmental conditions (Belozarov, 2009), this is especially evident in arid environments where the possibility of finding a host is unpredictable (Mans et al., 2011).

1.7 Parasite induced livestock health problems

Diseases caused through systematic effects are contracted through a wide variety of possibilities; airborne, foodborne, vectors (such as ticks or flies), horizontal transmission such as within groups, vertical transmission such as between mother and baby or, even be inherited (Roger, 2008). Diseases may be contracted from another animal or be caused through internal inflections such as immunodeficiency (Hansen & Perry, 1994b). From diseases that can be contracted from another individual three types exist; those that can be spread between species (species-specific), shared with other species (cross-species) and, zoonotic (spread from animal to human) (Roger, 2008).

Because parasites have an aggregated distribution on/within their hosts, the intensity of their effects on hosts differ based on the host genetics, diet and current parasitic load (Crofton, 1971b; Schmidt et al., 1977; Hansen & Perry, 1994b; Paterson & Banks, 2001). Host genetics may include, species, sex, and health of a host, all of which determine the resilience or immunity of a host to parasite infection. For instance, Nguni cattle are widely known for their tolerance to harsh external conditions as well as being resistant to both external and internal parasites (Muchenje et al., 2008). Additionally, due to the resource partitioning of sexually mature males, they tend to have higher parasite burdens than females (Cordoba-Aguilar & Munguia-Steyer, 2013). Moreover, with immune responses not yet fully developed in young animals, it allows them to fall victim to infectious diseases often (Colditz et al., 1996). The health of a host (impacted by management, stress, parasites, other hosts, etc.) affects their immune responses thereby increasing parasite infection, which is also an indirect response of a hosts' diet and nutritional intake (Bath et al., 2005). Lastly, a host with a pre-existing parasite load is more likely to pick up more parasites, this is because their immune responses are already lowered, attracting more parasites, thereby creating a breeding ground for parasites (Kemal et al., 2016).

Moreover, the intensity of disease differs with the type or species of parasite. For instance, a disease caused by endemic parasites is termed enzootic disease (African redwater and heartwater in cattle) and is less severe on host species that have co-evolved and adapted to endemic parasites (Fessl et al., 2006). This is evident with wild animals being less affected by parasite diseases than livestock (Smith & Parker, 2010). Epizootic disease (Asiatic redwater in cattle), on the other hand, is caused by parasites that are not endemic (alien species) called “accidental parasite” and pose greater health issues (Schmidt et al., 1977; Fessl et al., 2006). Thus far, these are the various livestock diseases that are of considerable importance in southern Africa listed in Table 1.1.

Table 1.1: List of livestock diseases in South Africa listed from important to less important (Adapted from Kusiluka & Kambarage, 1996b; Bath et al., 2005).

Type	Disease	Cause
Infectious diseases	Heartwater	Tick-borne bacterial disease
	Pulpy kidney	Bacterium induced toxin
	Pneumonia	Vector-borne disease
	Abscesses and pituitary abscess	Tick-borne bacterial infection
	Footrot	Tick-borne bacterial infection
	Orf	Virus
	Bluetongue	Vector-borne virus
	Botulism	Bacterium induced toxin
	Tetanus	Bacterium induced toxin
	Arthritis	Bacterial infection
Parasitic diseases	Intestinal parasites	<i>Haemonchus contortus</i> , <i>Trichostrongylus spp</i> , <i>Ostertagia/Teladorsagia circumcincta</i> , <i>Oesophagostomum columbianum</i> , <i>Nematodirus spathiger</i> , <i>Strongyloides papillosus</i> , <i>Gaigeria pachyscelis</i>
	Coccidiosis	Protozoan
	Ectoparasites	Mites, Ticks and Flies

As Table 1.1 shows, a large majority of livestock diseases are caused by parasites (helminths and tick-borne disease) therefore it is not unusual why through perception-based studies, farmers name parasites and disease as a main problem (Belay et al., 2013; Slayi et al., 2014).

Although local immunity to parasite infection is observed among indigenous hosts, the range expansion of certain parasites (ticks and worms for example that are transported across boundaries on/in hosts), and the resistance to preventative medication of others could prove troublesome for resource-poor farmers. This has the potential to increase disease susceptibility, increasing the risk of “accidental parasites” causing a loss in productivity and therefore a loss in economic benefit. All of these risks are magnified with continuous and unpredictable climatic changes such as; prolonged droughts, flooding, and heating or cooling of atmospheric temperatures in certain areas (Süss et al., 2008; Dunn et al., 2010; Vogel & van Zyl, 2016; Short et al., 2017). Already we find the movement of ticks to more arid regions, as these areas increase in habitat suitability and host availability (Olwoch et al., 2008; Nyangiwe et al., 2013b). Because parasites regulate host populations and alter their behaviour, this owing to their intimate relationship with their hosts (Moore, 2002; Hudson et al., 2006), we find that the presence and prevalence of parasites should serve as an indication of the health of the ecosystem or similarly the herd.

1.8 STUDY AREA

Steinkopf is located within the more semi-arid to arid extent of South Africa within the Namakwa District Municipality of the Northern Cape Province (Figure 1.3). The Steinkopf communal rangeland is the largest communal rangeland in the province, approximately 582 634 hectares which includes the additional land reform farms.



Figure 1.3: Eleven sampling sites located within the 582 634 ha of Steinkopf communal rangelands, in the Northern Cape Province of South Africa.

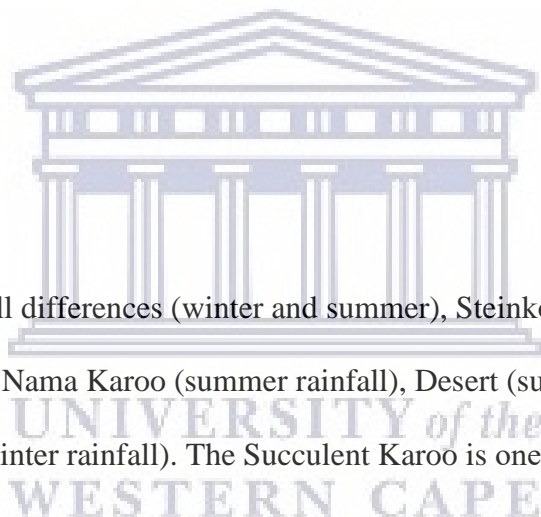
1.8.1 Climate

Steinkopf is divided across two different rainfall regimes; summer rainfall in the east and winter rainfall in the west (Mucina & Rutherford, 2006). The town receives between 100 - 250 mm annual rainfall (an average of 140 mm), with fog being a major contributor as

measured from the nearest town Springbok which is located 55 km from Steinkopf (SAWS, 2019). Precipitation is known to differ according to altitude and direction, for example, Anenous Plateau Shrubland (see Figure 1.4) in the west receives 120 - 160 mm p.a. and decreases as you move east towards Bushmanland. Temperatures differ significantly across seasons, with hot summers and cold winters. Maximum temperatures may reach 30 °C in summer and minimum as low as 6.7 °C in winter (SAWS, 2019). Average annual temperatures are 16.6 °C, averaging 21.9 °C in summer (January) and 10.3 °C in winter (July) (Climate-Data.org, 2019). Prolonged droughts and about 10 days of frost in the mountains are commonly experienced in this town (Mucina et al., 2006; Climate-Data.org, 2019; SAWS, 2019).

1.8.2 Vegetation

Interestingly, due to rainfall differences (winter and summer), Steinkopf is situated within three different biomes, the Nama Karoo (summer rainfall), Desert (summer rainfall) and Succulent Karoo biome (winter rainfall). The Succulent Karoo is one of the worlds' only two arid biodiversity hotspots (Mucina et al., 2006). This biome extends from the southern edge of Namibia along the west coast of South Africa, encompassing the Northern Cape, Western Cape, and parts of the Eastern Cape Provinces. Flora of the Succulent Karoo shows incredible speciation (Cowling et al., 1998), characterised by its rich diversity of dwarf-shrubs (< 1 m high) such as leaf-succulents and geophytes (Jürgens, 1986; Driver et al., 2003). These are categorised into the six main vegetation types found in Steinkopf which is the result of biogeographic processes resulting in, varying soils (Schmiedel & Jürgens, 1999), geologies (Van Wyk & Smith, 2001) and, moderate and predictable climates five million years ago (Esler et al., 1999). The six vegetation types include; Anenous Plateau Shrubland, Kosiesberg



Succulent Shrubland, Namaqualand Blomveld, Namaqualand Klipkoppe Shrubland, Namaqualand Shale Shrubland and Umdaus Mountains Succulent Shrubland (Mucina et al., 2006; CSA, 2012). Anenous Plateau Shrubland is dense shrubland, dominated by leaf-succulent dwarf shrubs with overgrazed areas dominated by annual herbs and geophytes. Dominant plant species include; *Galenia africana* with mosaics of *Leipoldtia schultzei* and *Pteronia glomerata*. Kosiesberg Succulent Shrubland is dominated by *Leipoldtia schultzei* and *Andromishus* cf. *triflorus*. Namaqualand Blomveld vegetation type is dominated by flowering dwarf shrubs such as the leaf-succulent or “vygie”, *Ruschia* species and *Tripteris sinuata*. The main feature of Namaqualand Klipkoppe Shrubland is rock sheets of granite, gneiss and boulders supporting dwarf and medium shrubs up to 1 m tall as well as smaller succulents in crevices. Dominant plant species include; *Ruschia* sp., *Leipoldtia* sp., *Eriocephalus* sp. and, *Othonna* sp. Namaqualand Shale Shrubland is dominated by plant species including; *Leipoldtia schultzei* with *Mestoklemma arboriforme*, *Galenia fruticosa* and *Adromischus* cf. *triflorus*. Finally Umdaus Mountains Succulent Shrubland is mostly dominated by Succulent Karoo vegetation types with Nama-Karoo elements, dominant plant species include *Leipoldtia schultzei* with mosaics of; *Mestoklemma arboiforme*, *Pteronia glomerata* and, *Galenia fruticosa* (Mucina et al., 2006; CSA, 2012).

The Succulent Karoo is also famous for its high endemism, with more than 6 356 species of vascular plants (Driver et al., 2003) 80 genera of which are endemic, occurring within an area of 100 251 km² (Cowling, 1986). Conservation efforts to protect the sensitive biodiversity of the Succulent Karoo have produced a multitude of publications (Cowling, 1986; Todd & Hoffman, 1999). Myers et al. (2000) have categorised biodiversity hotspots as areas of exceptionally high endemism and species richness, but that has also been subjected to at least

70% land transformation. Currently, only 5.8% of the land is formally conserved (6 500 km²) with 5% of land being irreversibly transformed (Driver et al., 2003).

1.8.3 Land uses

The major land use of this semi-arid region is livestock production, accounting for 90% of the region (Driver et al., 2003). Pastoralism and transhumance is a tradition forming part of indigenous culture as well as a major source of income to the community (Carstens, 1961). Transhumance specifically is an adaptation or movement to rainfall/climatic changes, for instance, seasonal rainfall or drought (Beinart & Brown, 2013). This traditional form of livestock production uses the technique such as herd mobility and is not generally production orientated. Farmed animals in Steinkopf include breeds of boer goats, sheep include Dorper, Merino (mutton breeds) and swakara (for pelts), mixed breeds are also prevalent, with cows and pigs present but appearing less (Bapela & Mariba, 2002; Schroeder et al., 2019). Horses and donkeys, which were previously used as draught-animals, now roam freely or are used as predator defence. Other land uses include mining such as granite and smaller areas of crop cultivation generally livestock forage along the Orange River.

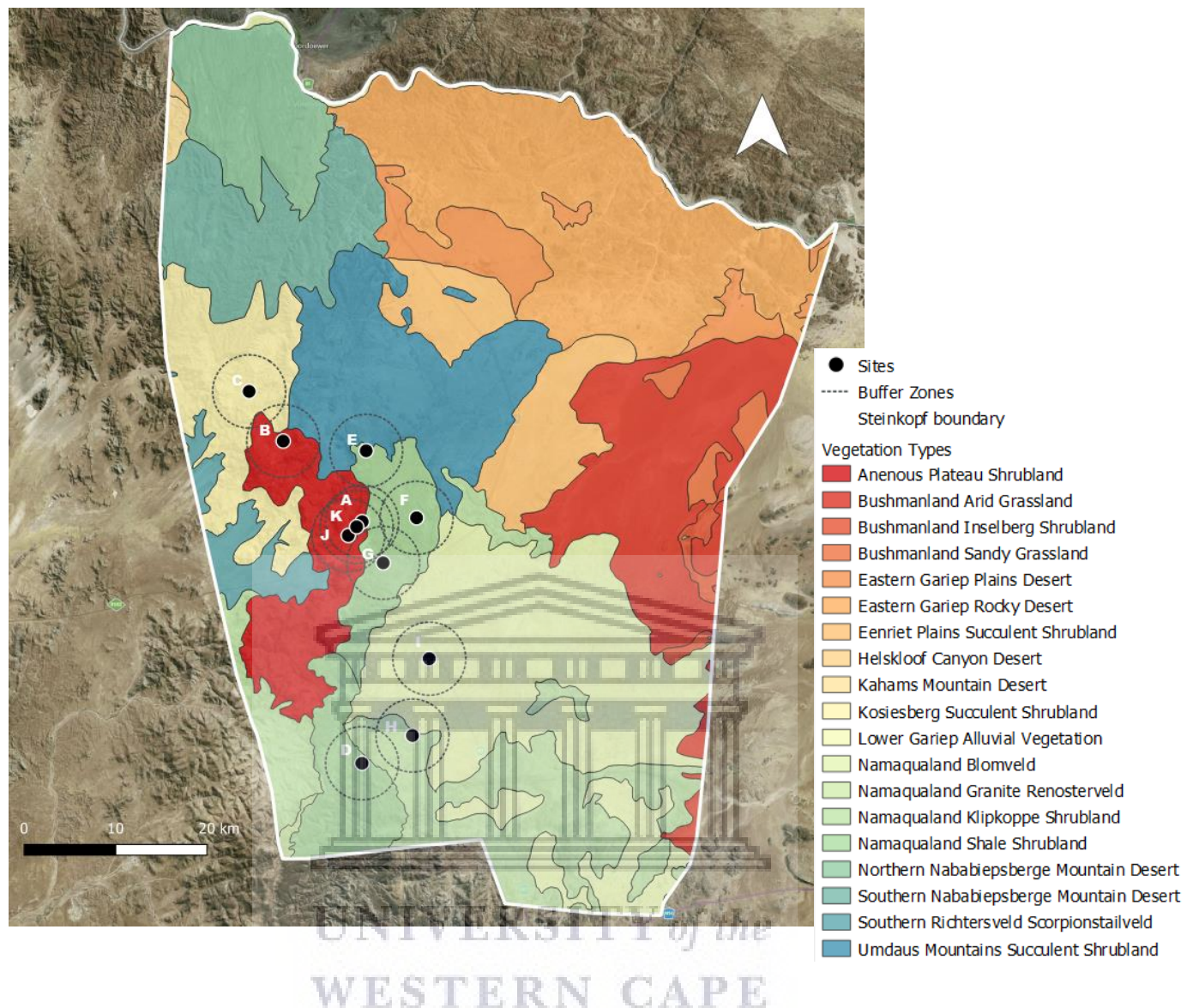


Figure 1.4: Vegetation types surrounding sampling sites (kraals) which include; Anenous Plateau Shrubland, Kosiesberg Succulent Shrubland, Namaqualand Blomveld, Namaqualand Klipkoppe Shrubland, Namaqualand Shale Shrubland and Umdaus Mountains Succulent Shrubland. Also showing buffer zones of 4 km radius around each site (Adapted from: South African National Biodiversity Institute, 2018).

1.9 SIGNIFICANCE OF THIS STUDY

Despite livestock farming being historically noted in this town, little work has been done on livestock parasites (Walker, 1991; Walker, 2003). Most notable publications lack information on species distributions particularly in this region of South Africa as these naturally occurring ticks are not listed as veterinary importance. By filling a knowledge gap this research would help to uncover the parasitic species found in the arid north-west of South Africa (Northern Cape Province) and their impact on rangelands and possibly the impact of livestock farming on parasite presence. We aim to accomplish this through the following research aims and objectives.

1.10 RESEARCH AIM

This study aimed to identify, quantify and determine internal and external parasite preferences for hosts (small ruminants) and the semi-arid environment of the Steinkopf communal rangeland.

1.11 RESEARCH QUESTIONS AND OBJECTIVES

- 1 What were the parasite species present and their prevalence in this grazing area?
 - Parasites were identified through morphology, prevalence determined for each breed, sex, and age to pinpoint most affected hosts for treatment/prevention measures.
- 2 Did the parasites prevalent show preference for hosts and the environment?
 - Determine preferences for hosts' based on host health and the environment done using generalised linear modelling and ordination techniques.



1.12 THESIS OUTLINE

Chapter 1 - introduces the topic at hand, stipulates the problem and significance of the study, the study area as well as highlights the aim, questions and objectives of the study.

Chapter 2 - the first data chapter focuses on gastrointestinal parasites and the results and discussion thereof.

Chapter 3 - the second data chapter reports on the external parasites examined, more specifically ticks (Acari: Ixodidae) and the results and discussion.

Chapter 4 - synthesizes the main findings of both data chapters and includes recommendations and the limitations of this study.



CHAPTER 2: Intestinal parasite burdens of small ruminants in Steinkopf, a communal rangeland in the Northern Cape Province, South Africa

2.1 Introduction

Gastrointestinal parasites are found in all climatic environments, where they decrease host health and fitness, thereby making these parasites a considerable source of economic loss to livestock farmers (Beck et al., 1985; McLeod, 1995; Torres-Acosta & Hoste, 2008). Another consideration, in South Africa, is the low rainfall and subsequent frequent drought periods that suggest undernutrition and thus additional health risks in livestock in communal rangelands (Danckwerts & Teague, 1989; Casey & Maree, 1993). Despite this, communal rangelands contribute 50% of the country's livestock production (Scogings et al., 1999). Furthermore, on communal rangelands, pastoralism is not only a means of income but also a mechanism of subsistence farming, as well as the holding of traditional and cultural value (Neely et al., 2009).

The town of Steinkopf hosts the largest communal rangeland in South Africa, but also the potential for degradation due to it being in the arid extent of SA where low rainfall and overgrazing threaten vegetation recovery (Mucina et al., 2006). Therefore, signifying the importance of proper rangeland management such as farming with sheep and goats compared to cattle, as they are more adaptable and resilient to the arid environment. Also, they require smaller investments with greater payoffs as they reproduce and grow faster (Sissay, 2007). Also, indigenous breeds of small stock show high resilience and tolerance to parasites making them ideal to farm with (Macivor & Horak, 2003; Hoste et al., 2008; Torres-Acosta & Hoste, 2008).

Regardless, we find that communal rangelands are generally characterised as being resource-poor, having low production, and high degradation (Lamprey, 1983; Bembridge & Tapson, 1993; Milton et al., 1994). The overall aim of this chapter was to understand the gastrointestinal parasite burdens of small-ruminants found in the Steinkopf communal rangeland, firstly through the identification of eggs, secondly their relationship with hosts through internal conditions and lastly, their relationship with hosts through environmental conditions using the following research questions and subsequent *hypotheses*:

1. What are the gastrointestinal parasite species found on small ruminants and what is their prevalence during seasonal sampling of the winter-rainfall region of Steinkopf?
 - I. *Expected prevalence is 50% or less.*
 - II. *Males and juveniles are predicted to show a higher parasite prevalence than females and adults.*
2. How does body condition affect gastrointestinal parasite abundance?
 - III. *Hosts with lower body conditions would possess higher parasite species richness and abundance.*
 - IV. *Larger herds would show higher parasite abundances.*
3. Which environmental variables are associated with high gastrointestinal parasite presence and abundances?
 - V. *Herds surrounded with more vegetation and those at higher elevations would have higher prevalence and abundance of gastrointestinal parasites.*

Hypothesis I: *Expected gastrointestinal prevalence for this town is 50% or less due to no previous studies being conducted in this town (Roscoe, 1975; Wall & Shearer, 2001). These*

authors suggest using 50% as an expected outcome to determine sampling population sizes to minimise statistical biases.

Hypothesis II: Genetics plays a role in parasite infection with some animals being more susceptible to parasites than others are. For instance, indigenous breeds possess higher resistance (immune responses) and tolerance to parasite infection (Macivor & Horak, 2003; Hoste et al., 2008). Additionally, commonly observed are sex-biased parasitism where males are more prone to parasites than pregnant females (Folstad & Karter, 1992; Sheridan et al., 2000). In this study, dry females (non-pregnant) and pregnant females were not differentiated between, this was due to the different breeding strategies employed by pastoralist, thus, I was not able to determine whether a ewe was pregnant or not (or for how long). Furthermore, young animals or juveniles (≤ 1 year) are also expected to have higher parasite loads, as immune responses are not yet established (Taylor, 2009; Villarroel, 2013). Therefore, *males and juveniles are predicted to show a higher parasite prevalence than females and adults.*

Hypothesis III: I argue that minimal forage intake and lowered nutrients, as well as added stresses of an extensive management system in an arid communal rangeland during droughts, increases the risk of parasites as immune systems are compromised (Holmes, 1993; Coop & Kyriazakis, 1999). *Therefore, higher parasite abundances is expected on hosts with lower body condition scores (≤ 2).* Additionally, *larger herds will show higher parasite abundances* (Van Andel et al., 2018).

Hypothesis IV: Intestinal parasites are found in every climate, making them resilient to various conditions, however, the larval stage (L_3 , the most infective stage) remains susceptible to drought and frost (O'Connor et al., 2006). Although this town receives between 100 - 250 mm rainfall annually with an average of 140 mm, it has experienced prolonged drought and occasional frost (Mucina et al., 2006; Climate-Data.org, 2019; SAWS, 2019).

Maximum temperatures may reach 30 °C in summer and minimum as low as 6.7 °C in winter (SAWS, 2019). Average annual temperatures are 16.6 °C, averaging 21.9 °C in summer (January) and 10.3 °C in winter (July) (Climate-Data.org, 2019). Optimal temperatures for helminth development is between 22 and 26 °C, with thresholds at 5 °C and 30 °C (Hansen & Perry, 1994b). Optimal humidity being 100% or as low as 85% (Hansen & Perry, 1994b). Generally, most helminths develop and survive in microclimates (Hansen & Perry, 1994b). In arid and semi-arid regions, mountainous ranges provide the ideal conditions of GIPs to thrive (Hansen & Perry, 1994b). Making it important where the farmer chooses to set up camp (kraal). *Here we expect that herds surrounded by more vegetation and those at higher elevations to have a higher prevalence and abundance of GIPs.*

2.2 Materials and methods

2.2.1 Field sampling

A non-intrusive method of gastrointestinal parasite sampling was done, with all animals carefully handled with the help of a herder or farmer (ethical clearance no.: 15/2/20). We sampled in the winter rainfall region of Steinkopf, which had 3 300 small stock among 21 herds (CSA, 2017). Faecal samples were collected from 11 herds with a total of 225 randomly selected animals comprised of mixed-breed sheep (111), swakara sheep (56), and goats (58) after the winter rains nearing spring (end August). Roscoe (1975) suggests a minimum of 30 individuals for each category of breed, sex, and age, however, due to the time constraint a simple random sampling method was opted for. First body condition was assessed for each animal (Jefferies, 1961; Russel et al., 1969). Thereafter faecal matter was collected from the recta of the animal and stored in airtight plastic bags removing any excess air, and stored in a cooler box with ice packs, while the remainder of sampling took place

throughout the day. When possible the samples were refrigerated at 4 °C (for two weeks of sampling in the Northern Cape) (Nielsen et al., 2010). Additional information included; species, sex, age, approximate herd size, kraal location as well as environmental differences including altitude.

2.2.2 Lab analysis

Since nematode eggs are similar in appearance and difficult to differentiate by species, a subset (1/4) of 55 animals from the 225 were randomly selected to complete faecal egg counts and, the rest of the samples were pooled and prepared as faecal cultures using the Baermann technique to positively identify which helminth species were present (Hansen & Perry, 1994a). These 55 samples included 36 mixed-breed sheep, seven swakara sheep, and 12 goats. To quantify the number of eggs per host, a modified McMasters technique was used (Hansen & Perry, 1994a; Zajac & Conboy, 2006). For each sample, four grams faeces were weighed and added to a 56 ml sodium chloride floatation solution and left for an hour before pipetted onto a McMasters slide. Eggs and oocytes were counted and multiplied by a dilution factor of 50 and identified by microscopy to genus level (Hansen & Perry, 1994a; Gibbons et al., 2005; Zajac & Conboy, 2006). As samples began showing signs of deterioration by the third week, iodine was added to the remaining samples to continue with egg counts (Gibbons et al., 2005). Unfortunately, after the 28 days of incubation and Baermann technique, no nematodes were found under microscope inspection of samples. We, therefore, continued with egg counts and nematodes identified in general as *Strongyle* sp. with the degree of infection for eggs per gram (EPG) noted as *light* (100 – 800 EPG), *moderate* (800 – 1200 EPG) or *heavy* (> 1200 EPG) (Hansen & Perry, 1994a; Urquhart et al., 1996; Gibbons et al., 2005) (Appendix A).

2.2.3 Statistical analysis

Gastrointestinal parasite species present and its prevalence

Parasite infection of hosts is described by; the number hosts infested and, the prevalence of hosts infested, using Fisher's exact test to statistically determine differences between samples for August 2017 (Reiczigel, 2003). Analyses were performed using Quantitative Parasitology 3.0 (Reiczigel et al., 2019). The equation (Eq) of prevalence as suggested by (Rózsa et al., 2000; Reiczigel et al., 2019);

Eq. 1:
$$P (\%) = \frac{i}{N} \times 100$$

where **P** is the prevalence expressed as a percentage, **i** is the number of animals that were found positive for presence of parasites, and **N** = the total number of animals sampled.

Host body condition impact on gastrointestinal parasite abundance

To determine if poor body condition of small ruminants yielded higher gastrointestinal parasite burdens, a generalised linear model (GLM) was run using quasi-Poisson distribution to account for the under-dispersed data ($\sigma^2 < \bar{x}$) (Crofton, 1971a; Elliot, 1977; Shaw & Dobson, 1995; Southwood & Henderson, 2009; O'hara & Kotze, 2010). The response variable was the number of different parasite species (diversity) found in each host, with the explanatory variable being body condition scores for these hosts (1 – 4). Additional explanatory variables included; herd sizes (small 70 – 90, medium 100 – 170 and large 250 – 300, these amounted to 83, 81, and 61 SSU respectively), host breeds (mixed-breed sheep, swakara sheep and goats), host sexes (male or female) and, host life stages (juvenile or adult) (see Figure 1.4). The generalised model (Dobson & Barnett, 2008) and simplified R formula (Fox & Monette, 2002) is represented as;

Eq. 2:
$$y_i = \beta_0 + \beta_1 x_{1i} + \dots + \beta_p x_{pi} + \epsilon_i,$$

Eq. 3:
$$y \sim x_1 + x_2$$

Where **y** was the number of GIPs found in each host, **x1** represented body condition scores and **x2** the additional host explanatory factors such as herd sizes, breed, sex, life stage, kraal, and location.

Furthermore, a multinomial logistic regression (MLR) was performed to determine whether body condition predicted specific changes in parasite species. This was done using body condition as the dependent variable and egg densities of each parasite species as multiple independent variables. Although MLR allows for predictive modelling, this was not considered since biases brought on by analysing parasite egg densities (Hansen & Perry, 1994b). To perform statistical analysis R version 3.4.3 (R Core, 2013) was used using MASS, sm, mlogit, and nnet packages and SPSS version 22.0 (Ho, 2013).

Environmental variables associated with gastrointestinal parasite presence and abundances

To model gastrointestinal parasite burdens as a function of environmental factors, a constrained redundancy analysis (RDA) was run using Hellinger transformation (Zuur et al., 2007). Response variables included six parasite species which showed highest egg densities at each kraal sampled namely; *Trichus* sp., *Ascaris* sp., *Monezia* sp., *Nematodirus* sp., *Strongyloid* sp. and, *Coccidia*. Additionally, the explanatory variables per kraal included; herd size (70 – 300 SSU), vegetation types (Kosiesberg Succulent Shrubland (KSS), Anenous Plateau Shrubland (APS), Namaqualand Klipkoppe Shrubland (NKS), Namaqualand Shale Shrubland (NSS) and, Namaqualand Blomveld (NB) (Mucina et al., 2014)), altitude (855 to

1123 masl), surface soil moisture (SSM) and, normalised differential vegetation index (NDVI). Soil moisture measurements (m^3 / m^3) and NDVI were obtained using NASA-USDA SMAP Global Soil Moisture Data ($0.25^\circ \times 0.25^\circ$ spatial resolution), USGS Landsat 7 Collection 1 Tier 1 and Real-Time data Raw Scenes layers respectively and, analysed using short-term time-series modelling in Google Earth Engine for the time of sampling (end August 2017) (Bolten et al., 2009; Fernandes et al., 2017; Gorelick et al., 2017). R statistical software version 3.4.3 (R Core, 2013), was used to run and plot redundancy analysis using the MASS, vegan, ggplot2 and ggord packages.

2.3 Results

Gastrointestinal parasite species present and its prevalence

Nine gastrointestinal parasite species were identified, with most showing no degree of infection and two namely; *Strongyle* eggs and *Coccidia* oocysts representing high degrees of infection (Table 2.1). The overall prevalence for GIPs was 100% with prevalence for individual parasites species highest in mixed-breed sheep followed by goats and lastly swakara sheep (Table 2.2). Fisher's exact test showed no significant differences between the parasite prevalence of hosts ($p > 0.05$).

Table 2.1: Average faecal egg counts (EPG) of gastrointestinal parasites and their degree of infection (light 100 – 800, moderate 800 – 1200 or heavy > 1200) found in small ruminants of the Steinkopf communal rangeland.

Intestinal parasite eggs	Average number eggs/oocytes per gram faeces	Degree of infection
<i>Trichuris</i> sp.	34.82	None
<i>Ascaris</i> sp.	230.36	Light
<i>Monezia</i> sp.	89.29	None
<i>Nematodirus</i> sp.	19.64	None
<i>Aonecotheca</i> sp.	3.57	None
<i>Paramphistimum</i> sp.	0.89	None
<i>Bunostomum</i> sp.	0.89	None
<i>Strongyle</i> sp.	6,002.68	Heavy
Coccidia oocysts	29,865.18	Heavy

Table 2.2: Number hosts infected and prevalence (%) of gastrointestinal parasites of mixed-breed sheep, goats and swakara sheep of the Steinkopf communal rangeland.

	Total	Mix-breed	Goats	Swakara sheep
	All livestock	sheep		
	No. (%)	No. (%)	No. (%)	No. (%)
<i>Trichuris</i> sp.	19 (33.9)	11 (30.6)	3 (23.1)	5 (71.4)
<i>Ascaris</i> sp.	45 (80.4)	31 (86.1)	9 (69.2)	5 (71.4)

<i>Monezia sp.</i>	56 (42.9)	36 (50.0)	12 (38.5)	7 (14.3)
<i>Nematodirus sp.</i>	12 (21.4)	7 (19.4)	3 (23.1)	2 (28.6)
<i>Strongyle sp.</i>	56 (100)	36 (100)	12 (100)	7 (100)
Coccidia	56 (100)	36 (100)	12 (100)	7 (100)

*significance at $p < 0.05$ showing differences between groups

Host body condition impact on gastrointestinal parasite abundance

Generalised linear model ($N = 55$, $X^2 = 6.71$, $df = 9$, $p = 0.010$) predicts for every one-unit increase in BCS 3 the expected log count of gastrointestinal parasite species would decrease by 0.27402 ($\beta = 0.35954$, $p = 0.0139$) (Appendix B). Body conditions 2 and 4 also predict this decrease in gastrointestinal parasite species given the increase in BCS, however these estimates are not statically significant ($\beta = -0.03347$, $p = 0.731$ and $\beta = -0.21207$, $p = 0.177$ respectively) (Figure 2.1). Furthermore, the model predicts for each one-unit increase in herd sizes medium and small the expected log count of GIPs increases by 0.22660 ($p = 0.039$) and 0.32317 ($p = 0.002$) (Figure 2.2). Additionally, the model suggests a one-unit increase in host types mixed-breed and swakara sheep would predict an increase in gastrointestinal parasite species ($\beta = 0.17931$, $p = 0.067$ and $\beta = 0.19730$, $p = 0.151$ respectively) (Figure 2.3). A one-unit increase in males (Figure 2.4) and juveniles (Figure 2.5) would result in a decrease in GIPs species $\beta = -0.06010$, $p = 0.504$ and $\beta -0.01955$, $p = 0.802$ respectively). The overall model fit was $R^2 = 0.12$ (Cragg-Uhler) or $R^2 = 0.03$ (McFadden). Predicted values of GIPs for explanatory variables are shown graphically in Figures 2.1 – 2.5. Lastly, the multinomial logistic analysis showed no significant ($p > 0.05$) associations between body condition and egg abundances for individual parasite species.

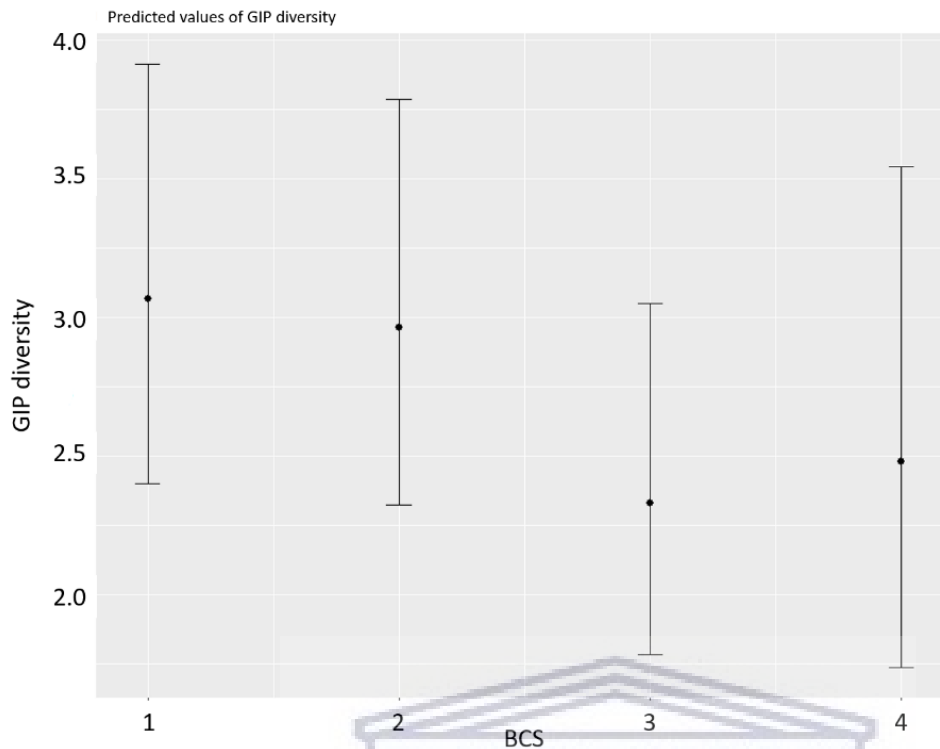


Figure 2.1: Marginal predicted values and standard errors from GLM of gastrointestinal diversity for body conditions (1 - 4).

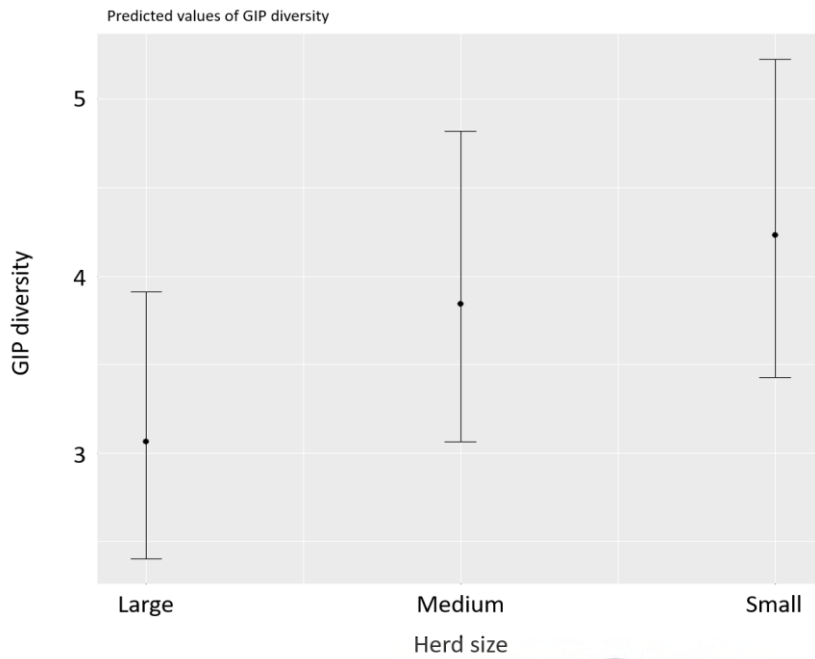


Figure 2.2: Marginal predicted values and standard errors from GLM of gastrointestinal diversity for herd sizes large (250 – 300 SSU), medium (100 – 170 SSU) and, small (70 – 90 SSU).

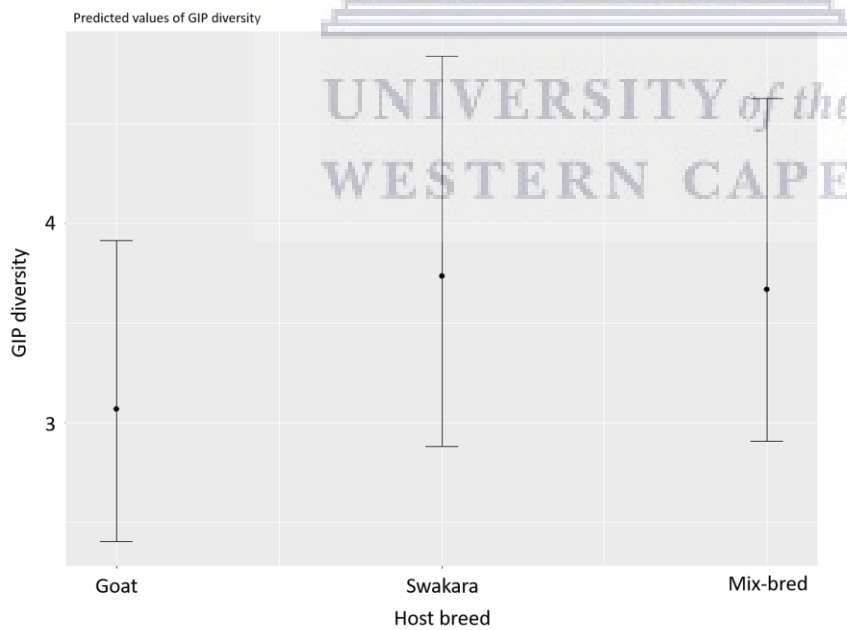


Figure 2.3: Marginal predicted values and standard errors from GLM of gastrointestinal diversity for host breeds (goat, swakara and, mixed-breed sheep).

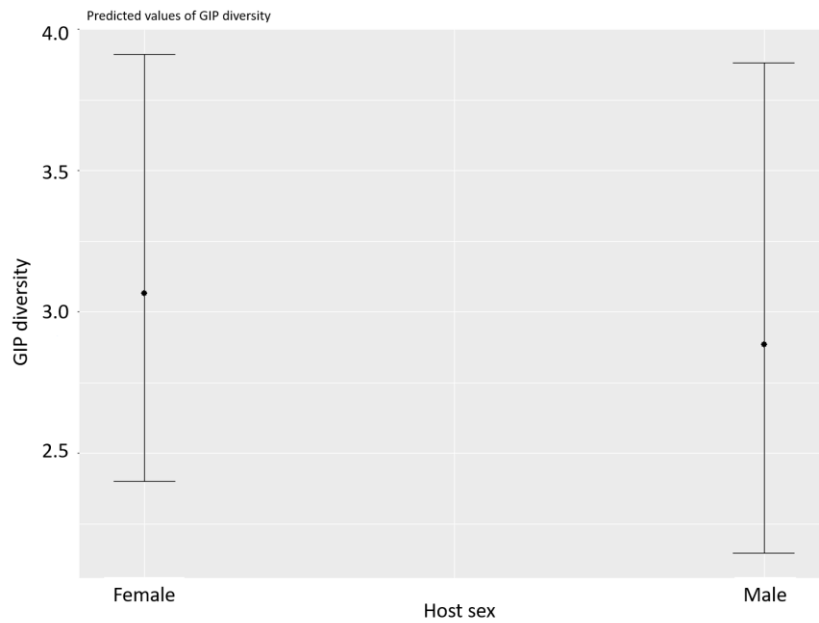


Figure 2.4: Marginal predicted values and standard errors from GLM of gastrointestinal diversity for host sexes (female and male).

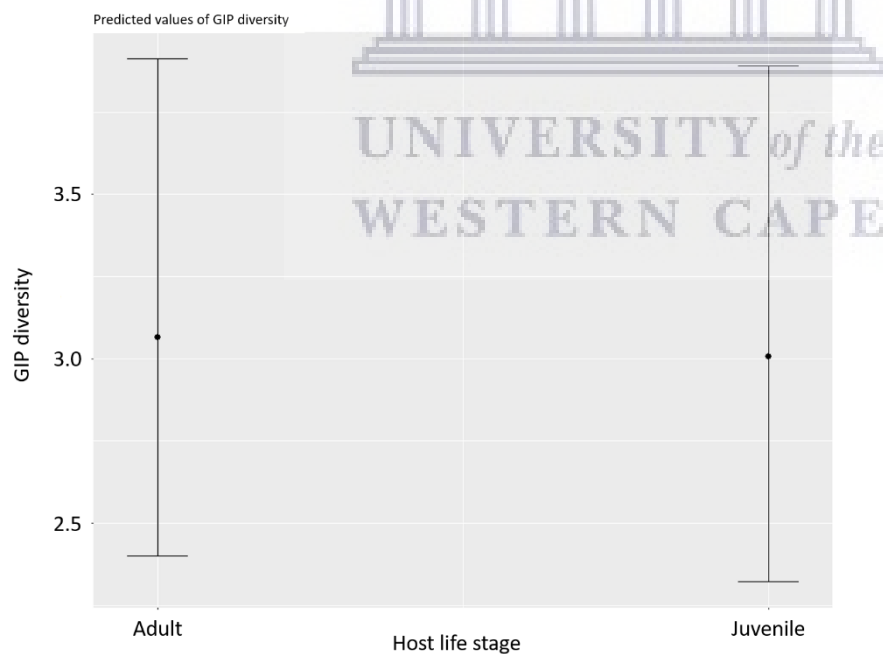


Figure 2.5: Marginal predicted values and standard errors from GLM of gastrointestinal diversity for host life stages (adult and juvenile).

Environmental variables associated with gastrointestinal parasite presence and abundances

The first two axes of the redundancy analysis explained 93.33% of the variation in gastrointestinal parasite presence and abundance to the environment (see Appendix B for eigenvalues). Analysis of constrained versus unconstrained variance shows much of the variation in the response data is accounted for by the explanatory variables (Constrained 0.011368 > Unconstrained 0.001668) (Ter Braak & Prentice, 1988). The plot showed a strong positive relationship between species (RDA; $F = 1.7041$, $df = 8$, $p = 0.352$, $R^2 = 0.0016678$) (Figure 2.6 and Appendix B for full results); *Nematodirus* sp., *Ascaris* sp., *Trichuris* sp., and *Monezia* sp., and environmental variables; altitude, NDVI, SSM and, vegetation type Kosiesberg Succulent Shrubland VTKSS). Additionally, the plot showed a strong positive association between Coccidia and vegetation types Namaqualand Blomveld (VTNB) and Namaqualand Klipkloppe Shrubland (VTNKS). Lastly, *Strongyle* sp. is positively associated with herd size and vegetation type Namaqualand Shale Shrubland (VTNSS). The plot also shows NDVI and herd size to be negatively associated with one another at opposite scales.

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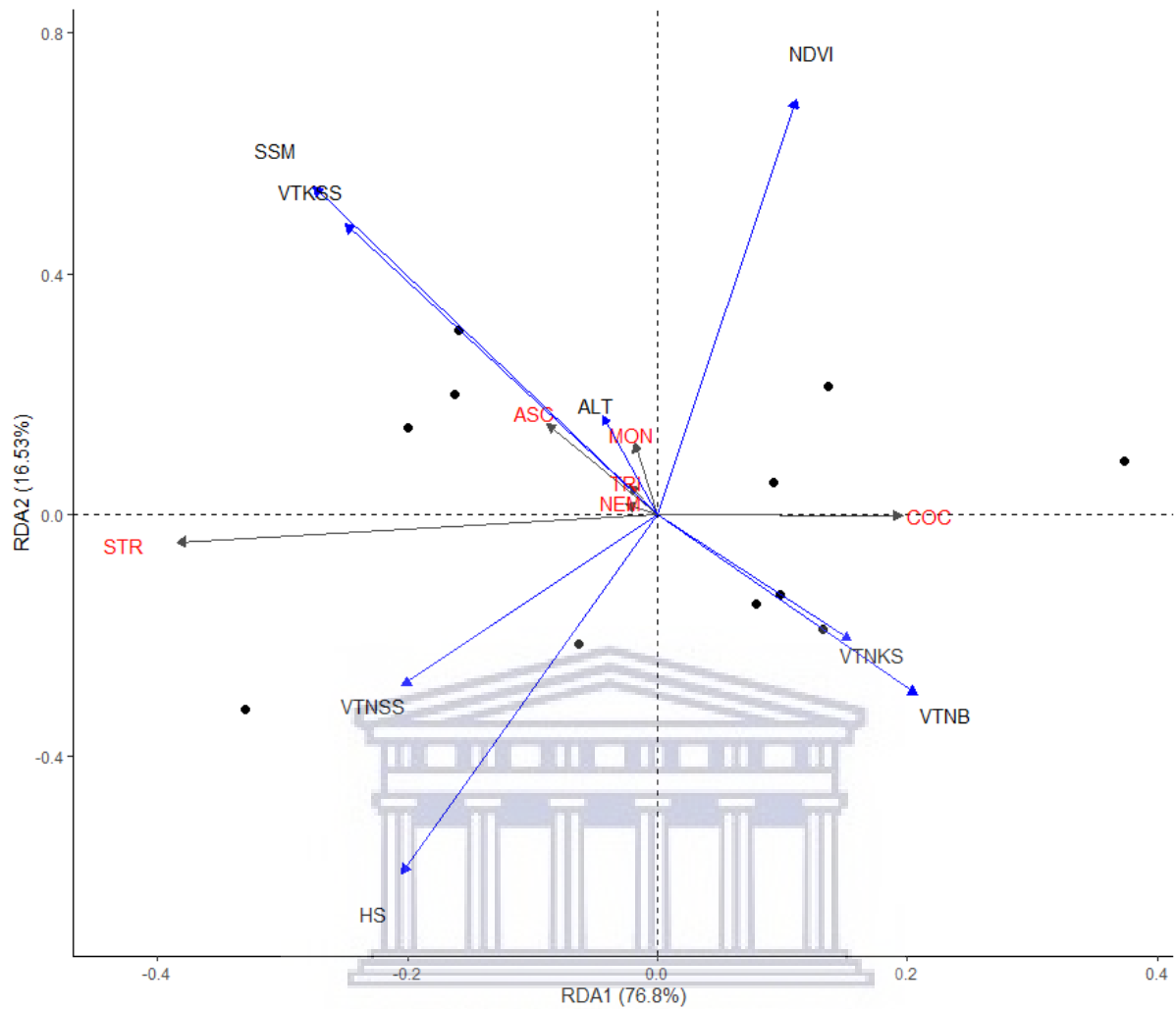


Figure 2.6: Redundancy analysis of gastrointestinal parasite burdens, herd size, and environmental variables from 11 kraals sampled in August 2017. Gastrointestinal parasite species include; *Trichuris* sp. (TRI), *Ascaris* sp. (ASC), *Monezia* sp. (MON), *Strongyle* sp. (STR), *Coccidia* (COC) and, *Nematodirus* sp. (NEM). Environmental variables include; altitude (ALT) and, normalised difference vegetation index (NDVI), surface soil moisture (SSM) and, vegetation types; Namaqualand Shale Shrubland (VTNSS), Namaqualand Blomveld (VTNB), Kosiesberg Succulent Shrubland (VTKSS) and, Namaqualand Klipkloppe Shrubland (VTNKS).

2.4 Discussion

Gastrointestinal parasite species present and its prevalence

Due to little parasite research, being done on this rangeland a 50% endoparasite prevalence was predicted. However, all hosts sampled were infected by one or more gastrointestinal parasite species, not supporting the first hypothesis. Brody (2019) suggests a gastrointestinal parasite prevalence of at least 30% warrants treating all livestock for parasite infection.

Usually, parasite population dynamics dictate a skewed distribution or over-dispersion, with few hosts harbouring high parasite burdens and the rest low to medium burdens (Barger, 1985; Sreter et al., 1994; Vlassoff et al., 1999; Hoste et al., 2001). Instead in this study a diverse range of GIPs were identified; *Coccidia* (Coccidial oocysts, *Eimeria* sp.), *Strongyle* sp., *Ascaris* sp. (roundworm), *Monezia* sp. (tapeworm), *Trichuris* sp. (whipworm), *Nematodirus* sp. (roundworm), *Aonchotheca* sp., *Paramphistimome* sp. (flatworm) and, *Bunostomum* sp. (hookworm).

The first six species were most abundant in all samples and, seen as more prevalent in mixed-breed sheep and swakara, as well as females and adults but statistically showed no significant differences thereby not supporting the second hypothesis (Figures 2.7 and 2.8). In comparison, other studies have shown when kept in mixed herds as opposed to separately, goats show higher parasite burdens compared to sheep as stocking density increased (Boomker et al., 1994; McGregor, 2010). Further, juvenile goats were more prone to diseases such as coccidiosis a disease caused by the protozoan parasite *Eimeria* spp. hereto referred to as *Coccidia* (Bath et al., 2005).

Studies on antihelminthic treatment advises not to treat low gastrointestinal burdens as this may result in heightened immunities of GIPs (Bath et al., 2005). The recommendation is to

treat *Coccidia* when you encounter more than 1 000 oocysts per gram faeces (Villarroel, 2013). In this study, the average host showed approximately 30 000 oocysts/g faeces (Table 2.1), higher than similar studies done on communal rangelands in South Africa (Harper & Penzhorn, 1999). *Coccidia* and *Strongyle* sp. were the most abundant oocysts/eggs appearing in all samples (Table 2.2). *Coccidia* is a common parasite found in livestock, with most animals infected but not affected (not diseased) as they have developed immunities to the protozoan over time (Luginbuhl & Anderson, 2015). Thus, it is the young (goats between 3 weeks and 5 months), the sick and, stressed animals most at risk at developing coccidiosis, with symptoms including diarrhoea and weight loss (Taylor, 2009; Chartier & Paraud, 2012). Other important parasite eggs found were roundworms, *Nematodirus* sp. and *Acaris* sp., which are detrimental to livestock as they cause anaemia. However, egg densities were not high. For Ascarid eggs to show significant infection it is advised to drench animals with faecal egg counts > 1 000 EPG, in this study we determined an average of 230 EPG (Table 2.1). As we could not identify any specific helminth species, we recognise they may fall under importance species generally found in arid regions such as; *Nematodirus spathiger*, *Strongyloides papillosus* (Gobabis Boksiekte), *Gaigeria pachyscelis* (sandveld hookworm) (Levine, 1980; Pienaar et al., 1999; Bath et al., 2005).

Host body condition impact on gastrointestinal parasite abundance

Significant (GLM) results indicate lower body conditions (≤ 2) show higher parasite numbers but no specific parasite genus (MLR) was correlated to poor health in these hosts. That is, a larger diversity of GIPs was found in hosts with poorer health. This validates the third hypothesis. However, the result does not verify the cause as being lowered nutrients (due to the lack of forage from the drought) as motivated by the hypothesis. Alternately, the reason for the lowered body condition may be the result of pre-existing gastrointestinal burdens

(Symons & Jones, 1975; Jones & Symons, 1982; Symons & Jones, 1983; Sykes et al., 1988; Parkins & Holmes, 1989; Butter et al., 2000; Roy et al., 2003). Although these GIPs are usually widely distributed in the gastrointestinal tract occupying different portions (small intestine, large intestine, abomasum), their accumulated impact on each host leads to body condition loss (Roy et al., 2003). Sheep that are infected with parasites exhibit reduced feed intake by 15 – 20%, as well as changes in nutrient partitioning, with altered carbohydrate, protein, mineral and hormone metabolism, as nutrients, are instead used for immune response and to repair damage brought on by the parasite rather than for growth (Nielsen, 1982; Sykes et al., 1988; Parkins & Holmes, 1989; Butter et al., 2000).

Research shows sheep (as opposed to goats) are more resilient in bouncing back from gastrointestinal parasite infections (Steel et al., 1980; McGregor, 2010). With malnourished goats being more susceptible to gastrointestinal parasite infection (Bath et al., 2005). The FAMACHA (FAffa MAlan CHArt) methods used to assess body condition score proved valuable in determining the gastrointestinal burdens of sheep and goats, suggesting to farmers to drench those animals with poor condition scores and/or showing signs of anaemia (Bath et al., 2005).

Lastly, herd size is the other factor influencing parasite abundances. With smaller and medium herds exhibiting higher parasite infection (abundances). This may be the result of smaller herds kept at a higher proportional density to larger herds as well as being owned by poorer farmers, who cannot afford antihelminthic drugs (Kusiluka & Kambarage, 1996a; Altizer et al., 2006).

Environmental variables associated with gastrointestinal parasite presence and abundances

As predicted, we found a strong relationship between vegetation (Kosiesberg Succulent Shrubland) and parasites, *Nematodirus* sp., *Ascaris* sp., *Trichuris* sp., and *Monezia* sp. These were also correlated to surface soil moisture. Due to the high altitude (500 – 1100 masl) of this vegetation type, which is a major part of the mountain ranges in the area, it experiences higher rainfall (100 – 200 mm) as well as fog, making the dominant plant types large shrubs. Although this vegetation type is not conserved the expansion of small stock farming here is a threat (Van Jaarsveld, 1981; Jürgens et al., 1997; Jurgens, 2004; Mucina et al., 2006). Proving that this area is a common grazing area, this increases host availability, which in turn influences parasite abundances.

Additionally, the most abundant parasite eggs *Strongyle* sp. were found strongly associated with vegetation type Namaqualand Shale Shrubland. A majority of this vegetation type is found at a high altitude (500 – 1 100 masl), with high plant species richness and abundance due to due to orogenic rains and clay soils retaining water (Mucina et al., 2006). The increase in herd size shown on the plot as well as the subsequent increase in *Strongyle* sp. as the continuous presence of hosts (small ruminants) with this area possessing some of the wettest areas in the region and vegetation diversity makes it an ideal area for parasite fostering.

Furthermore, we find that the most abundant parasite protozoa species *Coccidia* is strongly correlated to vegetation types; Namaqualand Blomveld and Namaqualand Klipkloppe Shrubland. Both these vegetation types are found in valleys and open plains, dominated by rocks (Namaqualand Klipkloppe Shrubland or have occasional rivers (Namaqualand Blomveld). Water is a common feature for both these vegetation types, thus explaining the

presence of *Coccidia* as these parasites are found in wet areas and where animals are known to congregate such as waterpoints.

Lastly, we found NDVI and herd size to be negatively associated. Suggesting larger herds have or are moving further from the more heavily grazed areas that we see with smaller herds, to increasing vegetation or “greenness” (as an increase in NDVI does not necessarily mean an increase in palatable species) where they are less affected by GIPs. These results suggest that the less disturbed areas, having more plant productivity and diversity, for animals to graze may improve their nutrition. Alternately, the greater the variety of plants could mean the presence of plants with antihelminthic properties such as *Aloe ferox* (Bath et al., 2005; Maphosa & Masika, 2012).

2.5 Conclusion

Although data was gathered from a smaller subset of the livestock population, the data showed GIPs to be widely distributed among hosts as well as in this rangeland. Though not all species eggs may develop in the animal (some are harsher than others), knowing and understanding which species are present may help to improve control strategies. In addition, this could help to identify grazing camps and assist in grazing systems.

CHAPTER 3: Seasonal sampling of ixodid ticks in Steinkopf semi-arid communal rangeland, Northern Cape

3.1 Introduction

Ticks belong to two major families, Ixodidae and Argasidae but our study focused on ixodid ticks (Acari: Ixodidae) and this family is of veterinary importance in the livestock industry. Many aspects regarding epidemiology of ticks such as distributions, range expansion, life-cycles, seasonal abundances, feeding strategies, preferred hosts, diseases transmitted as well as genetic makeup have been investigated by several authors (Coetzer & Tustin, 2004; Walker et al., 2005; Guglielmone et al., 2010; Baron et al., 2018). Despite this, we find a lack of studies done on communal rangelands in the Northern Cape Province. The Northern Cape Province of South Africa is largely a semi-arid to arid environment characterised by low rainfall and high evaporation rates which does not allow for much crop farming, making the main land use extensive livestock farming on both private and communal rangelands (Hoffman et al., 2009). Communal rangelands are generally characterised as being resource-poor, having low animal production, and high degradation (Lamprey, 1983; Bembridge & Tapson, 1993; Milton et al., 1994). Nevertheless, communal rangelands account for 13% of land used by (agro-) pastoralists where they contribute 50% of the country's livestock production (Scogings et al., 1999). On communal rangelands, pastoralism is not only a means of income but also a mechanism of subsistence farming, as well as the holding of traditional and cultural value (Neely et al., 2009).

Acarid ticks and tick-borne diseases account for the main economic loss to both communal and commercial farmers, therefore, they are considered to be of veterinary and economic importance (Fourie et al., 1988; Beinart & Brown, 2013). Consequently, a bulk of local

research focuses on high-risk areas such as the eastern and northeast extent of South Africa where tropical to subtropical conditions allow for higher potential for parasite and disease outbreak leaving semi-arid and arid communal rangelands such as Steinkopf in the Northern Cape less explored.

Therefore, the overall aim of this chapter is to understand the tick communities found in Steinkopf through identification of the species found, their relationship and impacts on hosts and lastly how abiotic and habitat influences their distribution, with the following research questions and *hypothesis*:

1. What is the prevalence and species richness of ticks found during seasonal sampling in the winter-rainfall areas of Steinkopf?
 - I. *We expect tick prevalence of 50 % or less.*
 - II. *We expect males and in particular adult males showing a higher prevalence than juveniles (≤ 1 year) and females.*
2. How does host health influence tick abundance?
 - III. *We expect higher parasite abundances on hosts with lower body condition scores.*
3. Which environmental variables are associated with tick presence and abundances?
 - IV. *We expect that herds surrounded with thicker vegetation and those at higher elevations to have higher prevalence and abundance of ticks, as well as larger herds.*

Hypothesis I & II: *We expect tick prevalence of 50% or less* (Roscoe, 1975; Wall & Shearer, 2001) due to no previous studies being conducted in this rangeland. Furthermore, studying

the physiology and behaviour of our host population, we expect higher tick prevalence on males for both host species. This is because of the parasite immunity of indigenous breeds; the mixed-breed sheep and boer goats (Macivor & Horak, 2003). Studies indicate higher testosterone in mature males leads to lowered immunity, and therefore higher parasite abundances when compared to females (Folstad & Karter, 1992). The opposite applies to pregnant females which have heightened immunity, leading to little or no parasite attachment. Therefore, *we expect males and in particular adult males showing a higher prevalence than juveniles (≤ 1 year) and females.*

Hypothesis III: The recent drought in South Africa (2014 - 2016) which was more severe in the winter rainfall region, has left many farmers seeking drought-relief (Vogel & van Zyl, 2016; Botai et al., 2017; Ndlazi, 2017; WeatherNet, 2019). Ignoring parasite resilience of indigenous livestock breeds, we argue that minimal forage intake and lowered nutrients increase the risk of parasites as immune systems are compromised (Coop & Kyriazakis, 1999). Therefore, *we expect higher parasite abundances on hosts with lower body condition scores (≤ 2).*

Hypothesis IV: For ticks to survive they require more than 85% humidity, and temperatures $7\text{ }^{\circ}\text{C} \leq 40\text{ }^{\circ}\text{C}$ (Süss et al., 2008). This town receives between 100 - 250 mm rainfall per annum with an average of 140 mm with humidity averaging 57% (Thorsen, 2019; Climate-Data.org, 2019; SAWS, 2019; WeatherNet, 2019). Maximum and minimum temperatures can reach $30\text{ }^{\circ}\text{C}$ and $6.7\text{ }^{\circ}\text{C}$ in summer and winter respectively (SAWS, 2019). Thus, average annual temperatures are $16.6\text{ }^{\circ}\text{C}$, averaging $21.9\text{ }^{\circ}\text{C}$ in summer (January) and $10.3\text{ }^{\circ}\text{C}$ in winter (July) (Climate-Data.org, 2019). Although temperatures do not play a significant role in tick distribution, it does influence humidity and aids development. Vegetation and varying vegetation types help establish microclimates through relative humidity (Ginsberg &

Stafford, 2005). Making it important where the farmer chooses to set up camp (stock-post). For instance, unpalatable plants are less disturbed and grow densely providing a stable habitat for ticks as they outcompete palatable plants (eaten by herbivores) thus, providing good height to attach to passing hosts, (MacDonald, 2018). Therefore, *we expect that herds surrounded with thicker vegetation and those at higher elevations to have higher prevalence and abundance of ticks, as well as larger herds.*

3.2 Research methods

3.2.1 Field sampling

Ticks were collected from 11 (easily accessible and willing) herds totalling 225 randomly selected small-ruminants comprised of mixed-breed sheep (111) (includes; Merino, Dorper, Meat master, Damara), swakara sheep (56), and boer goats (58). Full body searches were done with the help of the farmer or herder, paying special attention to common attachment sites (head, groin, legs) in some instances all ticks were removed or a subset of representative species due to time constraints and the “eyeball” method used to total amount of ticks on each host sampled (Drummond, 1967; MacIvor et al., 1987), (ethical clearance no: 15/2/20). Ticks were removed using fine-nosed tweezers and preserved in 70% ethanol solution (Schouls et al., 1999). In addition, each animal captured was assessed and scored on body condition 1 – 5 (‘1’ being poor and ‘5’ excellent), with further notes including; species, sex, age, approximate herd size, herd composition, stock-post location as well as environmental parameters including altitude (Jefferies, 1961; Russel et al., 1969; Gatenby, 1991; Steele, 1996).

3.2.2 Lab analysis

Ticks were identified to species level under a dissecting microscope using descriptions provided by Walker (2003), these included looking at; the colour and shape of the tick and its legs, the shape and length of the capitulum, the shape of the eyes and the length of the mouth as well as the position and presence or absence of punctuations on the body (Walker, 2003; Horak et al., 2018; Rapiya et al., 2019). Samples were pooled according to species and sex and tick identities were confirmed by an acarologist expert (Dohne Research Institute, Stutterheim, South Africa).

3.2.3 Statistical analysis

Tick species present and their prevalence

Parasite infection of hosts is described by; prevalence with upper and lower confidence intervals using Sterne's method and Fisher's exact test with Yates correction to statistically determine differences between samples (Reiczigel, 2003). Prevalence as suggested by (Rózsa et al., 2000; Reiczigel et al., 2019);

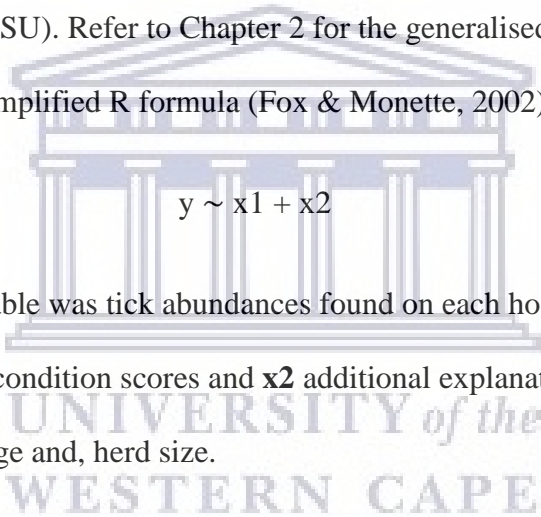
$$P (\%) = \frac{i}{N} \times 100$$

where **P** is the prevalence expressed as a percentage, **i** is the number of animals that were found positive for presence of parasites, and **N** the total number of animals sampled.

To further describe parasite infection; median abundances (more suitable for smaller sample sizes) as well as mean crowding were used (Reiczigel, 2003). For individual tick species, the number of hosts infested, the prevalence of hosts infested as well as the number of ticks recovered categorised by male, female and nymph were determined. Analyses were performed using Quantitative Parasitology 3.0 (Reiczigel et al., 2019).

Host body condition impact on tick abundance

As none of the data were normally distributed (Kolmogorov-Smirnov test: $p < 0.001$), a nonparametric analysis was used (Wilson & Grenfell, 1997; Alexander, 2012). To determine the effect of body condition on parasite (tick) abundances (categorical variables vs continuous data) we used negative binomial generalised linear modelling (GLM) with log-link function due to overdispersion of the count data ($\sigma^2 > \bar{x}$) (Shaw & Dobson, 1995; Southwood & Henderson, 2009; O'hara & Kotze, 2010). Additional explanatory variables included; host species (mixed-breed sheep, swakara sheep and boer goats), host sex (male or female), host life stage (juvenile or adult), herd size (small 70 – 90 SSU, medium 100 – 170 SSU and large 250 – 300 SSU). Refer to Chapter 2 for the generalised model (Dobson & Barnett, 2008). Here the simplified R formula (Fox & Monette, 2002) is represented as;


$$y \sim x1 + x2$$

Where **y** the response variable was tick abundances found on each host, **x1** the explanatory variable represented body condition scores and **x2** additional explanatory variables such as species, breed, sex, life stage and, herd size.

Environmental variables associated with tick presence and abundances

To model tick abundances as a function of environmental factors, redundancy analysis (RDA) was used (Zuur et al., 2007). Response variables were abundances for tick species found at each farm (stock-post) sampled. Explanatory variables included; altitude (855 masl to 1123 masl), surface soil moisture (SSM), normalised differential vegetation index (NDVI), vegetation type, internal parasite load, overall tick density and herd size. Soil moisture measurements (m^3 / m^3) and NDVI were gathered for the time of sampling (end August 2017)

for individual stock-posts using NASA-USDA SMAP Global Soil Moisture Data (0.25° x 0.25° spatial resolution), USGS Landsat 7 Collection 1 Tier 1 and Real-Time data Raw Scenes layers respectively and, analysed using short-term time-series modelling in Google Earth Engine (Bolten et al., 2009; Fernandes et al., 2017; Gorelick et al., 2017). Vegetation types for this region include; Kosiesberg Succulent Shrubland, Anenous Plateau Shrubland, Namaqualand Klipkoppe Shrubland, Namaqualand Shale Shrubland and, Namaqualand Blomveld (Mucina et al., 2014). R statistical software version 3.4.3, was used to run and plot redundancy analysis using the MASS, vegan, ggplot2 and ggord packages (R Core, 2013).

3.3 Results

Tick species present and their prevalence

A total of 225 small-ruminants were sampled of which 167 (74%) were sheep, either mixed-breed sheep (Merino, Dorper etc.) or swakara sheep, and 58 (26%) were goats (boer goats). From these hosts, 279 ixodid ticks were collected representing three species summarised in Table 3.1 and pictured in Figure 3.1. As shown in Table 3.1, three tick species were found with abundances that vary across species with *Rhipicephalus gertrudae* (Feldman-Muhsam, 1960), being the most abundantly found among hosts followed by *Hyalomma truncatum* (small smooth bont-legged tick) (Koch, 1844) and then *Rhipicephalus (Boophilus) microplus* (Asiatic blue tick) (Canestrini, 1888). The overall prevalence of tick infection was 56.4%; Fisher's exact test using Yates correction shows that there was no significant difference between prevalence of host species ($p > 0.05$). In addition, for both sheep and goats, there was no significant difference ($p > 0.05$) between the parasite prevalence of male and female or adult and juvenile.

Results of tick burdens for livestock of Steinkopf (Table 3.2) show mixed-breed sheep to be most burdened by all three species of tick, with *R. microplus* showing the highest prevalence and *R. gertrudae* with the highest intensity. Additionally, goats were second most burdened by ticks, with highest intensity and prevalence for *R. gertrudae*. Lastly, swakara sheep were the least burdened by ticks, with no *R. microplus* species found on these hosts, and *R. gertrudae* being the highest intensity but *H. truncatum* highest prevalence. Lastly, intensity and mean crowding of ticks were 1 to 2 ticks per host (Appendix B).



Figure 3.1: Tick species (from top left to right) *Rhipicephalus gertudae* female, male and nymph, *Rhipicephalus* engorged female and *Hyalomma truncatum* female. Tick hosts (bottom left) mixed herd with swakara sheep and goats, (bottom right) mixed herd of mixed-breed sheep and goat.

Table 3.1: Percentage of hosts infested with each tick species in addition to total number of ticks showing number of males, females and nymphs recovered.

	Host infested (%)	Number ticks recovered		
		Nymphs	Male	Female
<i>Rhipicephalus gertrudae</i>	83.92	16	105	107
<i>Hyalomma truncatum</i>	10.49	0	22	20
<i>Rhipicephalus microplus</i>	5.59	0	0	9

Table 3.2: Intensity and prevalence (Confidence Intervals) of tick (acarid) burdens of small ruminant hosts; goats, mixed-breed sheep and swakara sheep of the Steinkopf communal rangeland.

	<i>Rhipicephalus gertrudae</i>		<i>Hyalomma truncatum</i>		<i>Rhipicephalus microplus</i>	
	Intensity	Prevalence (CI)	Intensity	Prevalence (CI)	Intensity	Prevalence (CI)
Mixed-breed sheep	68	0.557 (0.467 - 0.644)	11	73.3 (0.466 - 0.903)	7	87.5 (0.500 - 0.994)
Goats	30	24.6 (0.175 - 0.332)	1	0.067 (0.003 - 0.302)	1	12.5 (0.006 - 0.500)
Swakara sheep	24	19.7 (0.134 - 0.278)	3	20 (0.057 - 0.466)	0	0

Host body condition impact on tick abundance

Although there is a significant difference between body condition scores ($p = 0.011$, Table 3.3 and Figure 3.2) it was not a good indicator for the number of ticks on hosts, therefore not supporting the third hypothesis (see Appendix B for full GLM results). The model (NBGLM; $N = 225$, $df = 215$, $X^2 = 226.18$, $p = 0.339$) showed; mixed-breed sheep (Figure 3.3; $\beta = 0.55237$, $p = 0.017$), males (Figure 3.4; $\beta = -0.48615$, $p = 0.048$), juveniles (Figure 3.5; $\beta = -0.45851$, $p = 0.019$), herd sizes medium ($\beta = 0.73082$, $p = 0.003$) and, small ($\beta = 1.04573$, $p < 0.01$) were good indicators for tick abundances (Figure 3.6). Furthermore, the model shows for each one-unit increase in BCS 2 the expected log count of the number of ticks decreases by 0.01880 which is significant predictor ($p = 0.001$). Thereafter BCS 3 and 4 show ($\beta = 0.20258$, $p = 0.433$) and ($\beta = 0.35954$, $p = 0.278$) for every one-unit increase in each an expected log count of ticks' increase by 0.20 and 0.43 respectively, these results are not significant. Lastly, host breed swakara was not a significant predictor ($\beta = 0.06908$, $p = 0.790$). The overall model fit was $R^2 = 0.16$ (Cragg-Uhler) or $R^2 = 0.05$ (McFadden).

Table 3.3: shows the proportion of hosts with low/poor body conditions (1 and 2) as most prevalent on this communal rangeland, with few hosts categorised as good (4) and none as excellent (5).

		1	2	3	4	5
Mixed-breed sheep		18%	32%	32%	17%	0%
	Male	5%	24%	38%	32%	0%
	Adult	7%	14%	36%	43%	0%
	Juvenile	4%	30%	39%	26%	0%
	Female	24%	36%	30%	9%	0%
	Adult	30%	40%	23%	8%	0%
	Juvenile	10%	29%	48%	14%	0%
Goats		50%	41%	5%	3%	0%
	Male	0%	86%	0%	14%	0%
	Adult	0%	100%	0%	0%	0%
	Juvenile	0%	83%	0%	17%	0%
	Female	57%	35%	6%	2%	0%
	Adult	64%	33%	3%	0%	0%
	Juvenile	40%	40%	13%	7%	0%
Swakara sheep		38%	41%	18%	4%	0%
	Male	25%	50%	25%	0%	0%
	Adult	0%	50%	50%	0%	0%
	Juvenile	50%	50%	0%	0%	0%
	Female	38%	40%	17%	4%	0%
	Adult	44%	32%	20%	5%	0%
	Juvenile	18%	73%	9%	0%	0%
Grand total		31%	37%	22%	10%	0%

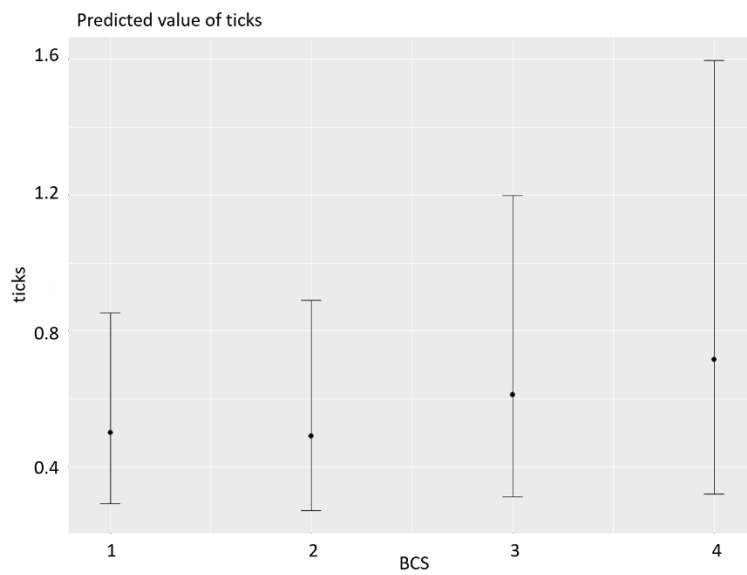


Figure 3.2: Marginal predicted values and standard errors from NBGLM of tick abundances for host body condition scores (1 – 4).

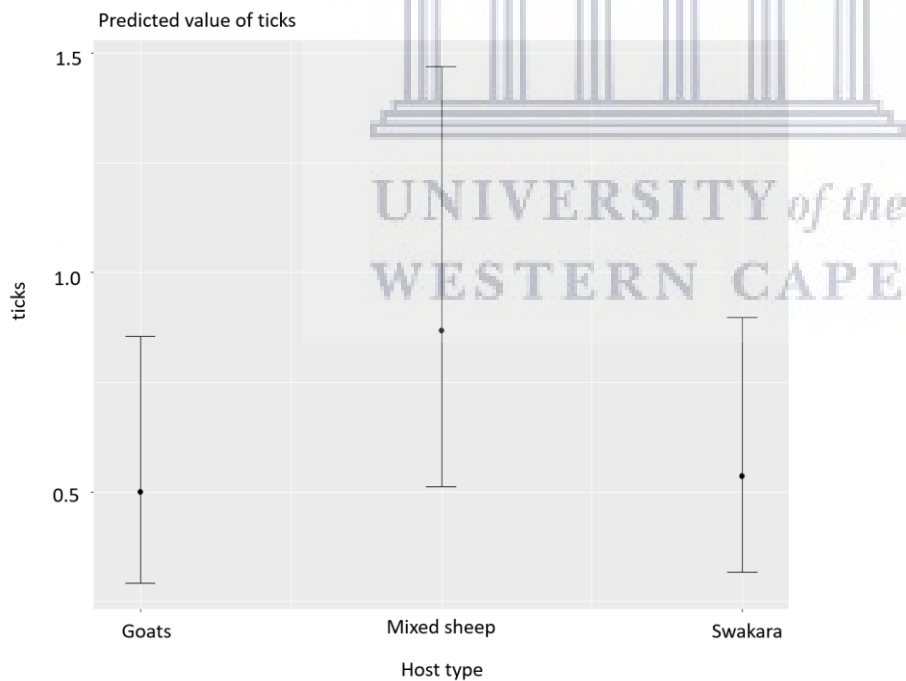


Figure 3.3: Marginal predicted values and standard errors from NBGLM of tick abundances for host breed types (goats, mixed-breed and, swakara sheep).

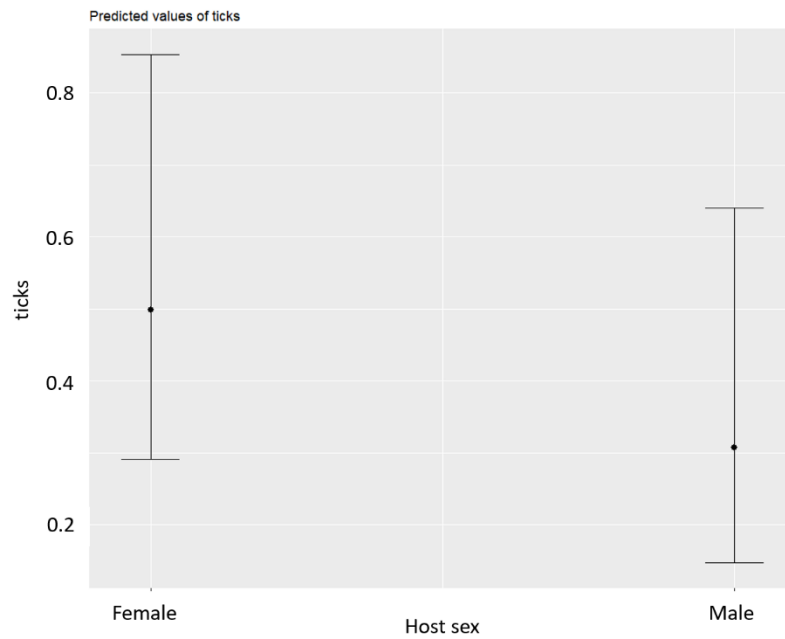


Figure 3.4: Marginal predicted values and standard errors from NBGLM of tick abundances for host sexes (female and male).

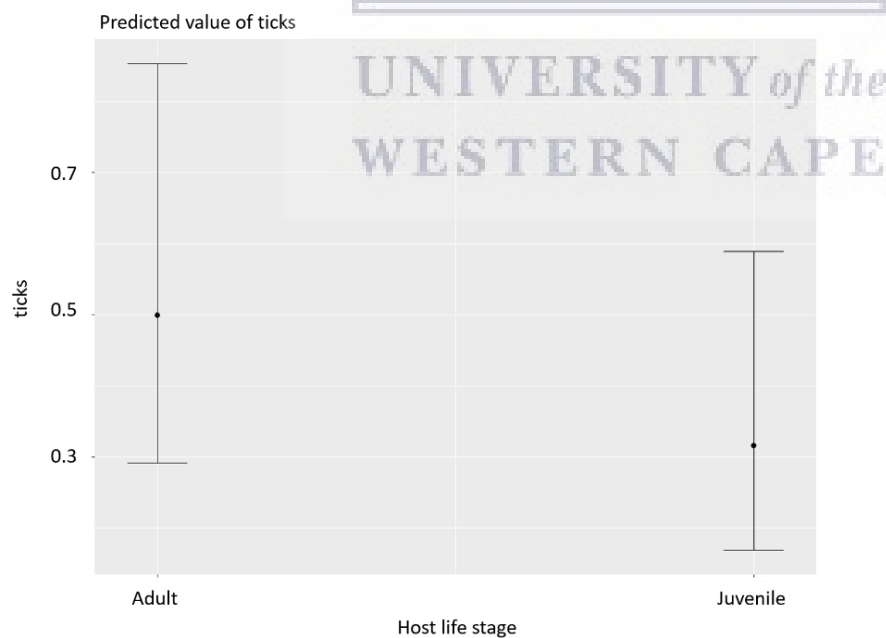


Figure 3.5: Marginal predicted values and standard errors from NBGLM of tick abundances for host life stages (adult and juvenile).

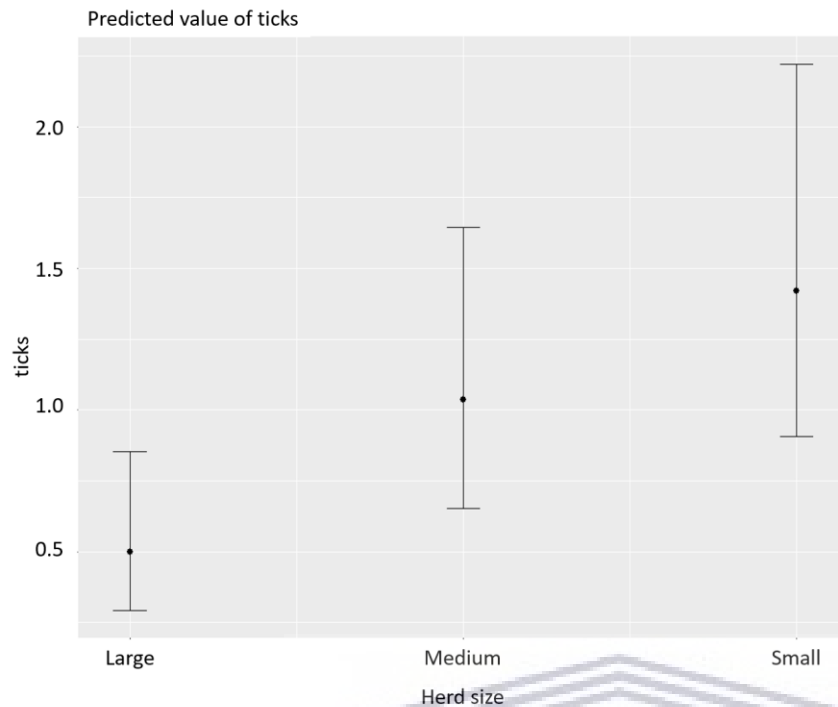


Figure 3.6: Marginal predicted values and standard errors from NBGLM of tick abundances for herd sizes (large, medium and small).

Environmental variables associated with tick presence and abundances

The first two axes of the redundancy analysis explained 98.96% of the variation in tick species and abundances to the environment (RDA; $F = 1.0043$, $df = 9$, $p = 0.621$, $R^2 = 0.010711$, see Appendix B for eigenvalues). Analysis of constrained versus unconstrained variance shows much of the variation in the response data is accounted for by the explanatory variables (Constrained 0.09681 > Unconstrained 0.01071). The triplot (Figure 3.4) shows a strong positive relationship between tick species *H. truncatum* and altitude, where this species is shown to be negatively associated with NDVI and herd size (see Appendix B for eigenvalues). Tick species *R. gertrudae* had a strong positive association with vegetation types Namaqualand Blomveld (VTNB) and Kosiesberg Succulent Shrubland (VTKSS) as well as with NDVI and, SSM. The species also had a negative association to altitude. Lastly,

tick species *R. microplus* is closely associated with vegetation type Namaqualand Shale Shrubland (VTNSS) and negatively associated with SSM and Kosiesberg Succulent Shrubland (VTKSS). The distribution of the three tick species is plotted to stock-post location in Figure 3.5. The figure shows *R. gertrudae* as the common species found at all stock-posts (A – K) sampled and the only species found at kraal “K”. Thereafter *H. truncatum* at fewer stock-posts and *R. microplus* at only four stock-posts.

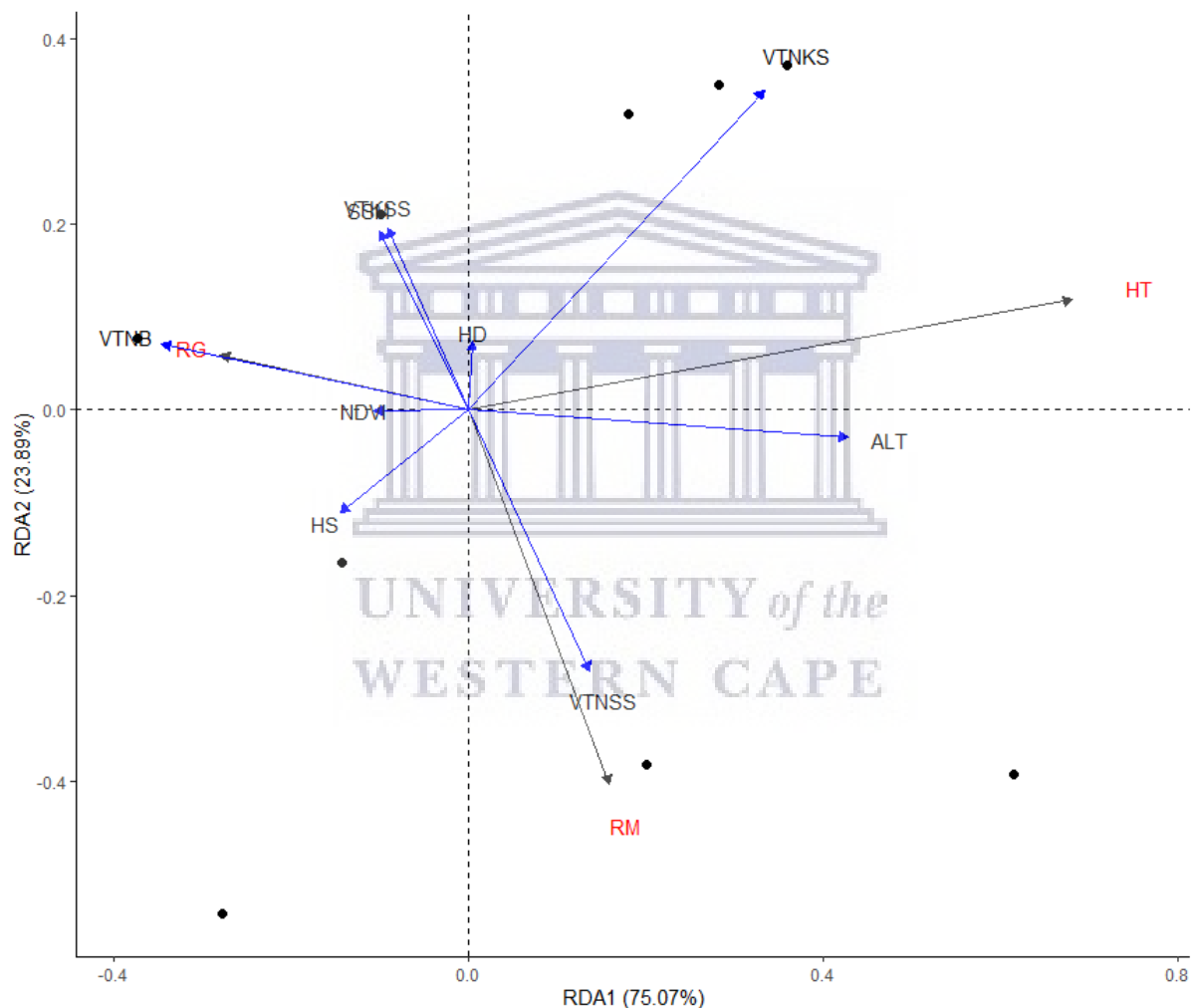


Figure 3.7: Redundancy analysis of tick abundances and environmental variables from 11 small stock herds sampled in August 2017. Tick species include; *Rhipicephalus gertrudae* (RG), *Hyalomma truncatum* (HT) and *Rhipicephalus microplus* (RM). Environmental variables include; altitude (ALT), normalised difference vegetation index (NDVI), surface

soil moisture (SSM) and, vegetation types; Namaqualand Shale Shrubland (VTNSS), Namaqualand Blomveld (VTNB), Kosiesberg Succulent Shrubland (VTKSS) and Namaqualand Klipkoppe Shrubland (VTNKS). Additional variables include; herd size (HS) and helminth diversity (HD).

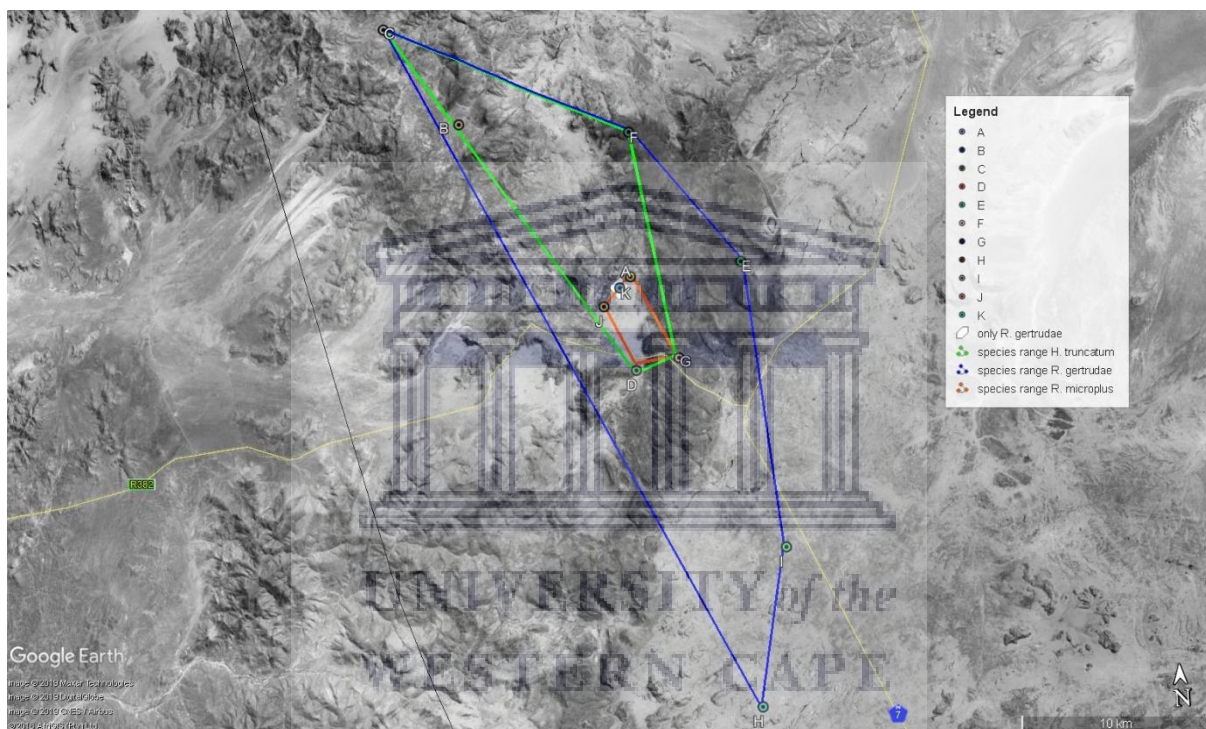


Figure 3.8: Tick species distribution mapped according to stock-posts labelled A – K, with purple line indication distribution of *Rhipicephalus gertrudae*, green line indicating *Hyalomma truncatum* and orange line *Rhipicephalus microplus*.

3.4 Discussion

Tick species present and their prevalence

The results confirm the first hypothesis as prevalence for this rangeland is 56.4%, higher than expected. Statistically there is no difference between the tick prevalence between the three host breeds, sexes or life stages. Generally, indigenous livestock breeds are preferred as they are less susceptible to parasites, showing tolerance and resilience (Bishop & Morris, 2007). For example, the boer goat is known to be particularly resilient to tick bites and tick attachment, allowing a relatively undamaged skin (MacIvor & Horak, 1987). As well as the Namaqua Afrikaner sheep shows higher tick tolerance to Dorper and Merino breeds (Cloete et al., 2013). Alternately, the swakara sheep are indigenous to Iran, and are chosen for their fur quality and resilience in the harsh drought-prone arid environment of the Northern Cape Province and Namibia (Schoeman, 1998). This shows that although these breeds are known for their resilience, management decisions override natural parasite systems. Furthermore, crossbreeding livestock may increase parasite resilience and tolerance as what has been occurring in the communal area among sheep for several decades (Baker, 1995; Bock et al., 1999).

In this study three ixodid tick species were found *Rhipicephalus gertrudae*, *Hyalomma truncatum* (small smooth bont-legged tick) and *Rhipicephalus microplus* (Asiatic blue tick). *Rhipicephalus gertrudae* and *H. truncatum* are common species found generally in high abundances in arid regions of South Africa such as the Northern Cape Province (Fourie & Horak, 1992; Guglielmone et al., 2010). *Rhipicephalus microplus* generally found more eastward in South Africa had its first record recently discovered in Namibia just north of Steinkopf (Nyangiwe et al., 2013b).

Subsequently, results showed *R. gertrudae* a three-host species (generalist), as the most abundant tick species found largely on mixed-breed sheep in this study. The preferred hosts of adult ticks include dogs and sheep validating their high presence on mixed-breed sheep in this study (Fourie & Horak, 1992; Horak & Matthee, 2003; Horak et al., 2018) as well as a multitude of bovine species, primates and humans (Brain & Bohrmann, 1992; Walker et al., 2005). Seasonal occurrences of adult *R. gertrudae* in the Northern Cape Province peaks between May to October (Fourie & Horak, 1992). Seasonal occurrence of this species validate the results of this study with high presence of adults as it is the beginning of their feeding season and the low presence of nymphs with the end of their feeding season. Found in this study were nymphs on the small ruminants sampled, usually the preferred hosts of nymphs are small mammals, however, Walker (2003) suggests the presence of nymphs on larger herbivores may be due to the absence of their preferred hosts (host availability). To prove the scarcity of small mammals in this area, results are confirmed by research done by Piers (2019) and (Van Deventer & Nel, 2006) who found small mammal densities at 14 and 30 per ha in the succulent Karoo.

The low presence of *H. truncatum* which is a two host species (generalist), is presumably due to adult ticks being most active during summer (October to March) and immature stages feeding during autumn (March to May) (Fourie & Horak, 1992). Unlike *R. gertrudae*, immature stages of *H. truncatum* were not found on the small ruminants sampled additionally, (Daniels, 2016) found no *H. truncatum* on small mammals (*Rhabdomys pumilio* and *Macroscelides proboscideus*) whilst sampling in the same area. But had we sampled scrub hares we may have found this tick species on them (Horak et al., 2005).

Rhipicephalus microplus is a one-host tick (specialist) commonly found on cattle. Studies show that the inclusion of goats with cattle increased tick prevalence for cattle, however, in

its absence cattle ticks preferred goats (Nyangiwe & Horak, 2008; Spickett et al., 2011). In this study *R. microplus* was found largely on mixed-breed sheep than goats (in mixed herds) thus, showing host availability plays a large role in this specialist species host preference. Seasonal occurrence data for this species is lacking in the arid Northern Cape but in the Eastern Cape Province, adults are present year-round, peaking in November (Nyangiwe et al., 2011). Research indicates *R. microplus* is expanding both the species it feeds on and the areas they are commonly found in, outcompeting indigenous tick species *R. decoloratus* in some instances (Estrada-Peña et al., 2004; Nyangiwe et al., 2013a). Furthermore, Nyangiwe et al. (2013a) suggests finding only female *R. microplus* on hosts (Table 3.1) proves that sampling is not “exhaustive”, indicating close monitoring of this species especially considering they are carriers of infectious haemoprotozoan parasites such as *Babesia bigemina* and *Babesia bovis* (Giglioti et al., 2018). Both *B. bigemina* and *B. bovis* cause the disease babesiosis in cattle, with *Babesia ovis* affecting small ruminants by causing Ovine babesiosis (Esmailnejad et al., 2015). Nevertheless, this leaves cattle on this rangeland at risk for infection, causing symptoms of anaemia, hemoglobinuria (excretion of blood in urine) and ataxia (damage to the brain, nerves and/or muscles) (Brown & Palmer, 1999; Gohil et al., 2013).

Lastly, in this study, we obtained a mean crowding average of one or two ticks per host, except for one juvenile sheep having the highest range of 16 ticks present. Studies on tick-induced host-paralysis in small ruminants show that for tick infestation to affect host health; 20 to 30 ticks per host is the norm (Horak et al., 1987; Fourie et al., 1988). However, aggregation of specifically *H. truncatum* with a minimum two ticks can cause lameness especially when attached to host leg muscles during walking (MacIvor & Horak, 1987; Kok & Fourie, 1995).

Host body condition impact on tick abundance

Generalised linear modelling results show that parasite abundances are not statistically affected by host condition. We know that hosts with poor immune systems are at higher risk for parasite disease, this is especially evident in winter (Alexandre & Mandonnet, 2005). Alternately, high parasite loads can cause lowered body conditions for hosts (Chapter 2), either through external lesions or lowering productivity and fitness (Howell et al., 1978; MacIvor & Horak, 1987). In our data, we found ticks to be over dispersed meaning ticks were evenly distributed across four out of the five body condition scores (BCS) (Petney et al., 1990). Furthermore, hosts with BCS of “2” were most prominent validated by Van Burgel et al. (2011) who suggest that the normal body condition expected for ewes should be between “2” and “3”.

Other than body condition, we found that ewes in mixed-breed sheep, as well as small (70 - 90 SSU) and medium (100 – 170 SSU) herd sizes had a significant response to tick abundance. Similar studies show the opposite with larger herd sizes being more at risk for parasite infection compared to smaller herds as the close proximity between individuals is more likely to increase the potential for parasite transmission (Van Andel et al., 2018). This suggests that smaller herds in our system had higher proportional densities because these herds are owned and managed by the poorer farmers with fewer veterinary resources to limit tick infestations such as acaricides. Furthermore, higher prevalence of parasites is inversely proportional to low host diversity. For example, in agricultural settings such as livestock production where hosts are kept in close proximity, the high densities and low host diversity (sheep or goat) show the potential for increased parasite intensity and disease transmission is high especially zoonotic (to humans) (Barré et al., 1987; Kusiluka & Kambarage, 1996b; Altizer et al., 2006).

Environmental variables associated with tick presence and abundances

Primarily, we find high humidity environments such as tropical regions are infamous for the risk of parasitic infections (Jensenius et al., 2003; Frean et al., 2008; Marufu et al., 2010). In this study, we found a positive relationship between altitude and species *H. truncatum*. Indicating that the higher the altitude in this region the more likely to find this tick species. Although this species is known to be drought-resistant and commonly found inhabiting arid regions, 40 °C heat in summer and the lack of moisture are deadly for invertebrates (Fourie & Horak, 1992). Higher altitudes allow for water moisture in the absence of rain (such as dew, fog and, mist) which help with the survival of both plants and these parasites. In Steinkopf, which has a vast mountainous area, higher up on inselbergs we find a larger range of plants species compared to the flats (Piers et al., 2019), hence farmers choose to walk their herds over mountains bringing hosts in contact with parasites. Conversely, *R. gertrudae* and *R. microplus*, both which are drought-resistant (Horak et al., 2017b), were not found closely correlated to altitude but showed a positive association to surface soil moisture (SSM). In semi-arid and arid environments the patchiness of vegetation is common, this is where SSM is mapped from satellite imagery (in the absence of vegetation), this does not, however, take away from the fact that vegetation also holds moisture (Mucina et al., 2014). Furthermore, we expected ticks would have a strong relationship with vegetation (Petney et al., 1987; Randolph, 2000; Rehman et al., 2017). The RDA plot showed a strong relationship between *R. gertrudae* and Kosies Succulent Shrubland, this vegetation type is synonymous with high altitudes, which experiences higher water from local rainfall than the rest of the area, suggesting that although vegetation type did not influence tick distribution, it does influence host-feeding strategies, allowing for frequent tick-host interactions. Additionally, we find a strong association with vegetation type Namaqualand Blomveld. Mucina et al. (2006) shows

this vegetation type as being highly overgrazed, validating the high abundances of *R. gertrudae* in this area due to the greater potential of hosts.

Furthermore, herd size increases with NDVI. Larger herds are found in areas of more vegetation, possible reasons may be that farmers with larger herds have funds to move their herds further away from the overcrowded regions to gain access to ungrazed areas (Samuels et al., 2008; Samuels et al., 2019). Alternately, Fryxell et al. (2015) shows habitat and vegetation variables are not enough to predict the complexity of tick populations. Thus, through mapping tick distribution to kraals (Figure 3.7) this study found that *R. microplus* was found only at permanent stock-posts, whereas herders that were moving and had temporary stock-posts hosted common tick species *H. truncatum* and *R. gertrudae*. In contrast, literature points to transhumance as a means of spreading of this invasive species (Adinci et al., 2018). These permanent stock-posts also kept other common hosts of *R. microplus* such as horses, donkeys and pigs. Furthermore, by mapping tick distributions (Figure 3.7) we can clearly see inside the orange polygon represents a tick hotspot, this is especially important as it acted as old crop fields. Due to the disturbance old crop fields take longer to recover in arid environments (Van der Merwe & Van Rooyen, 2011), thus allowing fast growing species to dominate such as *Galenia africana*, this species serves as both an indicator of land degradation and by creating vegetation cover allows for more small mammal activity and therefore more tick activity (Daniels, 2016; Perez et al., 2016).

Lastly, although GIPs are not strongly associated with any tick species (Figure 3.6), their presence has a positive association with SSM and vegetation types; Kosiesberg Succulent Shrubland and Namaqualand Klipkoppe Shrubland. These variables provide adequate moisture for survival as well as vegetation cover with Namaqualand Klipkoppe Shrubland being least transformed vegetation type (Mucina et al., 2006).

3.5 Conclusion

Compared to communal rangelands in the wetter regions of South Africa (Hlatshwayo et al., 2002; Macivor & Horak, 2003; Nyangiwe & Horak, 2008; Marufu, 2008; Nyangiwe, 2007; Horak et al., 2010; Nyangiwe et al., 2011; Horak et al., 2017a; Horak et al., 2017b; Horak et al., 2018) and arid regions of the world (Potgieter et al., 1983; Horak et al., 2009; Yakhchali et al., 2011; Desalegn et al., 2015; Rehman et al., 2017), tick prevalence in this area is remain relatively low. Livestock was found to be in general good health, where special attention is needed for juveniles and female mixed sheep, as they are most susceptible to tick infestations. Furthermore, although these results show low incidences for *H. truncatum* and *R. microplus* these species are among the few tick species representing main African tick vectors due to their wide distribution (Jongejan & Uilenberg, 2004). Invasive species; *Rhipicephalus microplus* is found to outcompete indigenous species *R. decoloratus* when conditions are favourable, as well as adapting and surviving varying conditions in Africa (Walker, 2003; Nyangiwe & Horak, 2007). Therefore, seasonal sampling is required for these species to determine their impact on host health. Important to note is the temporal niche differentiation of feeding adults (*R. gertrudae* May - Oct; *H. truncatum* Oct - May) which prove troublesome to economically impoverished farmers with ticks present all year round.

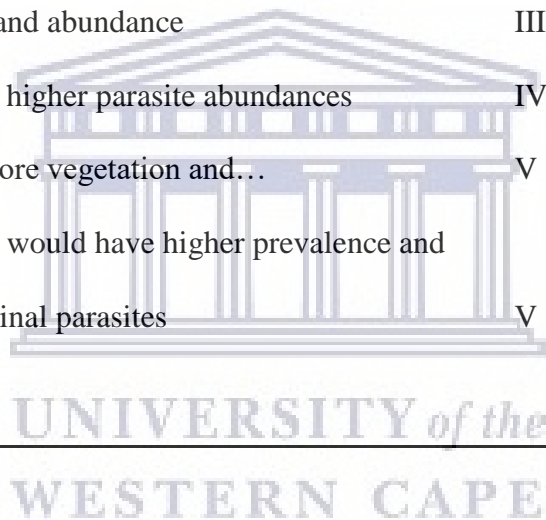
CHAPTER 4: GENERAL CONCLUSION

4.1 Introduction

The overarching aim of this thesis was to fill the knowledge gap of parasites infecting the small ruminants in the arid communal grazing rangeland of Steinkopf. In order to achieve this, two research questions were posed investigating internal parasites namely gastrointestinal parasites (Chapter 2) and, external parasites namely hard ticks (Chapter 3). The first question asked to identify parasites through morphology and to quantify these parasite prevalences for host species, sex and age. The second question asked, to determine parasites preferences for hosts based on host health using body condition scoring and, to determine parasite preferences for specific areas within the rangeland using environmental factors. To answer the first question, we used morphological keys to identify species either to species level or genus as in the case with the eggs. To describe parasite infections on hosts, prevalences were calculated using Quantitative Parasitology 3.0 (Reiczigel et al., 2019). To answer the second question was two-fold. First, host condition as parasite preferences was determined through generalised linear modelling, using parasite abundances and body condition scoring, these models included additional factors when body condition did not affect parasite abundances. Next, parasite preferences for microhabitats were determined through redundancy analysis, using parasite species, abundances and various environmental factors obtained through spatial data. Table 4.1 summarises hypothesis posed for each chapter and the results obtained for each.

Table 4.1: Overall results of study hypotheses

Hypothesis		Result
Intestinal parasites		
Expected prevalence is 50% or less	I	Not supported
Males and juveniles are predicted to show a higher parasite prevalence than females and adults	II	Not supported
Hosts with lower body conditions would possess higher parasite species richness and abundance	III	Supported
Larger herds would show higher parasite abundances	IV	Not supported
Herds surrounded with more vegetation and... those at higher elevations would have higher prevalence and abundance of gastrointestinal parasites	V	Not supported
	V	Supported
Ticks		
We expect tick prevalence of 50% or less.	I	Not supported
We expect males and in particular adult males showing a higher prevalence than juveniles (≤ 1 year) and females	II	Not supported
We expect higher parasite abundances on hosts with lower body condition scores	III	Not supported
We expect that herds surrounded with thicker vegetation and... those at higher elevations to have higher prevalence and... abundance of ticks, as well as larger herds	IV	Not supported
	IV	Supported
	IV	Not supported



Subsequently, the findings of this research shows the significance of parasite research on communal rangelands especially in arid regions. Combining these two chapters, we found;

All GIPs (Chapter 2) found on this rangeland confirm similar research as we found common parasites of small ruminants, there were no new or unidentifiable eggs or oocysts (Hansen & Perry, 1994a; Gibbons et al., 2005; Zajac & Conboy, 2006). There was however less tick species (Chapter 3) found than what was expected, but these are common for the region, climate and, hosts as identified by (Fourie & Horak, 1992). Furthermore the study confirms research by Nyangiwe et al. (2013b), showing *Rhipicephalus microplus*, as an important example of range shift, possibly due to climate change or poor livestock and range management. However, this needs further investigation. The results also suggest that although wild life plays an important role in the continuation of some tick species (two and three-host ticks), the absence or lack of a primary host (e.g. rodents) in this rangeland was not a limiting factor as the nymphs of *Rhipicephalus gertrudae* were found on livestock (Walker, 2003; Horak et al., 2005). Furthermore, this study showed that parasite prevalence was high for both GIPs and ticks (> 50%). Each host tested was positive for GIPs, this may be that farmers invest more in dipping their animals for ticks than antihelminthic treatments. The severity of some gastrointestinal parasite burdens was not expected as there was a drought, but the high presence of *Coccidia* is concurrent with the fact that this is a communal rangeland (Harper & Penzhorn, 1999), where antihelminthic treatments is expensive, animal mixing occurs and the same water points are used. Lastly, tick prevalence was higher than expected for this being the winter season and an arid to semi-arid environment going through a drought; however, results are concurrent with the lifecycles of tick species found.

Using body condition as a consideration for parasite infection, we found that ticks in this rangeland were spread across all body conditions found ("1" to "4" no host was categorised

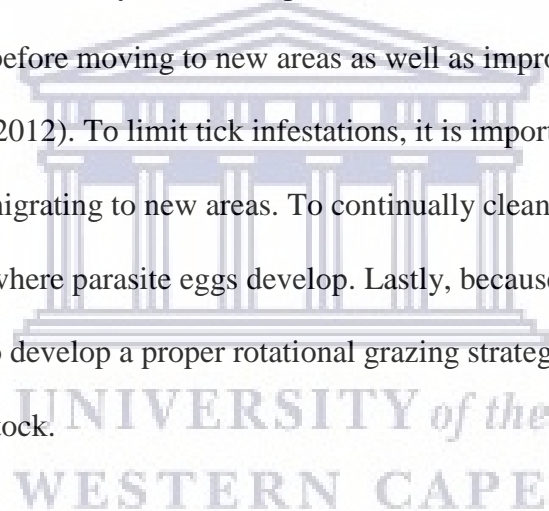
at “5”). Intestinal parasites on the other hand were correlated to low body conditions, this is a common result confirmed by multiple studies (Symons & Jones, 1975; Jones & Symons, 1982; Symons & Jones, 1983; Sykes et al., 1988; Parkins & Holmes, 1989; Butter et al., 2000; Roy et al., 2003). Whether low conditions attracted higher parasite diversity or higher parasite diversity caused the low conditions was not determined. Other than body condition, higher parasite burdens were also associated with small and medium sized herds (70 – 90 SSU and 100 – 170 SSU respectively) compared to larger herds, proving density plays a large role in parasite infection and contagion.

Finally, we found many species both GIPs and ticks to be correlated with environmental factors such as; altitude, surface soil moisture and, vegetation types confirming multiple studies such as Froeschke et al. (2010); and Scharsack et al. (2016). Knowing the regions where parasites are abundant is an important tool for farmers, which they can avoid on their grazing routes. Other than abiotic factors controlling parasite distribution, biotic factors and life strategies also play a large role in where parasites are found. For instance, we found that, *R. microplus* is limited by the fact that it is a one-host tick therefore restricted to permanent stock-posts. Another species *H. truncatum* is limited by the fact that it is a two-host tick, and its preferred primary host, Scrub hares are found in areas with shrub cover.

All but one objective for this study was met. This objective was to identify internal parasites on this rangeland. It was not fully met as GIPs were not identified to species level, therefore we do not know which exact species exist on this rangeland. Additionally, I believed using egg abundances as a factor to interpret parasite loads as biased. This is because one worm may lay up to 50 000 eggs. To combat this, parasite diversity was used for modelling.

4.2 Recommendations

Oyarzún et al. (2008) suggests the most effective management strategy for controlling parasites is to identify the common species, understand their life cycles and seasonal occurrences. This study accomplished this to some degree in the short time spent sampling. Moreover, Torres-Acosta and Hoste (2008) suggest three main ways to help minimise the impact of GIPs on small stock; (1) to eliminate the worms in the host (such as antihelminthic treatment), (2) to improve host resistance/resilience (e.g. increasing nutrition therefore immune strength) and, (3) reducing contact between host and parasite. Intestinal parasites reach larval stages as little as six days, this is helpful to herders to know when to move camps and to drench their herds before moving to new areas as well as improving hygiene (Michel, 1976; Chartier & Paraud, 2012). To limit tick infestations, it is important for farmers to dip animals before and after migrating to new areas. To continually clean (or disinfect with acaricide) or burn kraals where parasite eggs develop. Lastly, because this is a shared rangeland, farmers need to develop a proper rotational grazing strategy as well as mix their susceptible and resistant stock.



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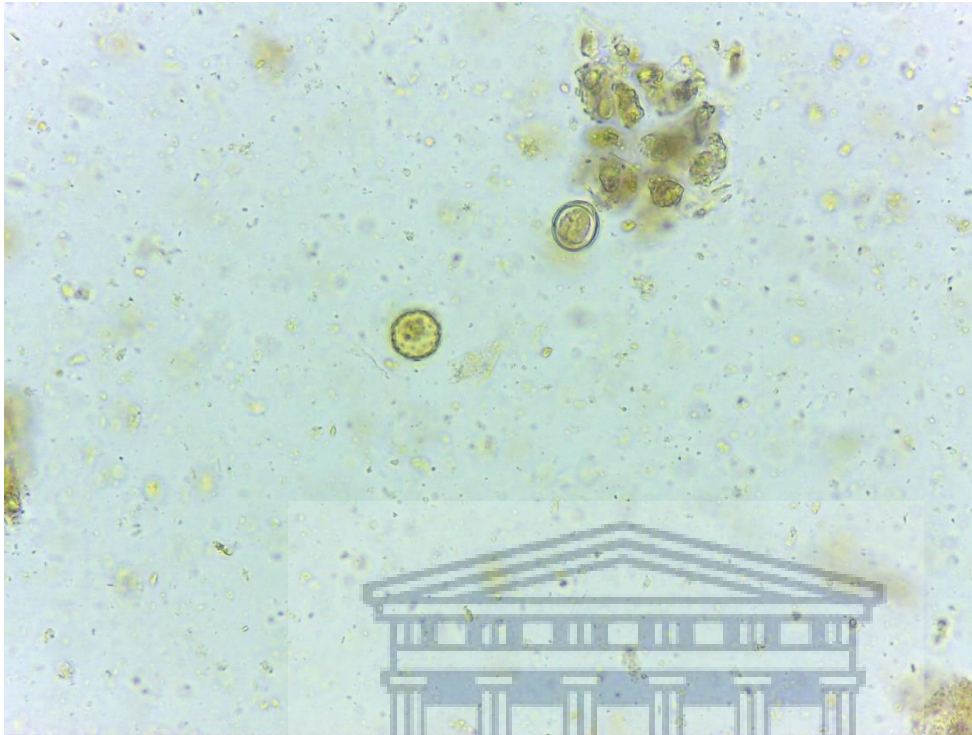
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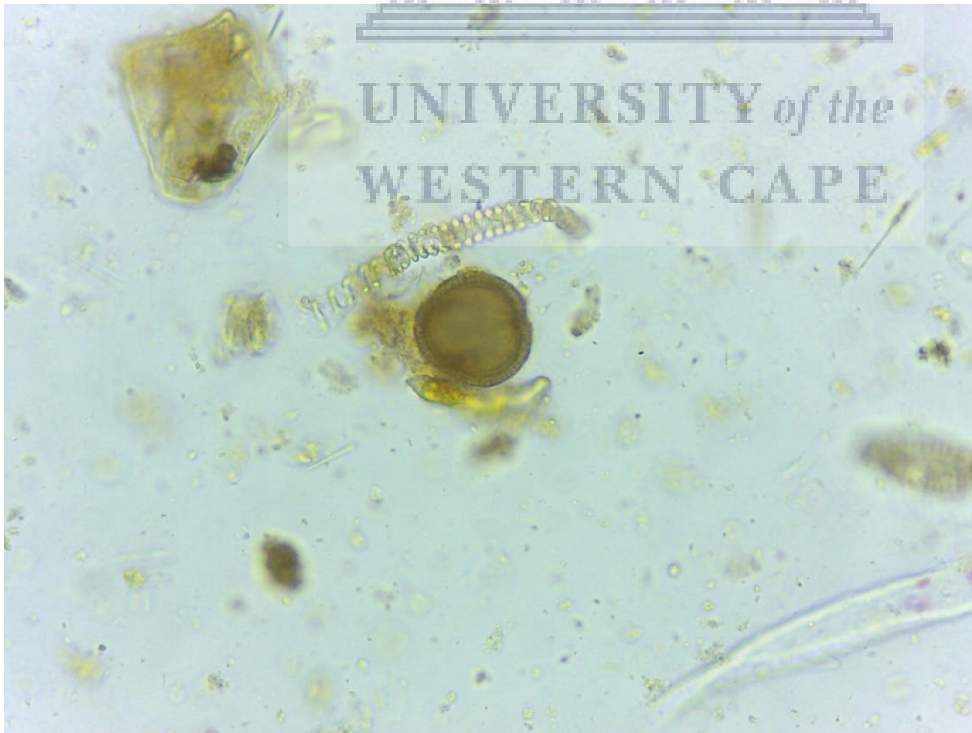
WESTERN CAPE

6 APPENDIX A

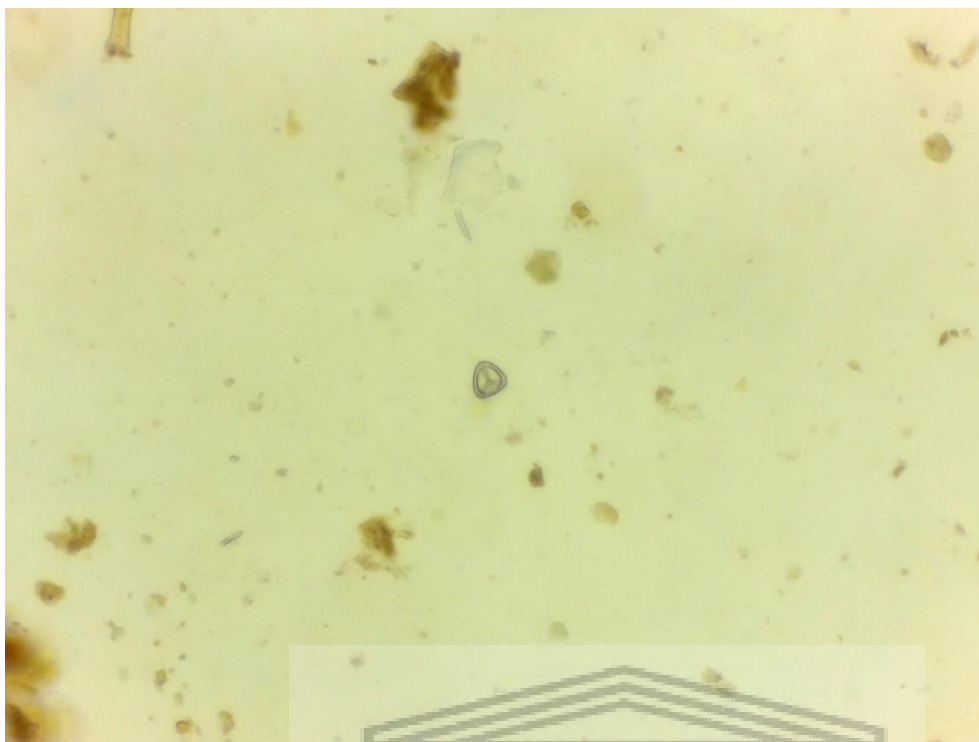
Intestinal parasite species



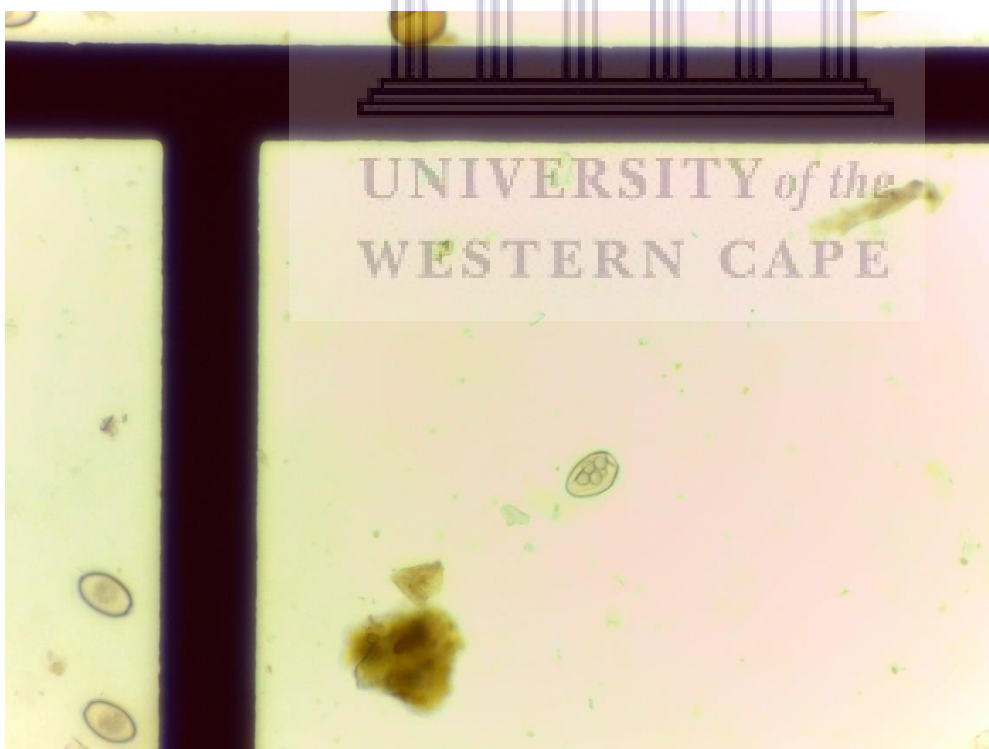
Coccidia oocysts (400x)



Ascaris sp. (400x)



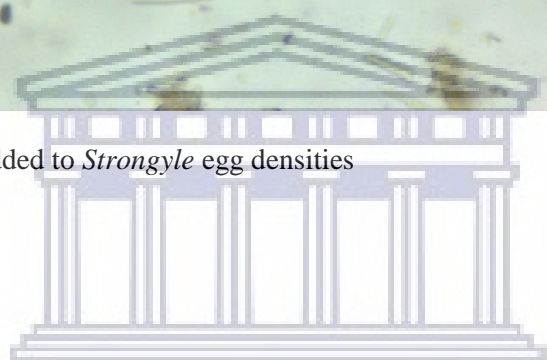
Monezia sp. (400x)



Strongyle sp. (400x)



Cooperia spp. egg. (400x) added to *Strongyle* egg densities



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7 APPENDIX B

Description of tick infestation on host population

Host	Intensity					Abundance		Crowding	
	Mean	CI 95%	Median	CI 95%	Exact CI	Mean	CI 95%	Mean	CI 95%
All hosts	2,18	1.89 - 2.61	1	1.00 - 2.00	96,20%	1,23	1.03 - 1.50	4,12	3.09 - 6.57
Sheep	2,32	1.95 - 2.88	2	1.00 - 2.00	95,70%	2,32	1.94 - 2.89	4,49	3.22 - 7.10
Males	1,83	1.43 - 2.35	1	1.00 - 2.00	95,30%	1,02	0.683 - 1.44	2,52	1.82 - 3.37
Females	2,47	2.00 - 3.20	2	1.00 - 2.00	96,80%	1,47	1.13 - 1.99	4,94	3.37 - 8.10
Goat	1,72	1.38 - 2.21	1	1.00 - 2.00	93,20%	1,72	1.38 - 2.20	2,44	1.86 - 3.21
Males	1,50	1.00 - 1.50	sample too small			0,43	0.00 - 1.00	1,67	1.00 - 1.67
Females	1,74	1.37 - 2.22	1	1.00 - 2.00	97,40%	0,92	0.608 - 1.27	2,49	1.87 - 3.28

GLM Results gastrointestinal parasites

MODEL INFO:

Observations: 55

Dependent Variable: egg_diversity

Type: Generalized linear model

Family: quasipoisson

Link function: log

MODEL FIT:

$\chi^2(9) = 6.71, p = 0.01$

Pseudo-R² (Cragg-Uhler) = 0.12

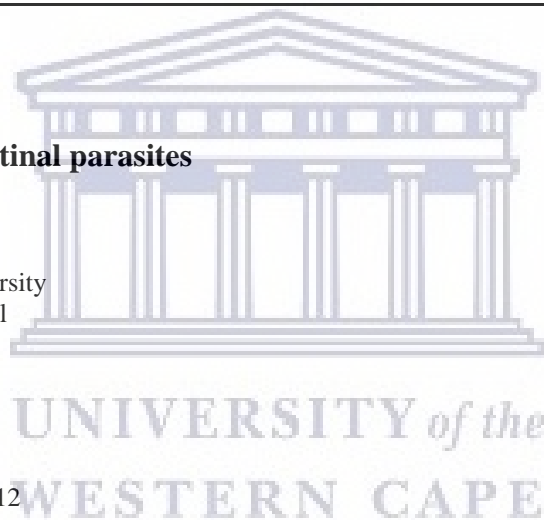
Pseudo-R² (McFadden) = 0.03

AIC = NA, BIC = NA

Standard errors: MLE

	Est.	S.E.	t	val.	p
(Intercept)	1.12	0.12	8.98	0.00	
bcs2	-0.03	0.10	-0.35	0.73	
bcs3	-0.27	0.11	-2.56	0.01	
bcs4	-0.21	0.15	-1.37	0.18	
typeSwakara1	0.20	0.13	1.46	0.15	
typeMix	0.18	0.10	1.87	0.07	
sexMale	-0.06	0.09	-0.67	0.50	
lifestageJuvenile	-0.02	0.08	-0.25	0.80	
herd_sizeMedium	0.23	0.11	2.12	0.04	
herd_sizeSmall	0.32	0.10	3.22	0.00	

Estimated dispersion parameter = 0.28



Negative binomial GLM results ticks

MODEL INFO:

Observations: 225

Dependent Variable: ticks

Type: Generalized linear model

Family: Negative Binomial(1.5085)

Link function: log

MODEL FIT:

$\chi^2() = , p =$

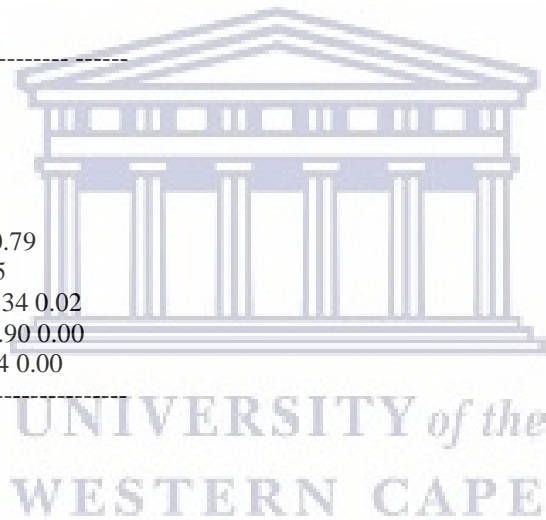
Pseudo- R^2 (Cragg-Uhler) = 0.17

Pseudo- R^2 (McFadden) = 0.06

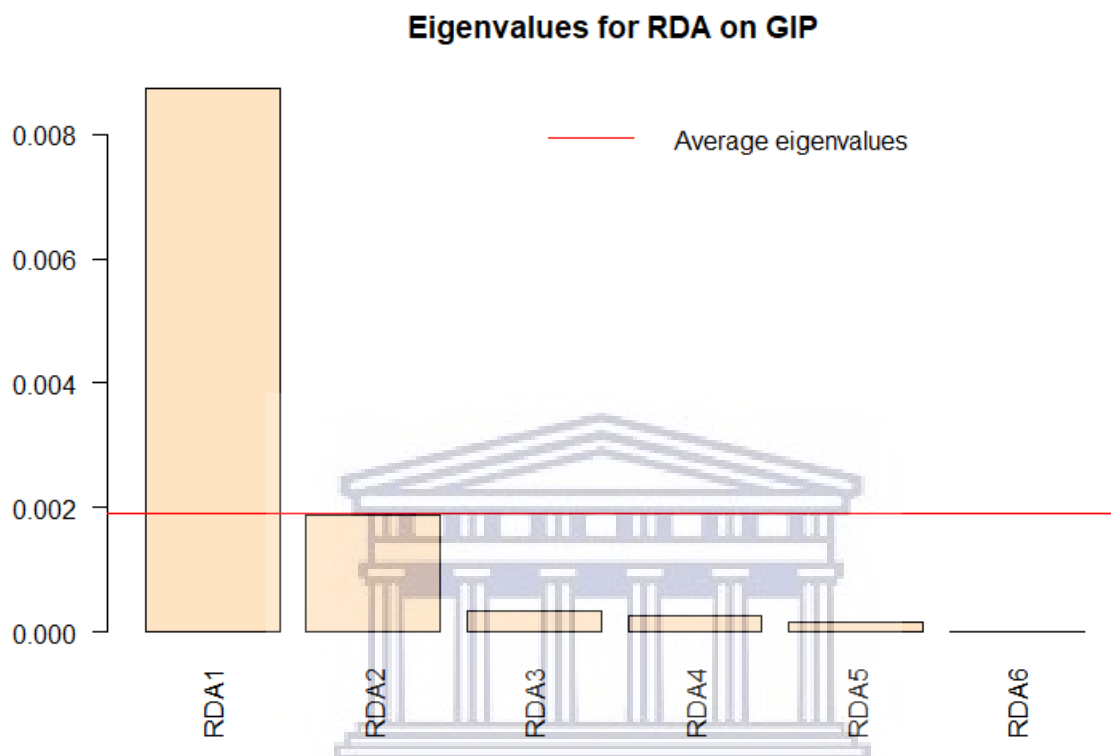
AIC = 674.98, BIC = 712.56

Standard errors: MLE

	Est.	S.E.	z	val.	p
-----	-----	-----	-----	-----	-----
bcs1	-0.70	0.27	-2.54	0.01	
bcs2	-0.71	0.30	-2.35	0.02	
bcs3	-0.49	0.34	-1.43	0.15	
bcs4	-0.34	0.41	-0.82	0.41	
typeMix	0.55	0.23	2.38	0.02	
typeSwakara	0.07	0.26	0.27	0.79	
sexMale	-0.49	0.25	-1.98	0.05	
lifestageJuvenile	-0.46	0.20	-2.34	0.02	
herd_sizeMedium	0.73	0.25	2.90	0.00	
herd_sizeSmall	1.05	0.24	4.34	0.00	



RDA output gastroIntestinal parasites



Call:

`rda(X = spe.hel3, Y = gastrointestinal_environ)`

Partitioning of variance:

	Inertia	Proportion
Total	0.013036	1.0000
Constrained	0.011368	0.8721
Unconstrained	0.001668	0.1279

Eigenvalues, and their contribution to the variance

Importance of components:

	RDA1	RDA2	RDA3	RDA4	RDA5	RDA6	PC1	PC2
Eigenvalue	0.00873	0.00188	0.0003407	0.0002487	0.0001673	1.619e-06	0.001246	0.0004219
Proportion Explained	0.66971	0.14418	0.0261358	0.0190768	0.0128348	1.242e-04	0.095575	0.0323629
Cumulative Proportion	0.66971	0.81389	0.8400266	0.8591035	0.8719382	8.721e-01	0.967637	1.0000000

Accumulated constrained eigenvalues

Importance of components:

	RDA1	RDA2	RDA3	RDA4	RDA5	RDA6
Eigenvalue	0.00873	0.00188	0.0003407	0.0002487	0.0001673	1.619e-06
Proportion Explained	0.76796	0.16533	0.0299701	0.0218756	0.0147177	1.424e-04
Cumulative Proportion	0.76796	0.93329	0.9632643	0.9851399	0.9998576	1.000e+00

Scaling 2 for species and site scores

- * Species are scaled proportional to eigenvalues
- * Sites are unscaled: weighted dispersion equal on all dimensions
- * General scaling constant of scores: 0.6008771

Species scores

	RDA1	RDA2	RDA3	RDA4	RDA5	RDA6
TRI	-0.02512	0.0544152	4.963e-02	-0.063002	0.02016	-0.0008329
ASC	-0.09851	0.1686849	-3.198e-02	-0.015835	-0.03457	0.0006916
MON	-0.02070	0.1331650	3.030e-02	0.048902	0.02681	-0.0016130
NEM	-0.02892	0.0195528	-6.931e-02	-0.014941	0.04538	-0.0003787
STR	-0.42753	-0.0502550	-1.806e-05	0.002508	-0.00526	-0.0029088
COC	0.21777	-0.0008213	-1.510e-02	-0.006845	-0.01506	-0.0056975

Site scores (weighted sums of species scores)

	RDA1	RDA2	RDA3	RDA4	RDA5	RDA6
sit1	0.37332	0.09002	0.07500	0.16785	-0.04395	1.77951
sit2	0.13647	0.21423	0.10077	-0.07614	0.06769	-0.67714
sit3	-0.15920	0.30705	-0.30014	0.10017	0.23709	-0.19185
sit4	0.07918	-0.14859	-0.12399	0.02692	-0.48579	0.95402
sit5	-0.32937	-0.32307	0.02453	-0.06950	0.09047	1.23554
sit6	-0.19929	0.14408	0.53403	-0.03295	0.17386	-1.68203
sit7	-0.06276	-0.21349	0.04398	0.37887	0.10585	-1.29778
sit8	0.09870	-0.13295	-0.08969	-0.30542	-0.03239	0.09843
sit9	0.13223	-0.19035	-0.09257	-0.26227	0.18455	-0.21105
sit10	0.09317	0.05409	-0.05312	0.15845	0.08257	-0.92831
sit11	-0.16246	0.19899	-0.11880	-0.08598	-0.37995	0.92068

Site constraints (linear combinations of constraining variables)

	RDA1	RDA2	RDA3	RDA4	RDA5	RDA6
con1	0.26196	0.07031	0.23045	0.18183	0.181795	0.06197
con2	0.14443	0.16009	0.04623	-0.11428	-0.012843	0.08005
con3	-0.15920	0.30705	-0.30014	0.10017	0.237086	-0.19185

con4	0.09762	-0.01431	-0.04729	0.11221	-0.371268	-0.25814
con5	-0.28370	-0.16376	0.07902	0.02589	0.173221	0.21255
con6	-0.11516	0.13876	0.40079	-0.05702	-0.020112	-0.15366
con7	-0.08120	-0.34778	-0.03272	0.29358	-0.008669	-0.08562
con8	0.09870	-0.13295	-0.08969	-0.30542	-0.032390	0.09843
con9	0.13223	-0.19035	-0.09257	-0.26227	0.184550	-0.21105
con10	0.18080	0.07900	-0.16808	0.15375	-0.084157	0.31575
con11	-0.27649	0.09394	-0.02599	-0.12843	-0.247213	0.13158

Biplot scores for constraining variables

	RDA1	RDA2	RDA3	RDA4	RDA5	RDA6
VTKSS	-0.2779	0.5359	-0.5239	0.1748	0.41382	-0.33488
VTNB	0.2308	-0.3322	-0.1616	-0.4578	0.32212	-0.36838
VTNKS	0.1723	-0.2321	-0.1565	-0.5331	-0.05654	0.17180
VTNSS	-0.2275	-0.3155	0.7067	0.4634	0.34030	0.03675
ALT	-0.0486	0.1828	0.9184	0.1101	-0.15709	-0.11747
NDVI	0.1235	0.7669	-0.3045	0.1778	-0.07630	0.04370
HS	-0.2279	-0.6614	-0.2269	0.1010	0.31621	0.05824
SSM	-0.3058	0.6054	-0.4620	0.2223	0.42215	-0.27867

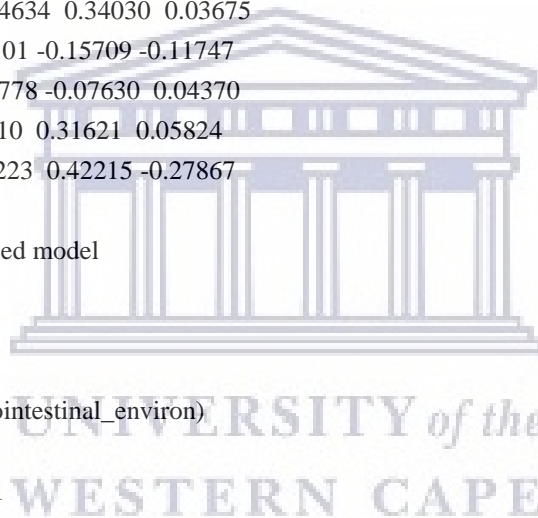
Permutation test for rda under reduced model

Permutation: free

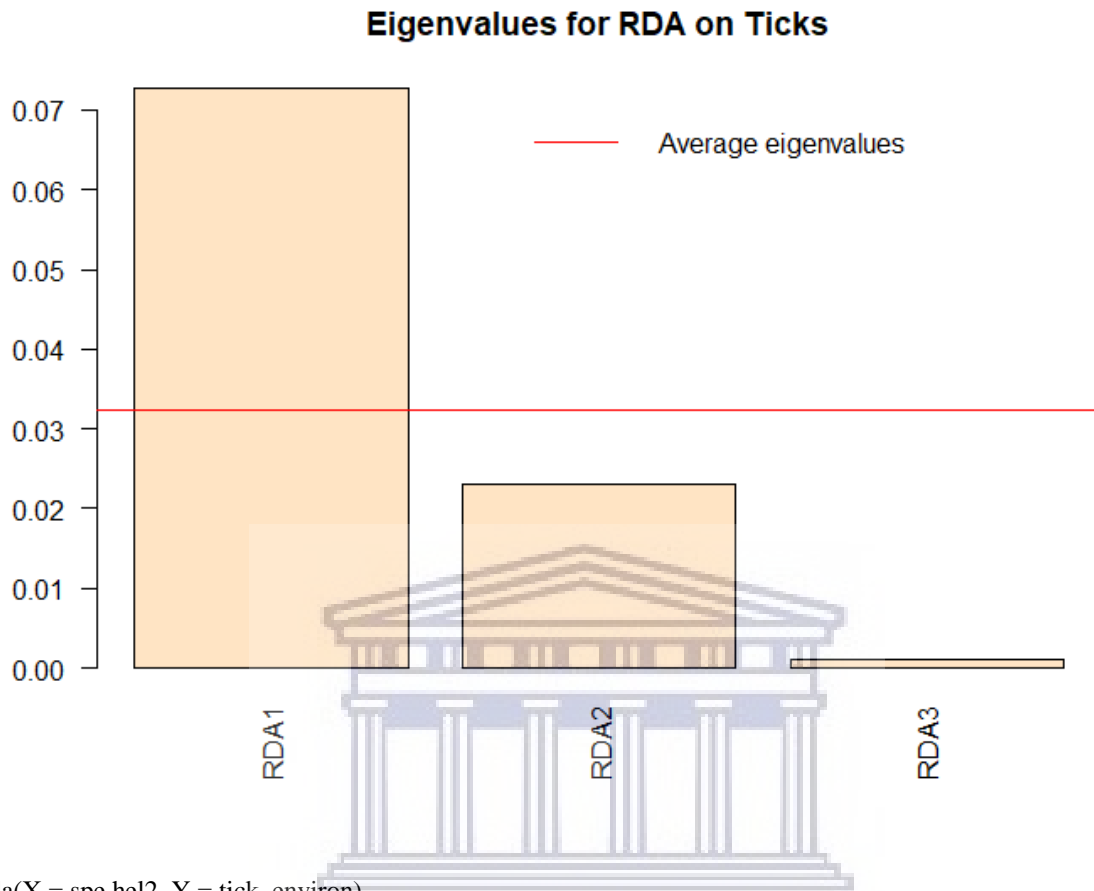
Number of permutations: 999

Model: rda(X = spe.hel3, Y = gastrointestinal_environ)

	Df	Variance	F	Pr(>F)
Model	8	0.0113682	1.7041	0.311
Residual	2	0.0016678		



RDA output ticks



`rda(X = spe.hel2, Y = tick_envirom)`

Partitioning of variance:

	Inertia	Proportion
Total	0.10752	1.00000
Constrained	0.09681	0.90039
Unconstrained	0.01071	0.09961

Eigenvalues, and their contribution to the variance

Importance of components:

	RDA1	RDA2	RDA3	PC1
Eigenvalue	0.07267	0.02313	0.001010	0.01071
Proportion Explained	0.67588	0.21511	0.009396	0.09961
Cumulative Proportion	0.67588	0.89099	0.900385	1.00000

Accumulated constrained eigenvalues

Importance of components:

	RDA1	RDA2	RDA3
Eigenvalue	0.07267	0.02313	0.00101
Proportion Explained	0.75065	0.23891	0.01044

Cumulative Proportion 0.75065 0.98956 1.00000

Scaling 2 for species and site scores

* Species are scaled proportional to eigenvalues

* Sites are unscaled: weighted dispersion equal on all dimensions

* General scaling constant of scores: 1.018294

Species scores

	RDA1	RDA2	RDA3	PC1
RG	-0.3111	0.06612	0.09059	0.12571
RM	0.1767	-0.44865	0.02274	-0.01839
HT	0.7568	0.13191	0.03193	-0.29521

Site scores (weighted sums of species scores)

	RDA1	RDA2	RDA3	PC1
sit1	0.61497	-0.39237	-0.56861	-2.705e-01
sit2	0.18108	0.31850	0.20633	-4.002e-01
sit3	-0.09847	0.21154	0.26800	3.213e-15
sit4	0.20013	-0.38260	0.49360	-3.771e-01
sit5	-0.37365	0.07696	-0.24928	-3.304e-01
sit6	0.28298	0.35030	0.04205	2.238e-01
sit7	-0.27698	-0.54328	0.02170	3.771e-01
sit8	0.35973	0.37162	-0.13364	3.227e-15
sit9	-0.37365	0.07696	-0.24928	3.282e-15
sit10	-0.14250	-0.16461	0.41842	5.586e-01
sit11	-0.37365	0.07696	-0.24928	2.187e-01

Site constraints (linear combinations of constraining variables)

	RDA1	RDA2	RDA3	PC1
con1	0.51237	-0.41951	-0.525756	-2.705e-01
con2	0.02931	0.27835	0.269728	-4.002e-01
con3	-0.09847	0.21154	0.267997	3.213e-15
con4	0.05710	-0.42044	0.553347	-3.771e-01
con5	-0.49897	0.04381	-0.196928	-3.304e-01
con6	0.36788	0.37276	0.006589	2.238e-01
con7	-0.13395	-0.50544	-0.038051	3.771e-01
con8	0.35973	0.37162	-0.133636	3.227e-15
con9	-0.37365	0.07696	-0.249280	3.282e-15
con10	0.06935	-0.10856	0.329921	5.586e-01
con11	-0.29070	0.09891	-0.283930	2.187e-01

Biplot scores for constraining variables

	RDA1	RDA2	RDA3	PC1
HD	0.005082	0.083288	0.6592	0
ALT	0.475614	-0.032560	-0.2637	0
NDVI	-0.118053	-0.001331	-0.4005	0
SSM	-0.111346	0.214826	0.2666	0
HS	-0.160931	-0.123139	-0.2107	0
VTKSS	-0.101421	0.217881	0.2760	0
VTNB	-0.384844	0.079269	-0.2567	0
VTNKS	0.370510	0.382757	-0.1376	0
VTNSS	0.152234	-0.312923	-0.4642	0

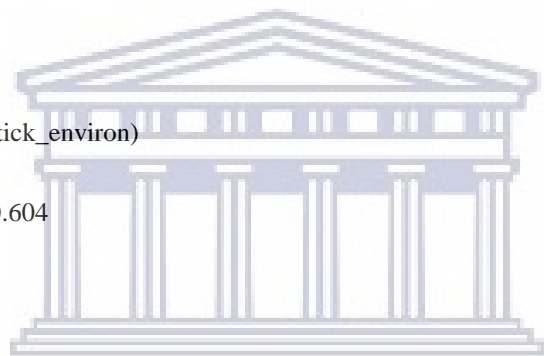
Permutation test for rda under reduced model

Permutation: free

Number of permutations: 999

Model: rda(X = spe.hel2, Y = tick_environ)

	Df	Variance	F	Pr(>F)
Model	9	0.096810	1.0043	0.604
Residual	1	0.010711		



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