INVESTIGATING THE HIDDEN COSTS OF LIVESTOCK GUARDING DOGS AND THE DIET OF A SYMPATRIC PREDATOR IN NAMAQUALAND, SOUTH AFRICA

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PLAGIARISM DECLARATION

I know that plagiarism is wrong. Plagiarism is using another's work and to pretend that it is one's own. I have used the Conservation Biology journal format as the convention for citation and referencing. Each significant contribution to, and quotation in, this project from the work, or works of other people has been attributed, cited, and referenced. This project is my own work. I have not allowed, and will not allow, anyone to copy my work with the intention of passing it off as his or her own work. I acknowledge that copying someone else's work, or parts of it, is wrong, and declare that this is my own work.

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ABSTRACT

The global decimation of carnivore populations has been called one of mankind's most pervasive impacts on the natural world. Human-wildlife conflict over the threat (both real and perceived) predators pose to livestock is one of the leading causes of carnivore decline worldwide. Livestock guarding dogs have been widely acclaimed as an environmentally friendly tool for reducing this conflict, yet little is known about the hidden costs of their presence.

This study used scat analysis to reconstruct the diet of livestock guarding dogs and local caracals (*Caracal caracal*) to better understand their impacts on biodiversity and livestock in Namaqualand, South Africa. For livestock guarding dogs, 187 scats revealed the consumption of (from most to least frequent): livestock, wild mammals (including ten native species), vegetation, anthropogenic items, invertebrates, reptiles, fruit and birds. However, the diet of dogs accompanied by a human attendant differed significantly ($\chi^2 = 94.075$, $p < 0.001$) from dogs guarding sheep independently. While 75% of scats collected from dogs operating independently contained domestic ungulates, less than 5% of scats from dogs with a human attendant contained livestock.

For caracals, 185 collected scats were analysed across two land uses: Namaqua National Park and surrounding farms. Eighteen mammalian prey species were identified in their overall diet, with medium sized (1-10 kg) mammals (particularly the rock hyrax, *Procavia capensis*) accounting for more than half of consumed prey (59.1%). Small mammals (<1 kg) and wild ungulates were consumed more frequently in the protected area than on farmland. Livestock comprised 16% of the mammalian biomass consumed on farms, however no livestock was found in caracal scat within the protected area. These results support a growing body of research that suggests caracals do not prefer livestock, but will consume them when their numbers are considerably higher than that of wild prey, as is the case on many farms.

Although this analysis cannot differentiate between predation and scavenging, the results provide novel insight into the potential impacts of livestock guarding dogs on the landscape and their overall effectiveness as a nonlethal predator management tool. This can help inform livestock guarding dog training and predator management while providing key information about the diets of both an indigenous and introduced predator.

INTRODUCTION

Amid Earth's sixth mass extinction, the global devastation of carnivore populations may be one of humankind's most pervasive impacts on the natural world (Estes et al. 2011; Ripple et al. 2014). Large carnivores face enormous threats from human activities including habitat loss and degradation, population decline, geographic fragmentation, persecution and prey loss (Ceballos & Ehrlich 2002; Morrison et al. 2007; Estes et al. 2011; Ripple et al. 2014). On average, large carnivores have lost approximately half of their historical ranges (Morrison et al. 2007). The disappearance of predators from vast stretches of landscape has far reaching impacts as carnivores play a vital role in structuring ecosystems (Hairston et al. 1960; Estes et al. 2011; Ripple et al. 2014).

Carnivores impact prey species both directly and indirectly. Directly, they influence prey population size and health through predation. Indirectly, they influence the movement and behaviour, both spatially and temporally, of prey species that adjust their foraging strategies to navigate a "landscape of fear" shaped by predation risk (Laundré et al. 2001). Carnivores also influence ecosystems more broadly by delivering many crucial ecosystem services. Their absence has cascading effects on ecosystem biodiversity, affecting mesopredators, avifauna, fish, pollinators and seed dispersers (Terborgh & Estes 2010). In riparian ecosystems, carnivores can help reduce erosion by increasing the vigilance of grazers, thus lowering herbivory and encouraging plant growth (Beschta & Ripple 2012). This new growth provides crucial habitat for riparian species and, in some areas, can strengthen climate change buffers by promoting the growth of plants which capture and store carbon dioxide (Terborgh et al. 2001; Ripple et al. 2014). They also play a critical role in disease dynamics and human health by reducing the prevalence of afflictions in prey populations, which serve as zoonotic disease reservoirs (Ostfield & Holt 2004). While the pivotal role of carnivores in maintaining ecosystem balance and structure has been known for many years, they continue to struggle globally and many carnivore species are in rapid decline (Weber & Rabinowitz 1996; Ripple et al. 2014).

Characterized by high metabolic demands, many carnivores have large home ranges and wide-ranging behaviour that take them outside protected areas, bringing them into contact with people and livestock (Woodroffe & Ginsberg 1998). These shared landscapes are crucial to carnivore conservation and recovery (Di Minin et al. 2016; Carter & Linnell 2016). However, for as long as humans and carnivores have shared a landscape, conflict has arisen due to the threat predators pose (both real and perceived) to human life, economic security, and shared resources (Kruuk 2002; Treves & Karanth 2003). In fact, predator control is one of the oldest forms of wildlife management (Berger 2006).

Lethal versus Nonlethal Predator Control

For most of history, humans have responded to the presence of carnivores with lethal control. Wolves were killed to protect livestock in ancient Greece 2,500 year ago (Reynolds & Tapper 1996). In 1442, Sweden codified the killing of predators into law and many countries continue to endorse state-sponsored predator removal programs (Reynolds & Tapper 1996). The United States, for example, spent $1.6 billion dollars on carnivore removal between 1939 and 1998 (Berger 2006). South Africa began subsidizing predator extermination in 1889, primarily targeting the black-backed jackal (*Canis mesomelas*) (Nattrass et al. 2017). Government sponsorship persisted for more than 100 years, supported by an “emerging colonial ecology depicting the species as cowardly, unworthy and as a threat to human civilisation” (Nattrass et al. 2017).

While traditionally considered the most economical and effective method, lethal control often fails to eradicate depredation, and at times may even be counterproductive (Minnie et al. 2015; Treves et al. 2016). This ineffectiveness has been documented in North America (Knowlton et al. 1999; Berger 2006), Australia (Greentree et al. 2000; Allen & Sparkes 2001), Europe (Sagør et al. 1997; Landa et al. 1999), and Africa (Skinner 1979; Frank et al. 2005; Conradie & Piesse 2013; Minnie et al. 2015). Lethal control tactics include shooting, poisoning, spearing, trapping and snaring. These methods are considered by some as inhumane because they cause suffering, as well as injury and mortality of non-target animals including domestic animals, protected species, and other wildlife (Treves & Naughton-Treves 2005; Rochlitz et al. 2010). Such criticisms have raised ethical concerns and public support for lethal control programs is dwindling (Arthur 1981; Reiter et al. 1999; Slagle et al. 2017).

Nonlethal predator management can address these concerns while preserving the vital role carnivores play in an ecosystem. Nonlethal tools fall into two general categories based on the type of repellent (Shivik et al. 2003). Primary repellents prevent depredations by immediately disrupting predator behaviour through the use of chemical, visual or auditory stimuli (Shivik et al. 2003). Such stimuli may include fladry (flags hung on fence lines), lights, and sirens. The effectiveness of primary repellents however, can decrease over time as predators become habituated to the stimulus (Shivik et al. 2003). Secondary repellents, on the other hand, rely on animal learning to condition predators. This method uses aversive stimuli such as taste and electric shocks to link behaviour with a negative response in hopes of preventing future occurrences (Shivik & Martin 2000).

Nonlethal techniques, when properly applied, have been shown to be cheaper and more effective than lethal control (McManus et al. 2015; Treves et al. 2016; Stone et al. 2017). A systematic evaluation of existing literature on carnivore interventions in Europe and North America found 80% of nonlethal methods effectively deter predation compared to just 29% of lethal control methods (Treves et al. 2016). Despite these encouraging results, predator control methods have been largely understudied, prompting requests from the scientific and conservation communities for evidence-based, scientifically rigorous analyses of available methods (Thorn et al. 2012; Treves et al. 2016; Carter & Linnell 2016; Eklund et al. 2017). This can prove challenging, however, as nonlethal methods are context-dependent and most successful when individually tailored to local conditions.

THE SOUTH AFRICAN CONTEXT

Despite contributing only 2% to South Africa's gross domestic product (GDP), farming is an important industry in South Africa (DAFF 2016). It is a significant source of employment, especially in rural areas, with 8.5 million people either directly or indirectly dependent on agriculture for income (Krugel & Karuthasen 2012). The livestock industry is a crucial component, contributing 44% of the agricultural sector's gross income (Krugel & Karuthasen 2012). Sheep farming has a particularly long history in South Africa. When Dutch settlers first arrived in the Cape in 1652, they purchased fat-tailed sheep from local Khoikhoi herders and joined the age-old struggle to protect livestock from local predators (Nattrass et al. 2017).

Human-wildlife conflict in South Africa is extensive and frequent (Thorn et al. 2012). Despite centuries of intensive lethal control (Nattrass et al. 2017) financial losses due to predators are estimated to total 1.4 billion rand per year (van Niekerk 2010). While financial estimates can vary greatly depending on how they are calculated, this number does help demonstrate the extent of the problem (Conradie & Nattrass 2017). One study conducted in northern South Africa found that one in five farmers consider predation to be their greatest source of economic loss (Thorn et al. 2012). Caracals (*Caracal caracal)*, are believed to be one of the most damaging predators, responsible for an estimated 30% of stock losses (van Niekerk 2010).

Figure 1. *Map of the Northern Cape, South Africa's largest province.*

Despite the temporal and financial extent of this conflict, the scarcity of scientifically rigorous research has prevented the development of a meaningful human-wildlife conflict management strategy in South Africa (du Plessis et al. 2015). Instead, predator management is based on assumptions, individual experience, or word of mouth (Avenant & du Plessis 2008). Calls for a nationwide formal scientific assessment have highlighted the paucity of available information on livestock predators and their management (Kerley et al. 2017). Research on caracals in particular is dated and limited to southern and western parts of South Africa (du Plessis et al. 2015). Studies are sorely lacking in small livestock farming areas such as Namaqualand in South Africa's Northern Cape Province (du Plessis et al. 2015).

The Northern Cape (Figure 1) is South Africa's largest province, occupying nearly one third of the country's total land area. Agriculture is the primary human land use in the region, dominated by livestock farming (Bradstock 2005). Predation rates in the Northern Cape are highest in the country however, estimated to cost more than 540 million rand per year in losses (van Niekerk 2010). In an attempt to reduce these losses, 90% of farmers practice lethal control (van Niekerk 2010).

Nonlethal control measures have also been widely adopted in the Northern Cape. Here, 87% of farmers report using at least one nonlethal control method, more than any other major small-livestock producing province (van Niekerk 2010). Jackal-proof fencing is the most commonly cited tool, primarily as a result of government subsidies, which were available until the early 1990s (van Niekerk 2010). In 2010, four percent of farmers in the Northern Cape reported using livestock guarding dogs to protect their herds (van Niekerk 2010).

Livestock guarding dogs are believed to have originated in Mesopotamia where animal husbandry was well developed (Landry 1999). Generally, dogs are placed with their intended flock during their primary socialization stage (six to eight weeks old) and raised as part of the herd to optimise their bonding with the livestock and ultimately their protective instincts (Smith et al. 2000; Leijenaar et al. 2015). While there are at least 40 different breeds of livestock guarding dogs used worldwide (Landry 1999), Anatolian shepherds (Figure 2) are widely used in South Africa due to the climatic similarities with the Turkish Anatolian Plateau where the breed originated (Leijenaar et al. 2015).

A review of published literature by Smith et al. (2000) on the efficacy of livestock guarding dogs in North America and Europe reports that guarding animals can reduce small stock depredations by 11%-100%. In South Africa they have been shown to reduce predation by 68%-100% (Rust et al. 2013) which, if applied across entire farming regions, could significantly impact predation rates and thus farm productivity. The dogs have the benefit of serving as both a primary repellent (disruptive stimulus) and secondary repellent (aversive stimulus) with the potential to change carnivore behaviour (Gehring et al. 2010). However, Anatolian shepherds are large enough to act as an introduced carnivore themselves, and the costs of their presence on both livestock and wildlife have been largely overlooked (Timm & Schmidtz 1989; Potgieter et al. 2016).

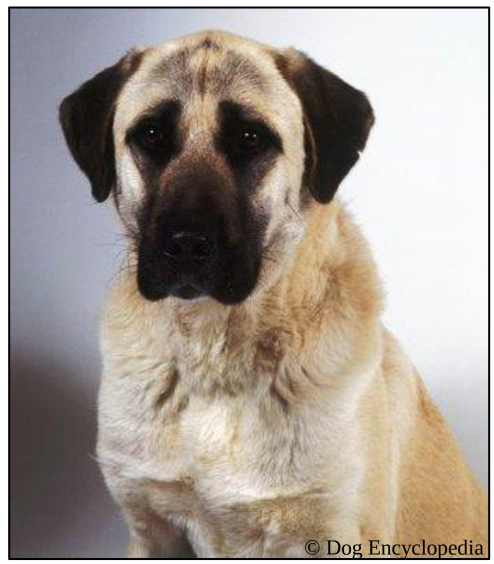

Figure 2: *Anatolian shepherds have an adult mass of 40-55 kg (female) and 50-65 kg (male).*

Anatolian shepherds have been known to kill wolves in Turkey (Urbigkit & Urbigkit 2010), and there are many anecdotal accounts of the dogs chasing and killing wildlife (Green et al. 1984; Timm & Schmidtz 1989; Smith et al. 2000; Marker et al. 2005a, 2005b; Gingold et al. 2009; Potgieter et al. 2013, 2016). One study of 83 livestock guarding dogs conducted in Namibia found that 53% of the dogs killed predators, and 18% of the dogs killed prey species (Potgieter et al. 2016). For example, thirty-seven dogs were reported to have killed jackals. In this case, farmers and dogs combined killed more jackals than the farmers did before the dogs were introduced as a "nonlethal" control method (Potgieter et al. 2016). This in fact implies an increase in lethal control and hence can no longer be considered nonlethal predator management.

Unfortunately, most studies concerning the effectiveness of livestock guarding dogs rely solely on farmer recollections, reports and anecdotes (Green et al. 1984; Marker et al. 2005a, 2005b; Leijenaar et al. 2015; Potgieter et al. 2013, 2016). While livestock producers may faithfully report their observations (Conradie & Nattrass 2017), such qualitative data are problematic for several reasons. First, carcass remains can be notoriously difficult to locate, especially on the open range (Lindzey & Wilbur 1989; Stoddart et al. 2001). Thus, only a fraction of carcasses may be found and, once located, remains are rarely found in good enough condition to determine the cause of death (Linnell et al. 2012; Conradie & Nattrass 2017). While many farmers claim they can differentiate between signs of predation, few if any record this information, necessitating reliance on long-term recollection (Marker et al. 2005a; Conradie & Nattrass 2017). Together, this over reliance on unverifiable reports has prompted the scientific community to prioritise empirical assessments for unbiased evaluation of this predation management tool (Gehring et al. 2010; Thorn et al. 2012; Treves et at. 2016; Potgieter et al. 2016; Allen et al. 2016; Eklund et al. 2017; Mkonyi et al. 2017).

AIMS AND OBJECTIVES

The goal of this study was to add to the growing literature assessing the effectiveness of livestock guarding dogs while helping fill current knowledge gaps in caracal ecology. As part of a larger study investigating predator ecology and human-carnivore conflict mitigation in the Succulent Karoo, eight livestock guarding dogs were placed on commercial farmlands in the Northern Cape Province. This provided the perfect opportunity to investigate the diet of both livestock guarding dogs and caracals to analyse and compare their impacts on domestic ungulates and native wildlife. Specifically, I aimed to answer the following questions:

i. Are livestock guarding dogs on small stock farms in Namaqualand eating anything other than pelleted dog food? If so, are they consuming native or domestic species?

ii. What are caracals (the most locally abundant carnivore) preying on and does their diet vary across land uses?

iii. How does the diet of livestock guarding dogs compare to that of a sympatric predator sharing the same landscape?

Predator diet lies at the nexus of carnivore ecology, predator management and human-wildlife conflict (Ripple et al. 2014). To retain ecologically viable populations managed in socially acceptable ways, we need to understand the overall impacts of the tools used in their defence as well as the choices they make to fulfil their energy requirements (Hayward et al. 2006, 2007; Lyngdoh et al. 2014). Due to their characteristic elusiveness, predator diets are frequently extrapolated from undigested prey remains found in scat samples (Korschgen 1980). Scat analysis is a well-established, non-invasive, and inexpensive technique that has been used in more than 15,000 published studies of predators around the world (Lockie 1959; Karanth & Sunquist 1995; Spaulding et al. 2000; Wang & Macdonald 2009; Klare et al. 2011; Kamler et al. 2012; Braczkowski et al. 2012a, 2012b; Mann 2014; Chakrabarti et al. 2016; Drouilly et al. 2017).

In pursuit of the questions above, 372 scats (187 livestock guarding dog samples and 185 caracal samples) were collected to help reconstruct the diets of these two carnivores. I predict that the diet of Anatolian shepherd guarding dogs will be comprised almost entirely of pelleted dog food. I hypothesize that caracal diet on farmlands will differ significantly from caracal diet within a protected reserve. I also hypothesize that the diet of caracals will differ significantly from livestock guarding dogs who are completely human dependent and have constant, unregulated access to commercial dog food.

These results will provide crucial insight into the relationship between livestock guarding dogs, caracals, and the species that share their landscape. The information gathered will help pave the way for more effective nonlethal predator management to both increase the productivity of South African livestock farmers and advance conservation measures for the country’s iconic carnivores.

METHODS

PRINCIPAL PROJECT DESIGN

Study Area:

This study was conducted in the semi-arid shrubland of South Africa's Northern Cape, the nation's largest and most sparsely populated province. The study area spans two land use types including the eastern part of Namaqua National Park (30º2'36 S, 17º35'10 E) and surrounding commercial farmlands to the north, east and south (Figure 3). The park is enclosed by an electric fence that separates it from bordering farms. Officially opened in 1999, portions of the park have been formally protected since 1988. Characterized by open shrubland up to one meter in height, the park falls within South Africa's Succulent Karoo biome (Figure 4). The Succulent Karoo is globally recognized for its exceptional biodiversity with more than 3,500 plant species in 135 families and 724 genera - more than 1,000 of which are endemic (Driver et al. 2003).

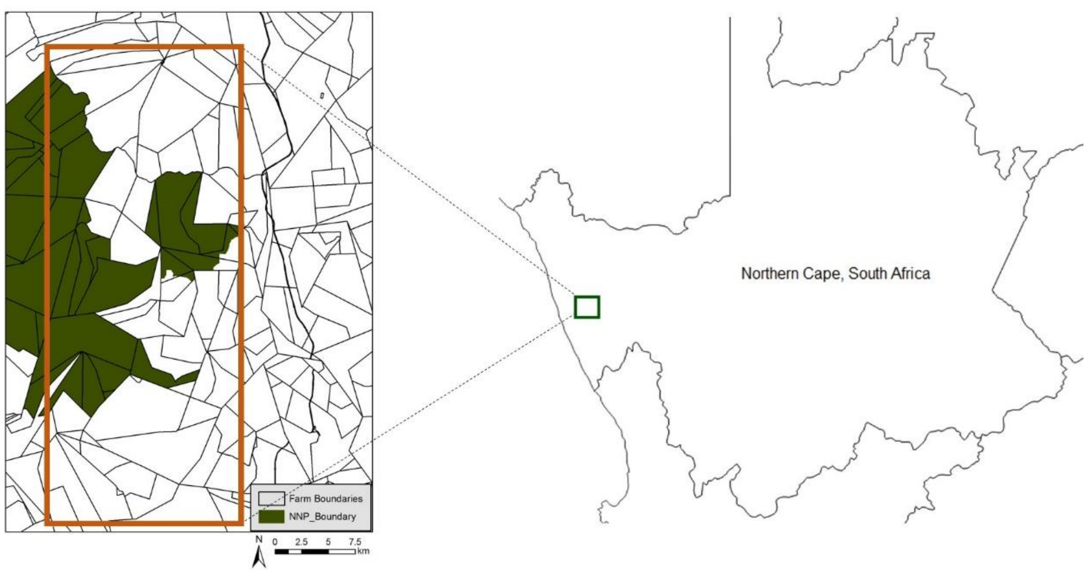

Figure 3. *The project area is located in South Africa's Northern Cape Province, including mountainous parts of Namaqua National Park and surrounding commercial farmlands (grey lines indicate farm boundaries).*

Water resources are limited and highly variable in the Succulent Karoo (Le Maitre et al. 2009). Classified as a winter rainfall region, annual precipitation ranges from 178-263 mm (Cowling et al. 1998). Summers have a mean maximum temperature of 30ºC but can drop as low at 5ºC in winter months (June-July). Elevation in the project area spans 250-760 meters.

Figure 4. *Map of the Succulent Karoo biome, home to some of the most diverse succulent flora in the world.*

Leopards (*Panthera pardus*) are the apex predator in the study area, whereas caracal and black-backed jackal (*Canis mesomelas*) are the most common mesopredators. The small carnivore guild consists of African wild cat (*Felis silvestris lybica*), grey mongoose (*Galerella pulverulenta*), yellow mongoose (*Cynictis penicillata),* bat-eared fox (*Otocyon megalotis*), Cape fox (*Vulpes chama*), common genet (*Genetta genetta*) and striped pole cat (*Ictonyx striatus*). Although lethal control is not administered within the park, intensive non-selective predator removal occurs on the surrounding farmlands, in addition to nonlethal methods including predator proof fencing (a fence packed with rocks at the bottom to discourage animals from digging underneath), electric fencing, livestock rotation, and fence patrols (Jansen 2016).

Project design:

This dissertation is the strictly defined diet portion of a much broader study on human-wildlife conflict called the Namaqua Predator Ecology and Coexistence Experiment (PEACE), a collaborative project between SANParks, the Cape Leopard Trust, Conservation South Africa and academic institutions including the University of Cape Town. The project was set up to test farm management methods that are both ecologically and economically sound. Baseline ecological data were collected from March 2014-May 2015, including an initial scat analysis (Jansen 2016). The initial analysis will eventually be combined with the present results to allow the study's principal investigator to conduct a Before-After-Control-Impact analysis, hence a direct and complete comparison of those results is beyond the scope of this dissertation.

As part of the overall PEACE Project, six comparable commercial farmlands were selected to participate in a livestock guarding dog study in 2015. The farms contained a total of 13 grazing areas scattered throughout the project area, each with its own flock. While both sheep and goat flocks were used in the study, the type of herd has been shown to have no influence over the effectiveness of livestock guarding dogs in South Africa (Leijenaar et al. 2015).

Originally, eight of the flocks were equipped with a livestock guarding dog, specially trained to monitor the flock 24 hours a day. Four of these flocks (three sheep and one goat) had a livestock guarding dog operating independently while the other four flocks (three sheep and one goat) had a livestock guarding dog accompanied by a human attendant. These human attendants, called ecorangers, were on site with the dogs from 8am-5pm seven days a week and remained camped in the fields overnight. The remaining five flocks (four sheep and one goat) were used as a control group where lethal control continued to be administered. Lethal control was not administered in dog-patrolled areas.

Unfortunately, due to livestock guarding dog mortalities and unforeseen circumstances, the study was reduced to six livestock guarding dogs. Four of these dogs (Farlas, Skollie, Kris and Ben) guarded their flocks independently without any human supervision while the other two (Rex and Fia) were accompanied by an ecoranger. All of the livestock guarding dogs were sterilised and all except Kris originated from the same litter. Each farmer was supplied with a strict management protocol to ensure the dogs had similar training. The dogs that were placed with ecorangers were trained by those ecorangers according to the same protocol. Site visits were conducted throughout the study by project partners to monitor the dogs and confirm consistency in their training.

Each Anatolian shepherd was introduced to its flock at seven weeks old. They were placed in small enclosures (known as kraals) for eight weeks with five ewes and five lambs or kids. At 16 weeks, the puppies and their flocks of ten were moved to small camps to give them more freedom of movement. The puppies stayed with the sheep or goats for another eight weeks, accompanying them while they grazed. At 24 weeks, the small training flocks were reintegrated into the main flocks, and the dogs then remained with their full flock permanently. The farmers and ecorangers continued to train the dogs until they were one year old, correcting behaviours such as chasing livestock and wildlife and returning to the farmer’s house. Automatic feeders were placed at livestock water points, giving the dogs consistent and constant access to pelleted dog food. All dog food was generously donated to the study from project sponsors and not provided at cost to participating farmers.

At the onset of the study (when the dogs were just over one year old), all six livestock guarding dogs were equipped with a GPS radio-collar and 17 caracals were captured and collared during the study. Field assistants used the GPS data to identify clusters, at which point they would investigate the kill site and collect any deposited scat. They also collected scats along transects and opportunistically. A total of 372 samples were collected, 187 from livestock guarding dogs and 185 from caracals. Collected scat samples were placed in paper envelopes, labelled, and dried at the field station in ambient temperatures before being transported to the lab for processing.

DIET STUDY

Scat Analysis:

Scat samples were autoclaved at 120ºC for 20 minutes for sterilization. To remove prey fragments from the faeces for identification, each scat sample was placed in a nylon stocking (tied off at both ends) and soaked in water overnight (Klare et al. 2011). In the morning, each sample was opened and washed through a sieve, manually broken up to ease the washing process while macroscopic contents were removed with tweezers. Once washing was complete, macroscopic remains (hair, bone, vegetation, etc.) were spread out on a petri dish and dried in an oven at 40ºC for 12 hours before being weighed. The hairs were then soaked in 70% ethanol to remove any remaining faecal particles, rinsed with distilled water and allowed to dry for at least 24 hours prior to analysis.

For each individual sample, macroscopic remains were identified to the lowest possible taxonomic level (Perrin and Campbell 1980; Douglas 1989; Keogh 1983, 1985; Brassine and Parker 2012). Undigested remains were separated into the following 15 broad categories micromammals, small carnivores, hyraxes, hares, porcupines, wild ungulates, domestic ungulates, unidentified mammals, invertebrates, birds, reptiles, fruit, vegetation, anthropogenic and unknown. The micromammal category included shrews and small rodents, excluding porcupines (Drouilly et al. 2017).

Carnivore scat is notoriously difficult to locate, especially in such vast territories. Due to the age and exposure of some samples to the harsh arid conditions of the Northern Cape, several scat samples were found to contain only tiny bone fragments. These samples were taken to small mammal bone experts at the Iziko South African Museum for assistance with identification. If identification to species level was not possible, the bones were categorized by size class [small mammal (<1kg), medium mammal (1-10kg), medium-large mammals (10-40kg)]. These classes were originally determined by the baseline caracal diet study (Jansen 2016) and have been adopted here at the request of the overall project's principal investigator to ease future comparisons between years.

Birds, reptiles, and invertebrates generally could not be identified any further, as the remains in scat samples were too fragmented to allow for accurate identification (Klare et al. 2011). However, finer classification was made note of whenever possible. Mammalian remains were identified to species level through the microscopic analysis of hair cross-sections and longitudinal hair scale patterns (Klare et al. 2011; Drouilly et al. 2017). Unidentified items were recorded as unknown.

Mammal hair cross-sections were prepared using the method proposed by Douglas (1989). Ensuring all hair types were represented, twenty clean hairs were randomly selected with forceps and placed longitudinally into a 3 millimetre plastic Pasteur pipette (Douglas 1989; Spaulding et al. 2000). Molten, transparent wax (Surgipath Paraplast, Leica Microsystems, Wetzlar, Germany) was drawn into the pipette to provide a matrix for hair cross-sections (Douglas 1989). The pipette was then immediately placed in a beaker of ice to allow the wax to set (Douglas 1989, Keogh 1983). Once set, a razor sharp surgical blade was used to slice five thin cross-sections from the plastic pipette. Cross-sections were mounted on a glass slide (Labstar plain microscope slide, Lasec, Cape Town, South Africa) and examined under a Leica DM500 compound microscope at 40x magnification (Leica Microsystems, Wetzlar, Germany) (Douglas 1989; Mann 2014; Jansen 2016; Drouilly et al. 2017).

Imprints of hair cuticle patterns were used to verify initial identification. Utilising multiple methods for hair analysis maximised the potential for positive identification, particularly for degraded samples. Imprints were prepared according to the method proposed by Dreyer (1966). A thin layer of clear nail polish was placed on a glass slide and allowed to dry for 20 seconds. Clean hairs were then randomly selected and placed on top of the slide, ensuring all types and sections of the hair were clearly represented. Hairs were then left to dry for at least one hour to allow the imprint to set before being carefully removed with fine-tip tweezers. Hair imprints were examined under a Leica DM500 compound microscope at 40x magnification (Leica Microsystems, Wetzlar, Germany).

Species were identified by comparing samples with reference keys (Dreyer 1966; Perrin & Campbell 1980; Keogh 1983, 1985; Brassine & Parker 2012). Macroscopic remains such as bones and teeth were used to corroborate hair analysis (Drouilly et al. 2017). When hair was not present in a sample, identification was made by comparing bones and teeth to an established key (Avery 1979) and specimens held at the Iziko South African Museum in Cape Town.

All prey identification was conducted blind, without knowledge of the assigned treatment. While the sampled species was apparent (caracal vs. dog), individual treatments within species (e.g. ecoranger versus unaccompanied) were only revealed once prey identification had concluded to avoid potential bias (Martínez-Gutiérrez et al. 2015).

Frequency of Occurrence:

The frequency of occurrence for each prey type was calculated for both livestock guarding dogs and caracals. The frequency of occurrence was calculated as the number of times a prey item occurred, divided by the total number of prey items identified from all scats (Lockie 1959). This number was expressed as a percentage for additional clarity (Lockie 1959; Klare et al. 2011). While this calculation is one of the most common methods for calculating predator diet (Klare et al. 2011), it has been heavily criticized for overestimating the importance of small prey items (Weaver 1993; Klare et al. 2011; Braczkowshi et al 2012b).

Small animals have a higher surface to volume ratio and are covered with more hair per unit of soft tissue (e.g. muscle and internal organs) than larger animals. When carnivores feed on small prey, they consume less prey mass to excrete one scat than when they feed on larger prey species with more digestible meat (Floyd et al. 1978; Weaver 1993; Wachter et al. 2012). While many factors can influence prey mass and the number of scats produced, this overall trend has been confirmed by feeding trials (Floyd et al. 1978; Weaver 1993). Furthermore, unlike large prey items, multiple small prey items (such as insects) can occur in a single scat, which can further inflate their importance (Klare et al. 2011).

To avoid such potential bias, a corrected frequency of occurrence was also used to allow prey items to be weighted accordingly (Floyd et al. 1978; Karanth & Sunquist 1995; Braczkowski et al. 2012b; Mann 2014; Jansen 2016). To calculate the relative frequency of occurrence, each scat was given a total weighting of one. If two prey items were present, they each received a weighting of 0.5 and so forth. The majority of scats (76% livestock guarding dog scats and 82% caracal scats) were comprised of a single prey item and assigned a weighting of one. Two prey species were identified in 21% of livestock guarding dog scats and 16% of caracal scats and three prey species were identified in 2% of livestock guarding dog scats and 2% of caracal scats. One livestock guarding dog sample contained five prey items.

Biomass Calculation Model:

Frequency of occurrence measurements can help establish the variety of prey items in a carnivore's diet, but not necessarily their quantity. Prey biomass consumed for the excretion of a scat varies according to prey size (Floyd et al. 1978). Biomass models thus use prey weights to calibrate consumption estimates, allowing a more accurate reconstruction of the predator's diet. Biomass models are the most ecologically relevant diet parameter and currently our best tool for approximating the true diet of predators (Klare et al. 2011; Chakrabarti et al. 2016).

This study used the generalized biomass model developed by Chakrabarti et al. (2016) to determine the diet of caracals:

$$Y = (0.033-0.025 \exp(-4.284(X/PBM))) \times PBM$$

where Y is the mass of prey consumed per collectable scat, X is the prey body mass, and PBM is the predator body mass. The mean adult body mass between males and females was used for both predators and prey (Skinner & Chimimba 2005). Unidentifiable samples within each size class (small, medium, medium-large) were assigned a prey weight by calculating the mean weight of all other prey species found within that class.

Unfortunately, reliable biomass estimates for the livestock guarding dogs were not possible. While there are biomass models available for canids, these do not account for the amount of pelleted dog food consumed by the livestock guarding dogs each day. Furthermore, as the dogs have constant, unregulated access to their food, there was no way to quantify how much pelleted dog food was consumed in relation to wild prey. Thus, only frequency of occurrence and relative frequency of occurrence were reported for livestock guarding dogs. Although not as specific as biomass models, the occurrence estimates do allow for comparisons with other diet studies on free-ranging dogs (See Appendix I: Diet of free-ranging dogs).

Diet Comparisons:

Dog scats were divided into two separate groups according to treatment types 1) unsupervised livestock guarding dog and 2) livestock guarding dog accompanied by an ecoranger. Each prey category was compared using a chi-square test to evaluate similarities and differences in diet by treatment type (Reynolds & Aebischer 1991; Vanak & Gompper 2009b; Drouilly et al. 2017).

Caracal scats were divided into two separate groups according to location 1) Namaqua National Park and 2) surrounding farmlands. Each prey category was compared using a chi-square test to evaluate similarities and differences in diet across land use (Reynolds & Aebischer 1991; Drouilly et al. 2017).

There are many scientific and statistical obstacles to comparing the diet of a wild felid with a domestic canid. However, once it was determined that both species were consuming prey on the same farm landscape, a chi-square test was used to compare each prey category in order to highlight significant differences in occurrence. Diet specialization on farmland for each species was calculated according to Levins' measure of niche breadth (Levins 1968; Krebs 1999):

$$B = (1/\sum \mathrm{p}_j^2)$$

where B is Levin's measure of niche breadth, and p_j is the proportion of items in the diet that are of food category *j*. Ten food categories were used (Pavey et al. 2008) including fruit, vegetation, invertebrates, birds, reptiles, small mammals, medium mammals, medium large mammals, sheep and goats.

RESULTS

GENERAL DIET COMPOSITION OF LIVESTOCK GUARDING DOGS

A total of 187 livestock guarding dog scats were analysed for prey identification. Four were discarded due to uncertainty in geographic location of the scat and hence allocation to a particular dog. Of the 183 remaining samples, only one scat did not contain evidence of a wild plant or animal species. Ninety percent of the samples contained at least one animal prey item. The remaining ten percent were comprised solely of vegetation, or accompanied by an anthropogenic item that had been consumed. Anthropogenic items included string, pieces of plastic, and a tea bag.

Table 1. *Livestock guarding dog (n = 6) diet composition expressed as frequency of occurrence (FO) and relative frequency of occurrence per scat (RFO). A total of 183 scats were analysed, yielding 234 prey occurrences.*

Dietary Items	**Number of Occurrences (Prey Items)** *n* = 234	**FO (%)**	**Number of Occurrences (Per Scat)** *n = 183*	**RFO (%)**
Invertebrates	9	3.8	4.2	2.3
Birds	1	0.4	0.3	0.2
Reptiles	3	1.3	1.5	0.8
Mammals	150	64.1	134.8	73.7
Micromammals	8	3.4	5.8	3.2
Small carnivores	1	0.4	1.0	0.5
Hyraxes	10	4.3	7.0	3.8
Hares	6	2.6	4.8	2.6
Porcupines	4	1.7	4.0	2.2
Wild ungulates	11	4.7	8.8	4.8
Domestic ungulates	108	46.2	101.8	55.6
Unidentified mammals	2	0.9	1.5	0.8
Fruit	2	0.9	0.7	0.4
Vegetation	49	20.9	32.2	17.6
Anthropogenic	11	4.7	4.7	2.6
No prey items*	1	0.4	1.0	0.5
Unknown	8	3.4	3.5	1.9

*One sample contained only gravel

Mammals comprised the vast majority of animal prey items (73.7%), including 12 different species. Prey remains were dominated by domestic ungulates with a relative frequency of occurrence per scat (RFO) of 55.6% (Table 1, Figure 5). The next most common mammalian prey category was wild ungulates with a RFO of 4.8% (Table 1, Figure 5). Birds and reptiles occurred in less than one percent of scats, while invertebrates were slightly more common (2.3%) (Table 1, Figure 5). Beetles were the most frequently observed invertebrate, although one scat was comprised entirely of termites. Bone fragments in 1.9% of samples were too small to positively identify and did not contain any other material (such as hair) that would aid identification. These samples were labelled "unknown."

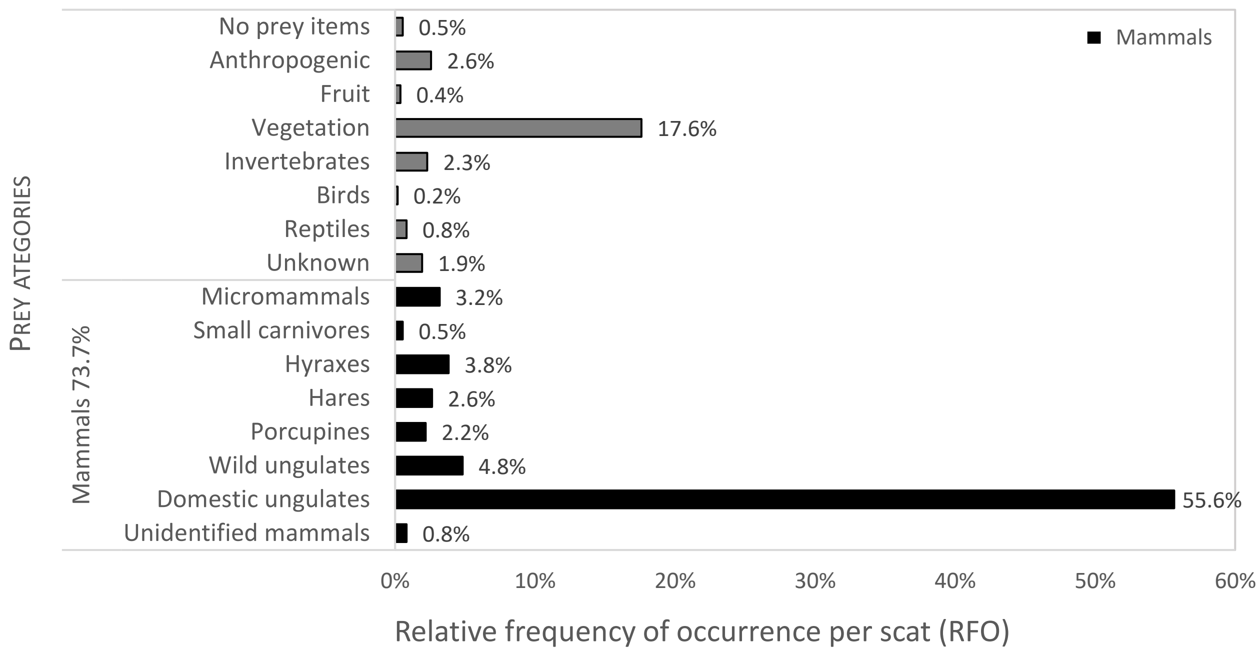

Figure 5. *Relative frequency of occurrence per scat (RFO) for all prey categories found in 183 scats of six livestock guarding dogs in Namaqualand, South Africa (Jan 2015 – Feb 2016).*

LIVESTOCK GUARDING DOG IMPACTS ON NATIVE SPECIES

Although domestic ungulates dominate the diet of livestock guarding dogs, nearly half of their (non-pelleted dog food) dietary consumption was comprised of wild plants and animals. Native animal species were consumed more frequently than plants, but not to a significant extent (χ^2 = 2.633, p = 0.1046), and most prey species were mammals (Figure 6). Invertebrates are the next most common prey category (5.6%), followed by reptiles (2.0%) (Figure 6). Only one sample contained feathers (0.4%), and even that scat was predominantly comprised of small mammal remains.

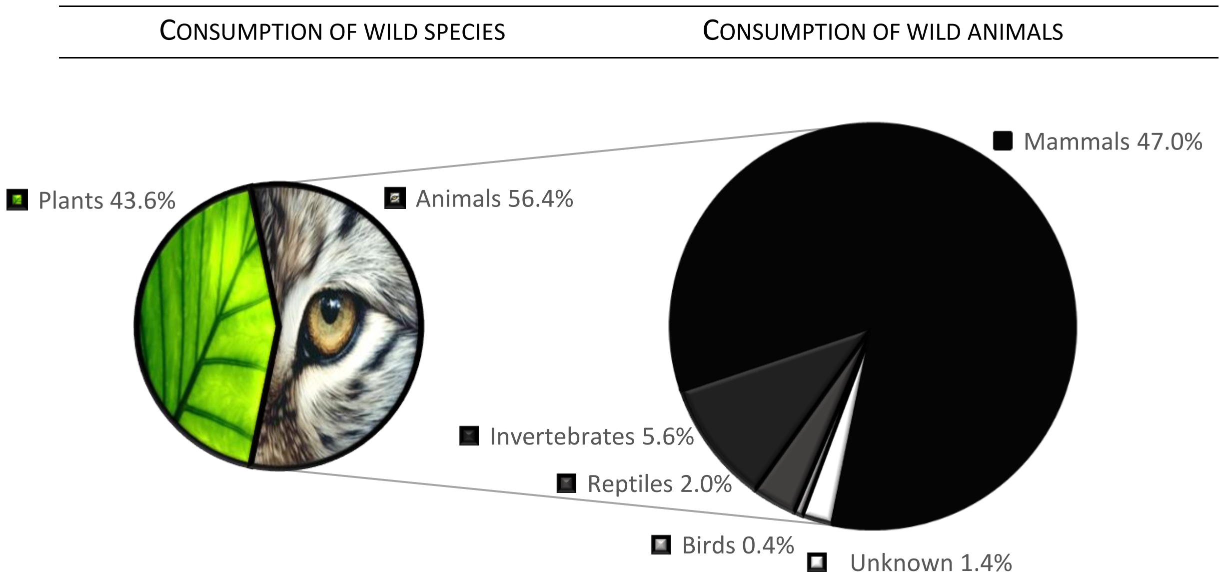

Figure 6. *Wild prey diet composition for livestock guarding dogs in the absence of domestic ungulates.*

Mammalian prey items were quite diverse, ranging from mice to antelope (Figure 7). Ten individual species were identified (in order of most to least frequent): rock hyrax (*Procavia capensis*), scrub hare (*Lepus saxatilis*), Cape porcupine (*Hystrix africaeaustralis*), klipspringer (*Oreotragus oreotragus*), common duiker (*Sylvicapra grimmia*), steenbok (*Raphicerus campestris*), bush vlei rat (*Otomys unisulcatus*), meerkat (*Suricata suricatta*), Namaqua rock mouse (*Micaelamys namaquensis*), and springbok (*Antidorcas marsupialis*).

Wild ungulates had the highest relative frequency of occurrence (RFO = 4.8%) of all wild mammal categories (Figure 7). However, medium sized mammals (including hyraxes, hares and porcupines) made up the bulk of the prey base (Figure 7).

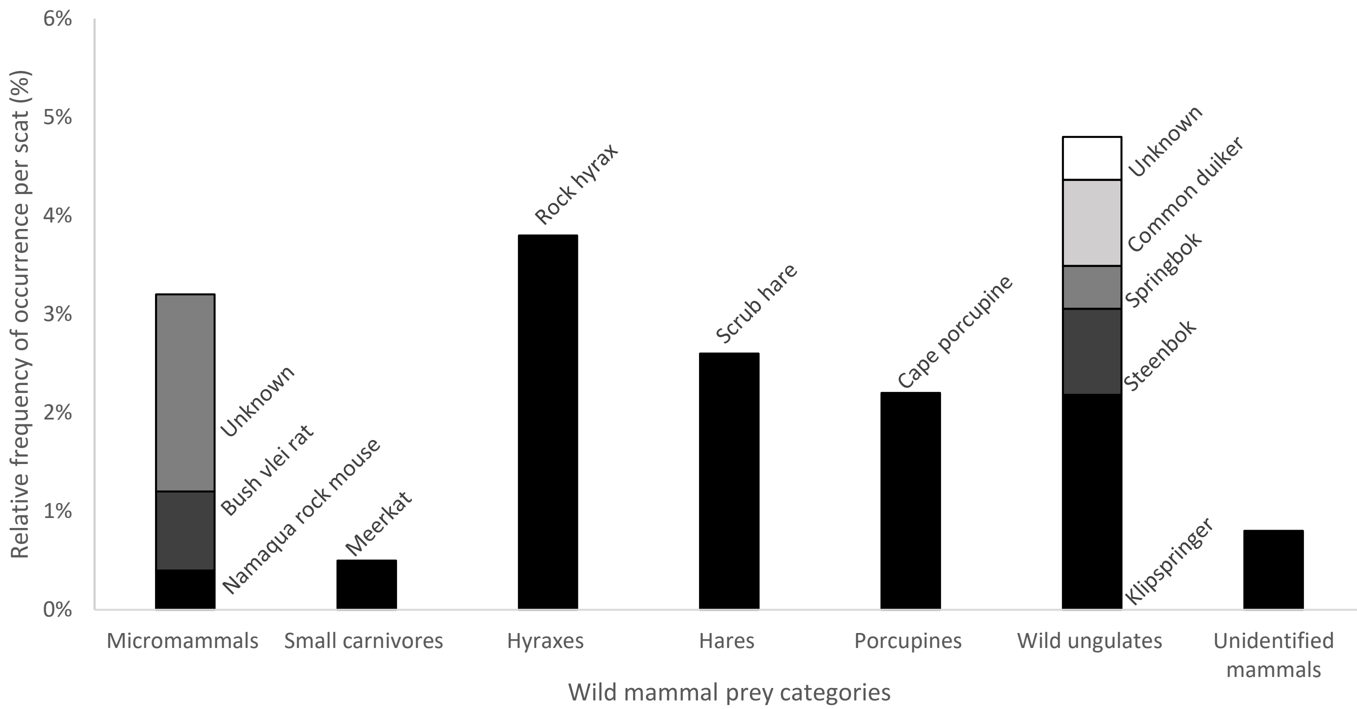

Figure 7. *Relative frequency of occurrence per scat (RFO) of wild mammals consumed by livestock guarding dogs in Namaqualand, South Africa (Jan 2015 – Feb 2016).*

LIVESTOCK GUARDING DOG IMPACTS ON DOMESTIC SPECIES

Domestic ungulate remains occurred in 60% of scat samples. The frequency of occurrence was 46.2%, which increased to 55.6% relative frequency of occurrence per scat (Table 1). As more sheep than goats were grazed in the project area (78% of the livestock were sheep), their consumption was not evenly distributed. Goats had a relative frequency of occurrence per scat of 3.8% while sheep had a relative frequency of occurrence per scat of 51.8% (Figure 8)

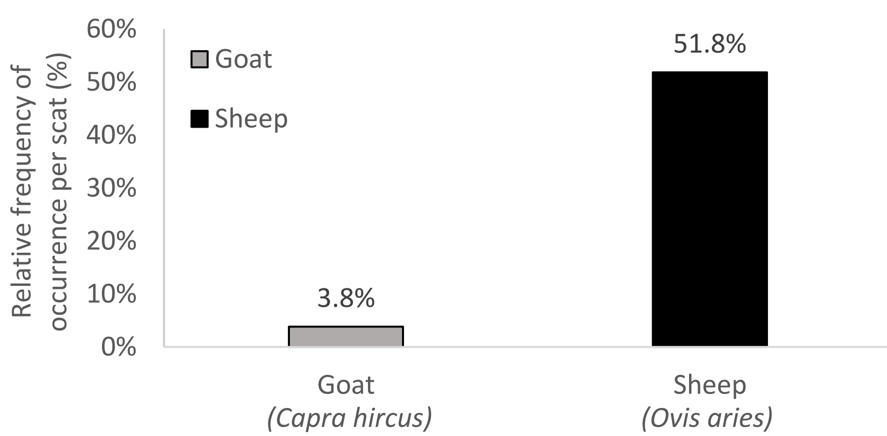

Figure 8. *Relative frequency of occurrence per scat (RFO) of domestic ungulates consumed by livestock guarding dogs in Namaqualand, South Africa (Jan 2015-Feb 2016).*

Diet of dogs with ecorangers versus unaccompanied

The diet of dogs accompanied by ecorangers was significantly different from the diet of dogs operating independently on the landscape ($\chi^2 = 94.075$, $p < 0.001$). For dogs guarding their flocks without human supervision, domestic ungulate remains occurred in 75% of scats (Figure 9). Conversely, only two scats (less than 5%) from dogs accompanied by an ecoranger contained livestock remains. One sample was comprised of goat hair and bones, however the other contained only a few sheep hairs, lacking a definitive indication of consumption (*e.g.* bones or pieces of skin).

Dogs accompanied by ecorangers consumed significantly more plants than their solitary counterparts ($\chi^2 = 9.738$, $p = 0.002$). Although they consumed wild mammals more than twice as frequently (32% compared to 14%), given the small sample size this was not found to be significant ($\chi^2 = 0.176$, $p = 0.675$) (Figure 9). Dogs accompanied by ecorangers also consumed more anthropogenic material.

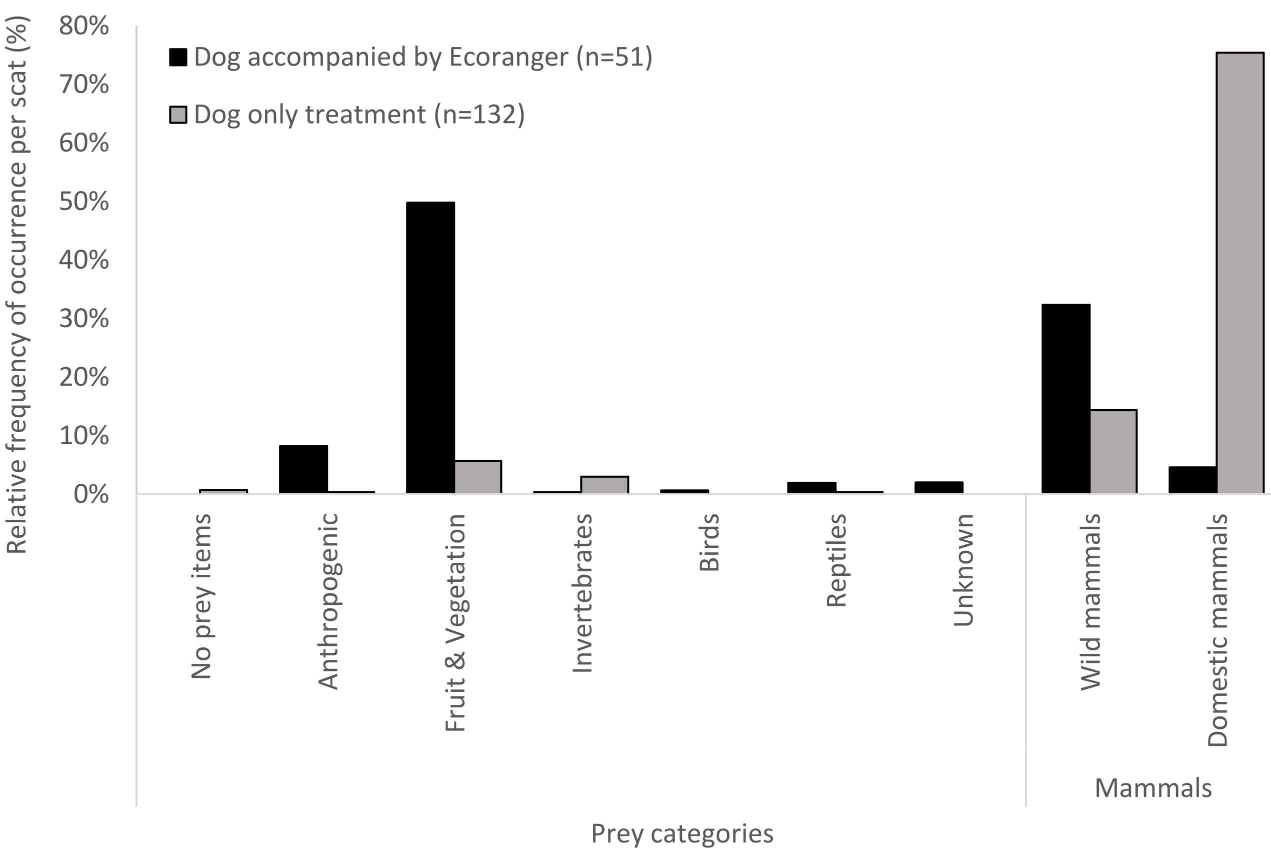

Figure 9. *Differences in diet composition of livestock guarding dogs across two treatment types: 1) dogs operating independantly on the landscape and 2) dogs guarding their flocks alongside human attendants know as ecorangers.*

VARIATION BETWEEN INDIVIDUALS

Six livestock guarding dogs participated in the study and all but Kris were from the same litter. While each dog was raised and trained according to the same protocol and supplied with the same type and amount of pelleted dog food, diet among individuals varied (Figure 10).

Fia consumed by far the most vegetation and was the only dog where livestock remains did not occur in any scat samples (Figure 10). She also consumed the greatest amount of anthropogenic material (primarily blue and white string). Both Fia and Rex were accompanied by an ecoranger, yet Rex consumed wild animals far more than the other dogs (including hares, hyraxes, rats, mice, porcupines and two different species of wild ungulate).

Farlas had the largest sample size, yet more than 80% of his scats contained remnants of livestock – more than any other dog (Figure 10). Animal remains occurred in 97% of his samples, while plant pieces formed a small proportion of only two (Figure 10). Skollie and Kris's diets were similar, although Skollie consumed more vegetation whereas Kris consumed

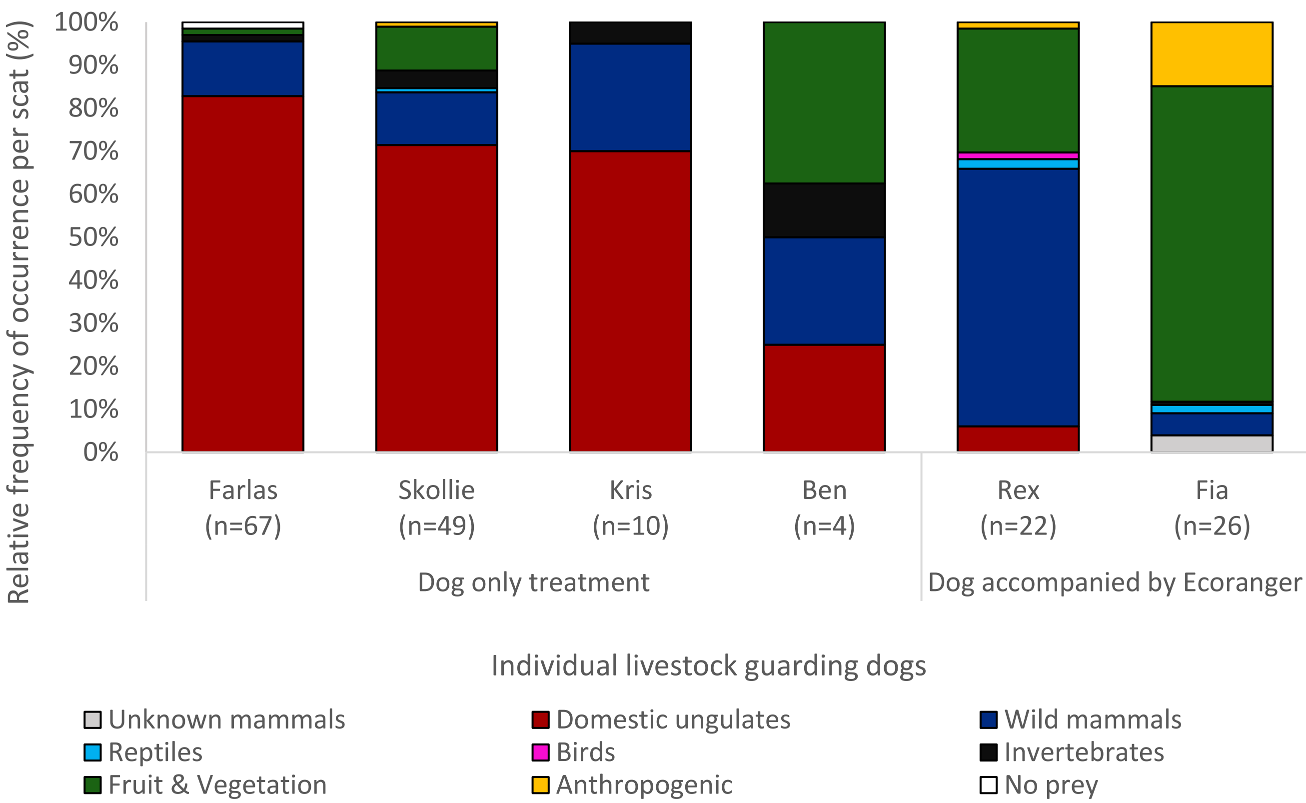

Figure 10. *Diet profiles for six livestock guarding dogs, four of which guarded flocks independently and two of which were accompanied by a human attendant known as an ecoranger.*

more wild animals. Ben had the most uniform distribution of prey categories in his diet, although the sample size of scats was very low (n = 4) (Figure 10).

GENERAL DIET COMPOSITION OF NAMAQUALAND CARACALS

A total of 185 caracal scats were analysed for prey identification across two land-uses: farmland and a protected area. Overall, mammals dominated the prey items with a frequency of occurrence (FO) of 84.1%, which increased to 89.1% once corrected to relative frequency of occurrence per scat (RFO) (Table 2). Eighteen mammalian prey species were identified, and medium sized mammals (1-10kg) were by far the most important prey base with rock hyrax (*Procavia capensis*) being the most frequently consumed species. Small mammals (<1kg) were the second most frequent prey category, consisting primarily of micromammals. Domestic ungulate remains occurred in only 8.6% of scats, although this accounted for 13.7% of mammalian biomass consumed (Table 2) as sheep and goats were by far the heaviest prey items, weighing more than double the heaviest wild ungulate consumed. According to Chakrabarti et al. (2016), this translates to 3.4 kg of sheep and 2.6 kg of goat consumed out of 183 scat samples.

Table 2. *Namaqualand caracal diet composition expressed as frequency of occurrence (FO), relative frequency of occurrence per scat (RFO), and percentage of mammalian biomass consumed. A total of 185 analysed scats yielded 220 prey occurrences.*

Dietary Items	**Number of Occurrences (Prey Items)** *n* = 220	**FO (%)**	**Number of Occurrences (Per Scat)** *n = 185*	**RFO (%)**	**Mammalian Biomass (%)**
Invertebrates	**8**	**3.6**	**3.7**	**2.0**	
Birds	**1**	**0.5**	**0.5**	**0.3**	
Reptiles	**1**	**0.5**	**0.3**	**0.2**	
Mammals	**185**	**84.1**	**164.8**	**89.1**	**100.0**
Wild mammals	168	76.4	149.0	80.5	86.3
Small mammals (<1kg)	40	18.2	32.7	17.7	8.9
Micromammals	24	10.9	19.3	10.5	4.5
Small carnivores	8	3.6	6.5	3.5	2.4
Unknown	8	3.6	6.8	3.7	2.0
Medium mammals (1-10kg)	119	54.1	109.3	59.1	73.0
Hyraxes	61	27.7	55.5	30.0	38.7
Hares	18	8.2	16.0	8.6	9.8
Unknown	40	18.2	37.8	20.5	24.6
Medium-large mammals (10-40kg)	7	3.2	5.0	2.7	4.3
Wild ungulates	7	3.2	5.0	2.7	4.3
Unidentified mammals	2	0.9	2.0	1.1	

Domestic ungulates	17	7.7	15.8	8.6	13.7
Sheep	9	4.1	9	4.9	7.8
Goats	8	3.6	6.8	3.7	5.9
Fruit	**5**	**2.3**	**2.3**	**1.3**	
Vegetation	**10**	**4.5**	**4.8**	**2.6**	
Anthropogenic	**3**	**1.4**	**2.0**	**1.1**	
Unknown	**7**	**3.2**	**6.5**	**3.5**	

Birds and reptiles occurred in less than 1% of caracal scats, while invertebrates were slightly more common at 2% (Table 2, Figure 11). Fruit and vegetation were similarly uncommon (1.3% and 2.6% respectively) whereas 3.5% of scats contained bone fragments too small to accurately identify and lacked any further means of categorization (such as hair). These samples were labelled "unknown." While they were not counted as a prey item, multiple ticks (at least two different species) were found in eight scat samples (whether they were attached to a prey item or feeding on the caracal itself is unknown).

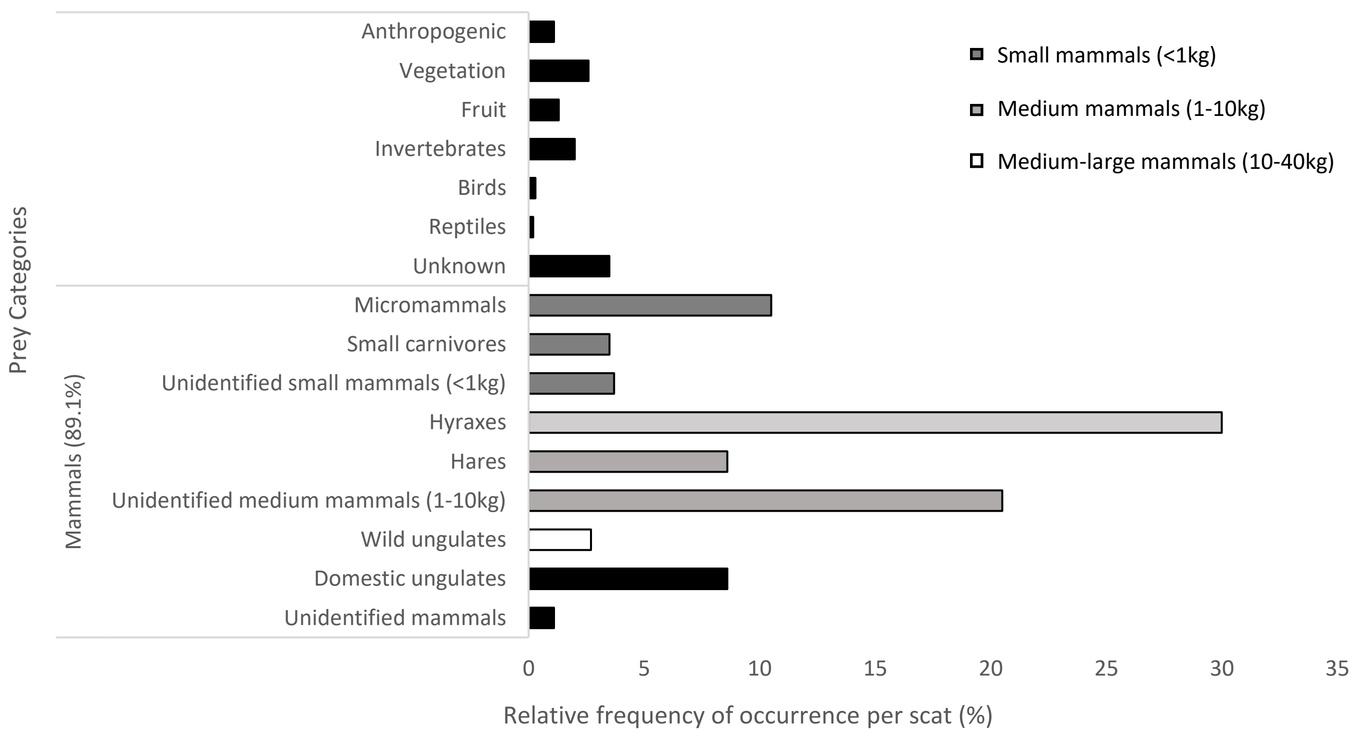

Figure 11. *Relative frequency of occurrence per scat (RFO) for all prey categories found in 185 caracal scats in Namaqualand, South Africa (April 2015 – Sept 2016).*

Caracal diet varied significantly between the protected area and surrounding farmlands (χ^2 = 13.721, p = 0.008). Small mammals were consumed significantly more in the national park than on farmland (χ^2 = 4.483, p = 0.034), and medium mammals were consumed significantly more on farmland than in the park (χ^2 = 59.584, p <0.001). Medium-large mammals (wild ungulates) were consumed more frequently in the park, although not significantly, and domestic ungulates were only consumed on farmlands (Table 3, Figure 12).

Table 3. *Namaqualand caracal diet composition expressed as frequency of occurrence (FO), relative frequency of occurrence per scat (RFO), and percentage of mammalian biomass consumed in Namaqua National Park and surrounding farmlands (April 2015 – Sept 2016).*

	Farmland			**National Park**		
Dietary Items	**FO (%)**	**RFO (%)**	**MB (%)**	**FO (%)**	**RFO (%)**	**MB (%)**
Invertebrates	3.8	2.2	-	2.6	1.1	-
Birds	0	0.3	-	0	0	-
Reptiles	0	0	-	2.6	1.1	-
Mammals	84.1	88.7	**100.0**	84.2	91.1	**100.0**
Wild mammals	74.7	78.5	83.9	84.2	91.1	100.0
Small mammals (<1kg)	15.4	14.3	6.9	31.6	35.0	20.4
Micromammals	9.3	8.6	3.6	18.4	20.0	9.7
Small carnivores	2.2	1.9	1.3	10.5	8.3	8.7
Unknown	3.8	3.8	2.0	2.6	3.3	2.0
Medium mammals (1-10kg)	56.0	61.3	74.4	44.7	47.8	64.7
Hyraxes	28.6	31.0	39.2	23.7	25.0	35.8
Hares	7.7	7.7	8.6	10.5	13.3	16.4
Unknown	19.8	22.6	26.6	10.5	9.4	12.6
Medium-large mammals (10-40kg)	2.2	1.6	2.5	7.9	8.3	14.7
Wild ungulates	2.2	1.6	2.5	7.9	8.3	14.7
Unidentified mammals	1.1	1.3	-	0	0	-
Domestic ungulates	9.3	10.2	16	0	0	0
Sheep	4.9	5.8	9.1	0	0	0
Goats	4.4	4.4	6.9	0	0	0
Fruit	2.7	1.5	-	0	0	-
Vegetation	3.3	1.8	-	10.5	6.7	-
Anthropogenic	1.1	1.0	-	0	0	-
Unknown	3.8	4.2	-	0	0	-

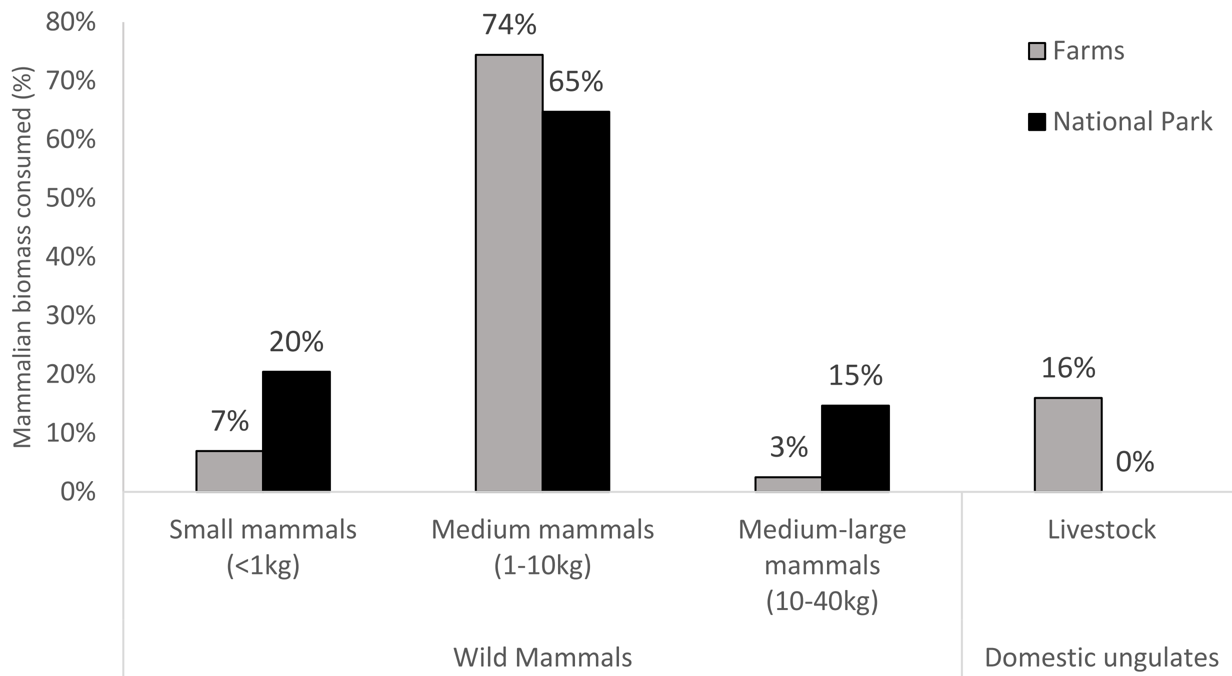

Figure 12. *Percentage of mammalian biomass consumed by Namaqualand caracals in Namaqua National Park compared to the surrounding farmlands (April 2015 – Sept 2016).*

AN INDIGENOUS VERSUS INTRODUCED PREDATOR

Levin's measure of niche breadth for livestock guarding dogs was slightly higher (B = 2.83) than for caracals on farmland (B = 2.15), indicating the dogs are more generalist feeders. A chi-square test revealed significant differences in the proportion of prey species that comprised the diet of caracals and livestock guarding dogs within the same farm landscape ($\chi^2 = 174.87$, $p < 0.001$).

Caracals ate significantly more small mammals ($\chi^2 = 8.1779$, $p = 0.004$) and medium sized mammals ($\chi^2 = 56.554$, $p < 0.001$) on farmland than the livestock guarding dogs. The frequency of occurrence of medium sized mammals was much higher for caracals relative to livestock guarding dogs, despite being the most commonly consumed wild prey size class for both species (Figure 13). Consumption of medium-large mammals did not differ significantly ($\chi^2 = 3.512$, $p = 0.060$). However, dogs had a much higher relative frequency of occurrence per scat (RFO = 55.6%) of livestock in their diet relative to caracal on Namaqualand farms (RFO = 10.2%) (Figure 13). This difference was found to be significant ($\chi^2 = 62.891$, $p < 0.001$).

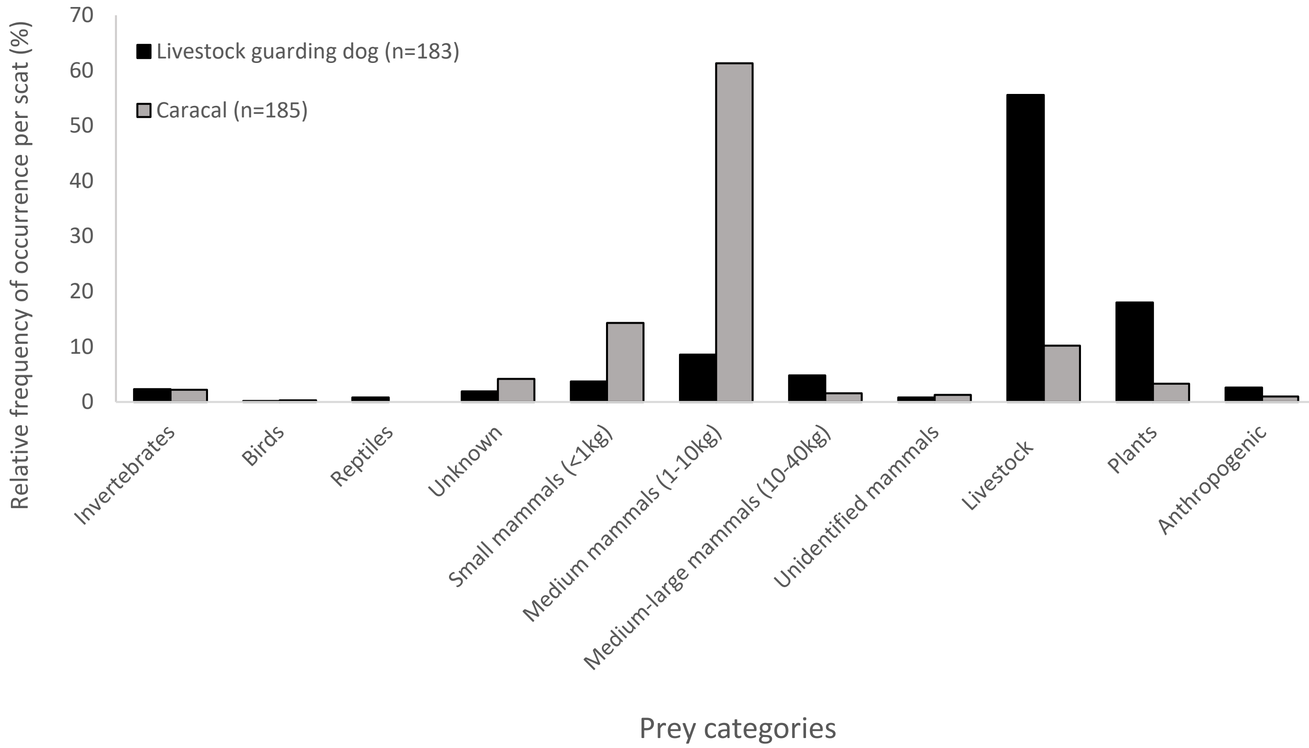

Figure 13. *The relative frequency of occurrence per scat (RFO) of livestock guarding dogs and caracals on farmland in Namaqualand, South Africa (Jan 2015 - Sept 2016).*

DISCUSSION

LIVESTOCK GUARDING DOG DIET IN A GLOBAL CONTEXT

This study marks the first attempt, to the researcher's knowledge, to quantify the diet composition of livestock guarding dogs. Contrary to prediction, most of the dogs in the study consumed both domestic and wild prey. Furthermore, all dogs guarding flocks unattended by human ecorangers had a higher frequency of occurrence of domestic livestock in their scat than the indigenous predator, the caracal. Although caracals on farmland consumed domestic ungulates at a relative frequency of occurrence of 10.2%, none of the caracal samples collected from the national park contained livestock.

One major limitation of scat analysis is that it does not allow for the determination of whether the prey was killed or scavenged (Chavez & Gese 2005). Preying on scavenged carcasses has artificially inflated livestock frequencies in other diet studies (Chavez & Gese 2005) and livestock guarding dogs specifically have been praised for leading range inspectors to carcasses (Hansen 2002). GPS data was collected by the PEACE project and GPS clusters may yield more information through carcass investigation, however that analysis was beyond the scope of this study.

Direct observation or video footage could also be used to determine whether the livestock guarding dogs are predating or scavenging livestock. Direct observers would need to ensure the dogs remained unaware of their presence and video footage would require frequent battery changes and film downloads. While more logistically complicated, these approaches could also illuminate whether the livestock guarding dogs are killing more wildlife than they consume, which has been reported in Namibia (Marker et al. 2005a; Potgieter et al. 2016), and in other studies on free-ranging dogs (Taborsky 1988). It should be noted, however, that scavenging has also been reported in caracals living in arid environments (Skinner 1979; van Heezik & Seddon 1998; Avenant & Nel 2002). If one assumes that domestic ungulate occurrence in livestock guarding dog scat is inflated from scavenging, it should not be out of the realm of possibility that the caracal's is as well.

It is well established that livestock guarding dogs chase and kill both wildlife and domestic animals on the farms where they are deployed (Green et al. 1984; Smith et al. 2000; Marker et al. 2005a, 2005b; Gingold et al. 2009; Potgieter et al. 2013, 2016; Timm & Schmidtz 1989; Hansen et al. 2002). One study surveyed 45 owners of 137 livestock guarding dogs (Anatolian shepherds were one of five breeds included in the study) cooperating in a study at the U.S. Sheep Experiment Station (Green et al. 1984). Fourteen of the dogs had injured or killed livestock in their lifetime and five of those dogs became habitual killers. Seven farmers owned fully-grown dogs that continued to "play" after maturation and chased sheep until they eventually killed and were put down (Green et al 1984).

In nearby Namibia, chasing wildlife is one of the most commonly reported behavioural problems in livestock guarding dogs (Marker et al. 2005a, 2005b; Potgieter et al. 2013). Dogs have been reported to chase and consume animals as large as kudu (*Tragelaphus strepsiceros*) (Potgieter et al. 2016). Suspecting that malnourishment could either encourage livestock guarding dogs to hunt or rob them of the energy to chase wildlife, Potgieter et al. (2013) investigated whether the level of care provided determined a dog's propensity to chase wildlife. Commercial farmers (such as the ones in the present study) were found to provide significantly better care to their livestock guarding dogs than subsistence farmers (Potgieter et al. 2013). However, level of care was not found to differ between livestock guarding dogs that chased wildlife and those that did not (Potgieter et al. 2013). Although domestic dogs more generally have been shown to increase predation when poorly fed (Silva-Rodríguez & Sieving 2011), it is unlikely to be a contributing factor in this study as the livestock guarding dogs had constant access to a trough of pelleted dog food (See Appendix 1 for more information about the diet of free-ranging dogs more broadly).

While small carnivore remains were found in one livestock guarding dog scat sample, none of the samples contained potential livestock predators. A study of 79 livestock guarding dogs placed on Namibian farms revealed 56% of the dogs killed predator species (Potgieter et al. 2016). Jackals were killed by 37 dogs, baboons were killed by eight dogs, caracals were killed by three dogs, and one dog killed a cheetah that jumped into a livestock enclosure during the night (Potgieter et al. 2016). The deaths of a bat-eared fox and African wildcats were also reported (Potgieter et al. 2016). It is entirely possible that the Anatolian shepherds in Namaqualand are also killing predators but not consuming their remains, in which case they would escape the detection of this study.

Importantly, all of the flocks guarded by livestock guarding dogs in the Namibian study were herded into enclosures every night (Potgieter et al. 2016). Thus, the dogs were more or less restricted to areas of the farm within walking distance of the enclosures and not as wide-ranging as the Namaqualand dogs that lived permanently in the veld. While it logically follows that wide-ranging dogs may have more encounters with wildlife, the diet of free-ranging rural dogs has also been shown to become more opportunistic and less human dependent as their ranging increases (Vanak & Gompper 2009a).

Potgieter et al. (2016) calls for further investigation as to whether or not the livestock guarding dogs are selectively killing predators that approach their flocks. Such analysis could help determine whether lethal control by livestock guarding dogs is more or less selective than other methods currently employed by farmers. Additional research is needed, however, as to whether or not “problem individuals” exist in mesopredator populations and whether selective lethal control could successfully reduce livestock losses in Namaqualand. Particularly in the case of black-backed jackals, lethal removal could encourage new immigration into farm areas, decrease the median age of the population and encourage compensatory reproduction (Minnie et al. 2015). This is especially concerning as there is no evidence that livestock guarding dogs establish any kind of territorial boundary that might help prevent the formation of a source-sink system (Allen et al. 2016). Wild dogs in Australia, for example, routinely enter paddocks patrolled by livestock guarding dogs (Allen et al. 2016).

The variation between individual diets observed in this study underscores one of the most important and relevant issues in the study of livestock guarding dogs. One cannot expect all livestock guarding dogs to function equally well (Hansen 2002). The success rate of livestock guarding dogs ranges from 66%-90% (Green et al. 1984; Smith et al. 2000). Although Anatolians have been rated less trustworthy than other breeds (i.e. Maremmas and Shar Planinetz) (Coppinger et al. 1988) no livestock guarding dog breed is rated more highly than the others when assessing them across multiple criteria (Green & Woodruff 1988). Livestock guarding dog breeds should be evaluated on the basis of three key traits: trustworthiness (they will not harm livestock), attentiveness (they remain with the flock), and protectiveness (they defend the flock) (Smith et al. 2000). Given variation in these traits, breeders can optimise field placement by aligning traits with the best fit in terms of livestock type, natural environment and management regime (Coppinger et al. 1988).

While individual traits can have a strong impact on a dog's inclination to harass other animals, corrective training of these behaviours by shepherds has proven successful in many cases (Green et al. 1984; Hansen 2002; Rigg 2004; Marker et al. 2005a, 2005b). In Namibia, wildlife chasing appears to be declining in the overall population of livestock guarding dogs and trustworthiness has increased thanks to improvement in training methods (Potgieter et al. 2013). Swift corrective action is crucial to the success of corrective training in livestock guarding dogs, however in order for the correction to take place the dogs must have regular human supervision (Marker et al. 2005b).

In this study, livestock guarding dogs paired with ecorangers had a very low occurrence of livestock in their scat. This suggests that the presence of an ecoranger either prevents the dogs from consuming livestock, or enables the correction of bad behaviour when it is witnessed so it does not become habitual. Domestic dogs more broadly have been known to avoid predating when humans are near (Ciucci & Boitani 1998). In central Italy, for example, out of 50 attacks by free-ranging dogs on livestock, not one occurred while a shepherd was in proximity (Ciucci & Boitani 1998).

Human presence also mimics the way livestock guarding dogs developed historically. Originally, they guarded small flocks accompanied by a human herder – a very different scenario from the large flocks they guard independently today (Smith et al. 2000). Researchers in Norway are resurrecting this approach by pioneering a combination of herding and guarding. With certain training modifications, livestock guarding dogs patrol sheep pastures alongside a human attendant instead of remaining with the sheep (Hansen et al. 2002). Although dogs in the study were also reported to chase livestock and wildlife, this behaviour was swiftly and successfully corrected by their attendant. Using this method, a significant reduction in predation was achieved in areas smaller than 10-12 km^2 (Hansen et al. 2002). Specially developed for sheep that do not flock, this approach could be particularly useful for South Africa's wide-ranging breeds and further investigation into its effectiveness and transferability should be undertaken (Hansen et al. 2002). A behavioural study investigating the level of bonding between livestock guarding dogs and their flocks when free-ranging vs. kraaled at night (thus working more closely with humans) may also help determine how human contact influences effectiveness.

Human vigilance is clearly advantageous for reducing the consumption of domestic ungulates by livestock guarding dogs. However, it comes with an expensive price tag, especially for small farms in arid areas with restricted budgets, limited infrastructure and extensive grazing areas (Hansen et al. 2002; Nattrass & Conradie 2015). It is interesting to note, however, that while dogs accompanied by ecorangers consumed far less sheep, Rex (one of the dogs accompanied by an ecoranger) consumed more wild mammals than all other dogs. Any training and management to correct consumption of livestock should be careful not to allow those animals to be replaced with wild mammals. Dogs with human attendants also consumed more anthropogenic material, which is not unexpected as the ecorangers remained camped in the field with them, allowing the dogs greater access to human derived items than their solitary counterparts.

The effects of livestock guarding dogs on domestic species could far surpass direct predation or consumption. Increased stock losses would incur financial hardship for the farmer, but the flock would also likely increase their nervous behaviour. This could potentially result in reduced body condition from less time spent grazing, an increase in injuries, and reduced reproductive success (Dwyer 2009).

Livestock guarding dogs may also indirectly influence wild species. Dogs are known to cause shifts in behaviour (Gingold et al. 2009), alter spatial and temporal habitat use (Gingold et al. 2009, Banks & Bryant 2007), adversely impact threatened species (Potgieter et al. 2016), reduce breeding success in wild ungulates (Gingold et al. 2009), and hybridize with local canids if not neutered (Gingold et al. 2009). Although these effects can be much more difficult to assess, one of the goals of the PEACE project is to determine whether the presence of dogs, and dogs with ecorangers, altered predator habitat use or the relative abundance of wildlife species. While these data are still being analysed it is important to note than none of the wild species that occurred in the dogs' diet in Namaqualand were considered threatened.

Livestock guarding dogs have been shown in many studies to be a highly effective tool for large carnivore conservation (Green et al. 1984; Black & Green 1985; Andelt 1992; Smith et al. 2000; Hansen et al. 2002; Marker et al. 2005a, 2005b; Potgieter et al. 2013, 2016). This study is in no way meant to undermine or cast doubt upon those findings. Merely, it seeks to illuminate the knowledge gaps in the ability and inclination of livestock guarding dogs to act as an introduced predator on both domestic and wild species in their environment. Although the results of this study should be regarded as preliminary due to the small sample sizes, there is evidence that human presence can reduce consumption of livestock. While too much human contact could reduce their effectiveness at livestock guarding, human presence should be regular enough to take swift corrective action for any undesirable behaviour (Marker et al. 2005b).

While livestock guarding dogs in this study are clearly consuming both wild species and domestic livestock, it is important to contextualise this finding with the diet of the predators they are meant to deter. Caracal are the most abundant wild carnivore on this landscape (The Cape Leopard Trust, unpublished camera data) and are widely regarded by farmers in the region as major contributors to livestock losses. Despite this, information on the diet of caracals in Namaqualand is scarce. This study confirms findings from a baseline analysis conducted in 2015, before the introduction of the dogs, which suggests that caracals consume far fewer livestock that in other semi-arid sheep farming areas (Jansen 2016) and less than the livestock guarding dogs in this project.

CARACAL DIET ON FARMLAND AND IN A PROTECTED AREA

Unlike most felids, caracals tend to be generalist, opportunistic feeders (Avenant & Nel 2002) and the results from this study were no exception. Caracals in the project area consume a broad diet of prey items that range from invertebrates to antelope. Despite this dietary breadth the vast majority of prey was comprised of mammals (89%) which is well within the 70%-100% range established by other studies on caracal diet in Southern Africa (Tables 4 & 5).

Caracals' reliance on rock hyrax (*Procavia capensis*) for food supports previous findings from the Eastern Cape that have not been documented elsewhere (Moolman 1986, Grobler 1981). Other studies have reported the caracals' preference for hyrax, but found other species occurred more frequently due to higher availability (Palmer and Fairall 1988; Drouilly et al. 2017). Palmer and Fairall (1988) found that wild ungulates (specifically grey rhebuck, *Pelea capreolus*) occur more frequently, which was attributed to a recent decline in hyrax and rodent numbers associated with local drought conditions (Palmer & Fairall 1988).

Palmer and Fairall (1988) also highlight the crucial service caracals provide to farmers by controlling hyrax and rodent numbers, which in turn protects the forage that domestic livestock rely on for food. Using the estimates of Grobler (1981), a population of 15 adult and 10 juvenile caracals consuming hyraxes at the 30% RFO recorded in this study would consume 1,606 hyraxes per year on farms in the study area. While hyrax and sheep do not consume all the same plant species, they do share some resources and a single adult hyrax consumes 650g of vegetation per day - more than 237kg per year (Olds & Shoshani 1982, Lensing 1983). The population control provided by caracals may become an increasingly important service as the plant community in Namaqualand struggles to adapt to a hotter, more arid future (Midgley & Thuiller 2007).

Along South Africa's border with Namibia, the springhare fills a similar prey niche to the hyrax in Namaqualand in terms of size and abundance (Melville et al. 2004). This may account for the higher reported occurrence of rodents in the diet of caracal from the Kgalagadi Transfrontier Park (Table 5). Palmer and Fairall (1988) argue that caracal selection for hyrax is density dependent. If hyrax numbers fall, other prey would then be targeted, including livestock.

Invertebrates in the study area were not an important source of prey (RFO = 2.0%), supporting the conclusion of Stuart and Hickman (1991) that insects do not contribute much to the diet of caracals. This is not true in all areas, however, and 12-13% occurrences have been documented both on farmlands and in protected areas, especially in the Karoo (Tables 4 & 5). As a core component of arid invertebrate fauna, insects could potentially serve as an important food reservoir for caracals in Namaqualand during times of scarcity, as has been observed in other regions (Palmer & Fairall 1988; Drouilly et al. 2017).

This flexibility in diet is characteristic of caracals (Avenant & Nel 1997, 2002; Drouilly et al. 2017). The broad dietary niche of caracals in this study area (B = 2.15) reflects their opportunistic hunting strategy. In fact, they were nearly as generalised in their consumption as the livestock guarding dogs (B = 2.83). This supports previous findings that canids tend to have more prey categories in their diets relative to felids, however the comparison is limited as it only captures the wild prey component of livestock guarding dog diet. Regardless, the diet of livestock guarding dogs did seem to reflect previous studies on the niche breadth of feral dogs (Vanak & Gompper 2009b).

***Table 4**. Summary table of caracal diet studies conducted on farmlands in South Africa. Diet composition is expressed as relative frequency of occurrence (RFO%) to allow for cross-study comparison.*

	Land Type						
	Farmland surrounding Namaqua National Park (2015-2016)[1]	Farmland surrounding Namaqua National Park (2014-2015)[2]	Central Karoo Farmland[3]	Farmland surrounding West Coast National Park[4]	Eastern Cape Farmland[5]	George Rangeland[6]	Fransmanshoek Conservancy[6]
Mammals	84	85	77	82	97	92	100
Rodents	9	27	15	74	24	69	70
Carnivores	2	2	6	0	0	8	18
Hyraxes	29	25	7	0	30	0	0
Hares	8	18	8	3	9	0	0
Other/Unidentified	29	2	5	0	0	1	11
Wild ungulates	2	4	12	1	10	14	2
Livestock	9	8	25	3	23	0	0
Birds	0	3	4	18	2	8	0
Reptiles	0	3	0	-	1	-	-
Invertebrates	4	5	12	-	0	-	-
Fruit & Vegetation	6	4	3	-	-	-	-
Anthropogenic	1	0	4	-	-	-	-

***Table 5.** Summary table of caracal diet studies conducted in protected areas in South Africa. Diet composition is expressed as relative frequency of occurrence (RFO%) to allow for cross-study comparison.*

	Protected Areas						
	Namaqua National Park (2015-2016)[1]	Namaqua National Park (2014-2015)[2]	Anysberg Nature Reserve, Little Karoo[3]	Kgalagadi Transfrontier Park[7]	Karoo National Park[8]	Mountain Zebra National Park[9]	West Coast National Park[10]
Mammals	84	81	75	81	85	94	70
Rodents	18	34	61	61	30	5	57
Carnivores	10	2	1	11	2	1	1
Hyraxes	24	28	1	0	17	53	1
Hares	11	13	5	5	15	11	1
Other/Unidentified	14	2	2	0	0	0	0
Wild ungulates	8	2	5	1	22	24	4
Livestock	0	2	1	4	0	0	-
Birds	0	6	5	7	2	5	16
Reptiles	3	1	3	0	-	1	8
Invertebrates	3	4	13	12	13	-	11
Fruit & Vegetation	10	5	4	-	-	-	0
Anthropogenic	0	0	0	-	-	-	-

[1] Present study
[2] Jansen 2016
[3] Drouilly et al. 2017
[4] Avenant & Nel 2002
[5] Moolman 1986 (adapted from Melville et al. 2004)
[6] Braczkowski et al. 2012a
[7] Melville et al. 2004
[8] Palmer & Fairall 1988
[9] Grobler 1981
[10] Avenant & Nel 1997

Birds and reptiles were also a negligible food source for caracals. Birds in particular (RFO = 0.3%) presented one of the lowest recorded occurrences in the country (Tables 4 & 5). A similar scarcity recorded in Karoo National Park was attributed to a lack of vegetative cover making birds more difficult to stalk, and hence catch (Palmer & Fairall 1988). It is also worth noting that dogs have been shown to negatively affect bird diversity, abundance, breeding success and survival in Australia and New Zealand (Taborsky 1988; Lord et al. 2001; Banks & Bryant 2007; Young et al. 2011). In one instance, a single free-roaming dog killed 600-800 kiwi birds (*Apteryx mantelli*) in just six weeks, many of which were not consumed (Taborsky 1988). While this study was not designed to monitor bird abundance, it should be incorporated into long-term monitoring programs for livestock guarding dogs given the drastic impacts observed elsewhere. Even in the absence of predation, Banks and Bryant (2007), found that walking leashed dogs through forest patches reduced bird diversity by 35% and abundance by 41% (Banks & Bryant 2007). Additional research on the impact, temporal and spatial extent of such disruptions in Namaqualand could unveil another contributing factor to low bird occurrence in caracal diet.

Arguably one of the most important findings of this study is the low level of occurrence of livestock remains in caracal scats. Two separate analyses conducted over a two-year period found that domestic ungulates account for less than 9% of caracal diet in Namaqualand (the present study and Jansen 2016). According to the most accurate and up to date biomass model for felids, this heavily persecuted predator believed to be responsible for millions of rand in damage consumed only 3.4 kg of sheep and 2.6 kg of goat in my study. This seems an especially insignificant amount when compared to other root causes of stock loss – such as the 1,356 police reports filed last year for stock theft in the Northern Cape alone (SAPS 2017).

These findings are markedly different from the observations of Pringle and Pringle (1979) who recorded a 46%-68% occurrence of livestock remains on farmlands in the Eastern Cape over a four-year period. These results are artificially inflated however, as they are based on the analysis of stomach contents from caracals destroyed in retaliation for livestock predation (Pringle & Pringle 1979; Palmer & Fairall 1988). The highest unbiased record of livestock occurrence in caracal diet is 25% on Central Karoo farmlands, where caracals ate 8.9 kg of sheep and 4.3 kg of goat (Drouilly et al. 2017). Even at the upper boundary of predation, caracal always selected wild mammals over domestic ungulates (Drouilly et al. 2017).

This trend is further supported by the lack of livestock remains found in caracal scat collected inside Namaqua National Park, despite the occasional presence of a flock of sheep allowed to graze within park boundaries (K Teichman, personal communication). This adds important geographic variation to other studies of protected areas where livestock remains were also completely absent (Grobler 1981; Palmer & Fairall 1988; Avenant & Nel 1997; Mukherjee et al. 2004) or occurred at very low percentages in the scat of predators (Melville et al. 2004; Drouilly et al. 2017). Even some studies conducted on farmlands reported very low occurrence (Avenant & Nel 2002) or complete absence of livestock remains (Braczkowski et al. 2012a).

The results in the present study should be interpreted with caution. Challenges in locating scat samples were experienced by field assistants. Predator scats can be difficult to find, especially in large protected areas, and they deteriorate rapidly under hot and sunny conditions. This leaves a very short window for collection and subsequent hair identification. Utilisation of multiple methods for microscopic hair analysis helped maximise the chances of positive identification, however the sample size is still very small. Due to the constraints, these results should be considered preliminary, however the findings do support a growing body of literature that suggests caracal do not prefer livestock and will only resort to domestic ungulates when wild prey is not sufficiently abundant (Moolman 1984; Palmer & Fairall 1988; Avenant & Nel 2002; Drouilly et al. 2017).

These findings provide strong support for maintaining biodiversity on farmlands and the relative abundance of key prey species including hyrax. This can be a key point of entry for conversations with farmers and land managers. Healthy lands supporting healthy populations of diverse mammal species will offer caracal an entire buffet of prey items to minimize predation on less preferred domestic ungulates.

CONCLUSIONS

This study reveals that while livestock guarding dogs are a widespread form of nonlethal management in southern Africa and globally, they can pose a risk to both livestock and wildlife. The most frequently consumed prey item of livestock guarding dogs in this study was livestock. Although sample sizes were low, the near absence of livestock from the scat of dogs accompanied by ecorangers suggests that human presence may greatly reduce this undesirable behaviour. It is important to note, however, that human presence did not deter the dogs from consuming wild prey. While the PEACE project was ambitious in its initial scope, unforeseen events have greatly limited the final sample size of dogs in different treatments and thus while the results presented here are of concern to both farmers and conservationists, they should be interpreted with caution.

Encouragingly, caracal in the study area seldom eat livestock and consume substantially less than in small livestock regions of the central Karoo. Rock hyrax were their main prey, both on farmland and in the park. The absence of livestock consumption within the protected area, despite the occasional presence of sheep, supports growing literature that caracal will not choose to prey on livestock when wild prey is available. While preliminary, the results of this study suggest natural prey management may be a more effective means of reducing depredation on Namaqualand sheep farms than livestock guarding dogs. Conversely, should hyrax numbers drop substantially, as has been recorded in many other regions of South Africa (Barry & Mundy 1998), this could drive increased livestock depredation. Determining how the presence of livestock guarding dogs may be influencing caracal diet and habitat use across the project area thus remains an important goal of the ongoing PEACE project. Their results will help unravel the costs and benefits of ecorangers and livestock guarding dogs in reducing livestock losses to predators.

The caracals’ opportunistic feeding strategy means that it consumes very different prey depending on the region, which has enabled it to persist even in human dominated landscapes such as Cape Town (Peterson et al. 2012; Bateman & Fleming 2012). This dietary flexibility makes it particularly difficult to manage across its range, further highlighting the need for case studies across its distribution and under different land use and land management regimes.

Nonlethal tools to prevent or reduce caracal predation on livestock are clearly needed by small livestock farmers but the total costs and impacts of those tools need to be carefully assessed before they are accepted as successful. Placement of livestock guarding dogs on any landscape should be accompanied by long term monitoring (particularly in areas with threatened species), to take note of any negative effects on the species that share their landscape. If chasing and killing other animals can be reduced through corrective training, the ability of livestock guarding dogs to serve as both a primary and secondary repellent (Gehring et al. 2010) provides obvious benefits to farmer productivity (Green et al. 1984; Andelt 1992; Smith et al. 2000;

Andelt & Hopper 2000; Marker et al. 2005b). When livestock guarding dogs are combined with other nonlethal methods the options to move away from indiscriminate lethal management will improve and positive outcomes for farmers, livestock, and biodiversity may well be realised.

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APPENDIX I: DIET OF FREE-RANGING DOGS

Domestic dogs (*Canis familiaris*) are the most numerous carnivores in the world today, yet little is known about the extent of their impacts on native species (Butler et al. 2004; Vanak & Gompper 2009a). While some dogs, like livestock guarding dogs, are highly trained and offer tremendous benefits to conservation (Hurt & Smith 2009), others, such as feral dogs, are ecologically disruptive and can cause ecosystem-wide disturbances (Feldmann 1974; Young et al. 2011). Distinguishing between groups of dogs can be difficult both taxonomically and in terms of their level of association with humans, but they are generally grouped into six broad categories for the purposes of scientific literature (Vanak & Gompper 2009a; Ritchie et al. 2014).

1. Owned dogs are restricted to a proscribed indoor or outdoor area.
2. Urban free-ranging dogs are not owned by humans, but subsist on human derived food (such as garbage) and rarely come into contact with wildlife.
3. Rural free-ranging dogs are peripherally associated with humans (they have owners) but are not confined. This category includes dogs whose daily activities are likely to bring them into contact with wildlife such as stray dogs, herding dogs, pastoral companion dogs and livestock guarding dogs.
4. Village dogs are unconfined and associated with rural human settlements but rarely leave the village.
5. Feral dogs are wild and independent of human derived food sources.
6. Wild dogs include dingoes, feral dogs and their hybrids in Southeast Asia and Australia that are no longer considered domesticated.

Each of these dogs can differ dramatically in terms of training, breeding, instinct and nourishment, even within the same category. For example, it is important to differentiate between livestock guarding dogs and herding dogs (Smith et al. 2000). Herding dogs originated much more recently (circa 1200) than livestock guarding dogs and are behaviourally much closer to actual predators, threatening sheep to move as directed with predatory mannerisms (Smith et al. 2000). Livestock guarding dogs have been bred away from such behaviour while encouraging trustworthy, attentive and protective traits (Smith et al. 2000). Unfortunately, many studies fail to identify the types of dogs found in their study or conflate multiple different types into broad categories such as "free-ranging."

Although diet studies on livestock guarding dogs are lacking, there is a growing body of literature investigating the impacts of free-ranging dogs more broadly. These studies have found that free-ranging dogs can spread disease, compete with endemic species, disrupt ecosystems, and harass and kill wildlife (Butler et al. 2004; Vanak & Gompper 2009a; Young et al. 2011; Sepúlveda et al. 2014). While livestock guarding dogs are occasionally included in studies of free-ranging dogs, most dietary analysis has focused on strays. The chart below from Ritchie et al. (2014) illustrates the vast diversity in rural free-ranging dog diets depending on geographic location and prey availability.

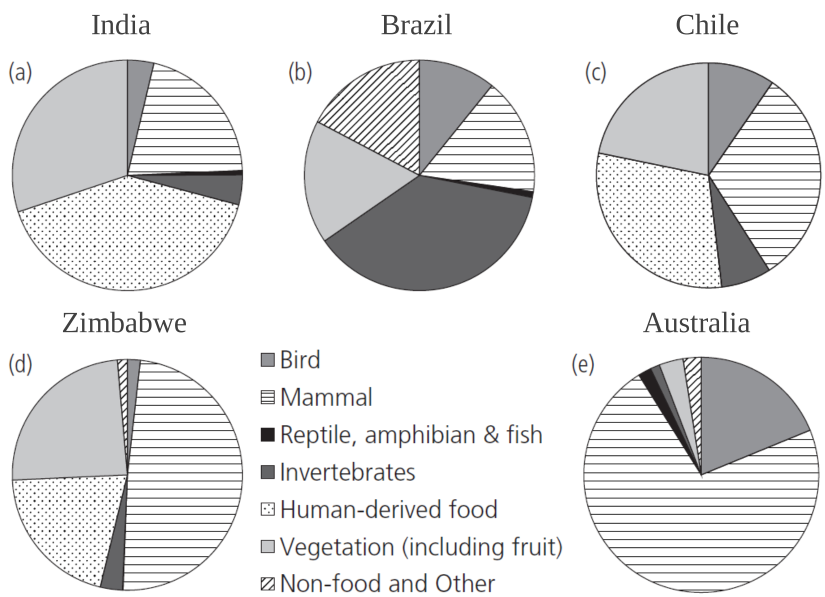

Figure 14. *Summary chart (adapted from Ritchie et al. 2014) comparing five studies of rural dog diet from four continents: a) Free-ranging dogs in India (Vanak and Gompper, 2009b); b) Free-ranging dogs in Brazil (Campos et al. 2007); c) Free-ranging dogs in Chile (Silva-Rodríguez et al. 2010); d) Free-ranging dogs in Zimbabwe (Butler et al. 2004); and e) Dingoes in Australia (Corbett 1995).*

In the studies above, livestock is considered a human-derived food source. While none of the studies approach the 55.6% occurrence of livestock demonstrated by guard dogs in this study, livestock predation and consumption is nevertheless commonplace. In India, human derived food accounted for 40.7% of the dogs' diet, including 13% from sheep and goats, with a similar niche breadth (2.75) to the dogs in the present study (Vanak & Grompper 2009b). Although herding dogs were included in this study along with other free-ranging dogs, it is not clear what percentage they represented (Vanak & Grompper 2009b). Livestock did not occur in the studies conducted in Brazil or Chile (aside from sawed cattle bones provided by humans), however in Zimbabwe domestic goats were the most common prey killed by free-ranging domestic dogs (Butler et al. 2004). Chasing scrub hares, harassing duikers and predating sheep were also recorded (Butler et al. 2004).

In Tuscany, domestic dogs were deemed responsible for 50 out of 577 depredation events (Ciucci & Boitani 1998). A team in Spain, believing they were performing genetic analysis on wolf scats, found that 53 of their 136 samples actually belonged to domestic dogs (Echegaray & Vilà 2010). Whereas 73% of the wolves' diet was comprised of wild animals, domestic animals accounted for 54% of the prey items found in the dog scats (Echegaray & Vilà 2010).

This pattern is further supported by government data. In the United Kingdom 5,000-10,000 sheep (especially lambs) are killed by dogs each year (Taylor 2005). In 1999, dogs in the United States killed 41,300 lambs and sheep, 15% of the estimated total predation by predators (USDA 2000). These deaths, when incorrectly attributed to wild carnivores can increase tensions, promote retaliatory behaviour, and damage conservation outcomes (Echegaray & Vilà 2010).

From these reports, it is clear that domestic dogs can develop a propensity to hunt and consume both wild and domestic prey species across the globe. Although livestock guarding dogs are (generally speaking) better trained, better nourished, and more highly valued by their owners than the free-ranging dogs in these studies, they can still be classified as a rural free-ranging dog. The reservations in classifying them so only serve to highlight the importance of fine scale diet analysis to establish how, if at all, they differ.