Evaluating the success of phased-release reintroductions for captive-born cheetah (*Acinonyx jubatus*) in South Africa

by

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Abstract

The global cheetah population has declined to an estimated 7,100 individuals, with half the global population currently found in southern Africa. Where natural metapopulation dynamics are no longer possible, human-mediated gene flow is coordinated in the form of managed metapopulations. In 2011, the Endangered Wildlife Trust (EWT, South Africa) established a Cheetah Metapopulation Project (CMP) to ensure the genetic and demographic viability of cheetah on small, fenced reserves in South Africa. Research from the CMP indicates that a new source population is required to ensure new genetics enter the metapopulation as the current rate is below the required four individuals per year.

A phased-release method, consisting of two distinct phases, allows for the reintroduction of captive-born cheetah into the cheetah metapopulation in South Africa. The limited research on the reintroduction of captive-born carnivore studies indicates that captive-born cheetah are able to express behaviour seen in wild-born cheetah. This study aimed to provide an evaluation of a phased-release methodology for the reintroduction of captive-born cheetah in South Africa. This was achieved by determining criteria to evaluate the behavioural, spatial, and foraging ecology of each captive-born cheetah at both an individual-level and a population-level to allow for comparisons with wild-born cheetah and other methods of captive release.

Post-release movements were calculated at month intervals, using data from GPS collars and post-release monitoring data from October 2019 to August 2021. Home-range (95%) and home-range overlap estimates were established for all cheetah. Of the twelve cheetah released following the phased-release method, five individuals settled after an exploration period, while five other individuals were still in their exploration stage at the end of the current study. The twelve cheetah used all available habitat types at some point during their movements, and all females birthed their first litter within seven months post-release. Alterations to a male cheetah's social group also caused a change in habitat utilisation. Nineteen different prey species were identified at kill sites and prey consumption estimates indicated that the majority of the cheetah were able to reach the monthly energy requirement, although excessive supplement feeding was provided unjustifiably for four individuals. Body condition scoring and monitoring of kill sites was dependant on consistent monitoring which, when compromised or inconsistent, proved to limit the accuracy of these criteria.

The criteria used for the evaluation of behavioural, spatial, and foraging ecology, proved successful on an individual level, and indicated areas that needed further investigation. When applied to a population level, phased-release cheetah showed similar characteristics to those of wild-born cheetah. It is recommended that the evaluation of this phased-release method is continued over a longer time period to further determine the success of this release method.

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Opsomming

Die wêreldwye jagluiperdbevolking het tot 'n geraamde 7,100 individue afgeneem, met die helfte van die wêreldbevolking wat tans in Suider-Afrika voorkom. Waar natuurlike metapopulasiedinamika nie meer moontlik is nie, word mens-gemedieerde geenvloei gekoördineer in die vorm van bestuurde metapopulasies. In 2011 het die Trust vir Bedreigde Natuurlewe (EWT, Suid-Afrika) 'n Jagluiperd-metabevolkingsprojek (CMP) gestig om die genetiese en demografiese lewensvatbaarheid van jagluiperds op klein, omheinde reservate in Suid-Afrika te verseker. Navorsing van die CMP dui daarop dat 'n nuwe bronpopulasie nodig is om te verseker dat nuwe genetika die metapopulasie binnedring aangesien die huidige koers onder die vereiste vier individue per jaar is.

'n Gefaseerde vrystellingmetode, wat uit twee afsonderlike fases bestaan, maak voorsiening vir die herinvoering van jagluiperds wat in gevangenskap gebore is in die jagluiperd-metapopulasie in Suid-Afrika. Die beperkte navorsing oor die herinvoering van gevangene-gebore karnivoor studies dui daarop dat gevangen gebore jagluiperds in staat is om gedrag uit te druk wat gesien word in wild gebore jagluiperds. Hierdie studie het ten doel gehad om 'n evaluering te verskaf van 'n gefaseerde vrystellingmetodologie vir die herinvoering van jagluiperds wat in gevangenskap gebore is in Suid-Afrika. Dit is bereik deur kriteria te bepaal om die gedrags, ruimtelike en vreet-ekologie van elke jagluiperd wat in gevangenskap gebore is te evalueer op beide 'n individuele vlak en 'n bevolkingsvlak om vergelykings met wildgebore jagluiperds en ander metodes van vrylating in gevangenskap moontlik te maak.

Na-vrystelling-bewegings is met maandelikse tussenposes bereken, met behulp van data van GPS-halsbande en na-vrystelling moniteringsdata van Oktober 2019 tot Augustus 2021. Tuisafstand- (95%) en tuisafstand-oorvleuelingsskattings is vir alle jagluiperds vasgestel. Van die twaalf jagluiperds wat vrygelaat is volgens die gefaseerde vrystelling-metode, het vyf individue na 'n eksplorasieperiode gevestig, terwyl vyf ander individue nog in hul eksplorasiestadium was aan die einde van die huidige studie. Die twaalf jagluiperds het op 'n stadium tydens hul bewegings alle beskikbare habitattipes gebruik, en alle wyfies het hul eerste werpsel binne sewe maande na vrylating gebore. Veranderinge aan 'n jagluiperdman se sosiale groep het ook 'n verandering in habitatbenutting veroorsaak. Negentien verskillende prooispesies is by doodmaakplekke geïdentifiseer en prooiverbruikskattings het aangedui dat die meerderheid van die jagluiperds in staat was om die maandelikse energiebehoefte te bereik, alhoewel oormatige aanvullingsvoeding onregverdig vir vier individue verskaf is. Liggaamstoestandtelling en monitering van doodmaakplekke was afhanklik van konsekwente monitering wat, wanneer dit gekompromitteer of teenstrydig was, bewys het om die akkuraatheid van hierdie kriteria te beperk.

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Die kriteria wat gebruik is vir die evaluering van gedrags-, ruimtelike en vreet-ekologie, was suksesvol op individuele vlak, en het gebiede aangedui wat verdere ondersoek benodig. Wanneer dit op 'n bevolkingsvlak toegepas word, het gefaseerde vrystelling jagluiperds soortgelyke eienskappe getoon as dié van wildgebore jagluiperds. Dit word aanbeveel dat die evaluering van hierdie gefaseerde vrystellingmetode oor 'n langer tydperk voortgesit word om die sukses van hierdie vrystellingmetode verder te bepaal.

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Preface

This thesis is presented as a compilation of five chapters. Chapter 1 provides an overall literature review and background of the study. Chapter 2 provides a clarification of materials and methods employed throughout the study. Chapter 3 and 4 state and discuss the results of the study, first at the individual- then at the population-level. Chapter 5 is prepared to summarize major findings and provide practical and evidence-based management recommendations towards the future improvement of the rewilding and release of captive-born cheetah. It is hoped that this study will provide evidence and guidelines for future conservation-driven rewilding by organizations such as Ashia Cheetah Conservation (ACC) and the Endangered Wildlife Trust (EWT).

Chapter 1 **Introduction and literature review**

Introduction and literature review

Chapter 2 **Detailed materials and methods**

Evaluation criteria Methods and Materials

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Individual Evaluation Outcomes (IEO)

Chapter 4 **Research results and discussion**

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List of abbreviations, acronyms, and common contractions

ACC	Ashia Cheetah Conservation
CBD	Convention on Biological Diversity
CMP	Cheetah Metapopulation Project
DCA	Damage-Causing Animals
EWT	Endangered Wildlife Trust
HR	Home-Range
IUCN	International Union for Conservation of Nature
MI	Month Interval
PA	Protected Area
RWCP	Range Wide Conservation Program of Cheetah and African Wild Dogs
SSC	Species Survival Commission

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List of definitions

Boma	An erect on-site holding facility to temporarily hold individual(s) to acclimatize them to their new environment and break homing tendencies (Potgieter *et al.,* 2012)
Hard release	An animal is immediately released at the recipient site without a period of familiarisation, and no supplementary food, water or shelter is artificially provided (Campbell and Croft, 2001; Hardman and Moro, 2006; Richardson *et al*., 2015)
Hard reserve	A 'hard' reserve has a high density of known predators (van der Merwe, 2019)
Kleptoparasitism	A carcass is seized by other competing predators (Mills *et al*., 2004)
Metapopulation	A set of discrete populations of the same species, in the same general geographical area, that may exchange individuals through migration, dispersal, or human-meditated movement (Akçakaya *et al*., 2006; Hanski, 2008)
Reintroduction success	Reintroduction success is defined by the following short and long term factors: the survival of the released individual, the ability to reproduce by the released individual and subsequent offspring; and the continuation of this re-established population (Gusset, 2009; Seddon, 1999)
Rewilding	The process of releasing of captive-born animals to wilderness areas (Jorgensen, 2014)
Soft release	The release of the animal is delayed allowing for a period of familiarisation at the recipient site in a boma, including the supplementary provisioning of food, water, and shelter (Campbell and Croft, 2001; Hardman and Moro, 2006; Johnson *et al*., 2010; Richardson *et al*., 2015; van der Merwe, 2019)
Soft reserve	A 'soft' reserve is considered to have a low density of predators that complete with and kill cheetah (van der Merwe, 2019)
Translocation	The deliberate movement of an organism from one site to another site for release (IUCN/SSC, 2013)

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CHAPTER 1

Introduction and literature review

1.1. General introduction

The human population is expected to reach 9.7 billion by 2050 (United Nations, 2019), with the African population expected to grow to 2 billion by the end of the century (Di Minin *et al*., 2021). By 2022, Africa will boast around 1.4 billion people, with the continent representing one of the fastest-growing human population densities globally (United Nations, 2019), thus, proportionally increasing both threats to biodiversity and human-wildlife conflict (Woodroffe, 2000; Balmford *et al*., 2001). The transformation of wild areas to rural settlements, agricultural lands, and sprawl of other human developments, has led to the widespread loss and reduction of natural habitats (Hutton and Leader-Williams, 2003). Protected areas (PAs) have thus been established to safeguard these nutrient-rich and biodiverse areas against anthropogenic pressures, which tend to attract dense human settlement (Balmford *et al*., 2001; Wittemyer *et al*., 2008; Di Minin *et al*., 2021).

The size and relative habitat quality of the PA determines the viability of a species as larger areas of high-quality habitat sustain larger populations when compared with smaller PAs (Cant-Salazar & Gaston, 2010; Di Minin *et al*., 2013; Sievert, 2020). Ideally, PAs are designed and managed to ensure that local populations of wildlife are connected to other populations (Akçakaya *et al*., 2006; Wegmann *et al*., 2014). Connectivity between different PAs allows for natural metapopulation dynamics, as migration between local populations ensures that demographic and genetic integrity is maintained (Akçakaya *et al*., 2006; Wegmann *et al*., 2014). The isolation and fragmentation of PAs is rapidly increasing due to habitat loss, overharvesting, impermeable infrastructure (e.g., concrete channels, fences, and roads), and an ever-increasing incidence of edge effects (Brashares *et al.,* 2001; Wittemyer *et al*., 2008). This interferes with and restricts natural processes and patterns of resource use such as migration, resulting in an increase of human-wildlife conflict over access to resources, such as water, food, space, and mates (Newmark, 2008; Wittemyer *et al*., 2008).

Large carnivores and other predatory species have naturally large home-ranges (HRs), and often occur outside of these reserves, where their requirements conflict with those of the local communities (Nowell & Jackson, 1996; Brugière *et al*., 2015). Carnivores are often hunted for real or perceived livestock depredation and the potential threat to human life or captured for the growing illegal wildlife trade (Woodroffe, 2000; Madden, 2004). Such anthropogenic pressures coupled with ever-reducing reserve size have shown to be the main contributing factors for the high extinction rate predicted for carnivores (Brashares *et al*., 2001). Therefore, it is important that predator and prey species are managed within these PAs to ensure the long-term demographic and genetic integrity of these populations (van der Merwe, 2019). Guidelines and

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requirements are provided by national and local governments and international organisations, such as the International Union for Conservation of Nature (IUCN), to ensure the management of these isolated areas and populations meet the minimum requirements (Glowka *et al*., 1994).

Where natural metapopulation dynamics are no longer possible, human-mediated gene flow is coordinated in the form of managed metapopulations (Akçakaya *et al*., 2006). This is achieved through conservation tools such as translocations, where individuals are intentionally moved from one area to another area (IUCN/SSC, 2013). Translocations and reintroduction techniques are implemented using various approaches such as 'hard'- or 'soft'-release methodologies. During a hard-release, an animal is immediately released at the recipient site without a period of familiarisation, and no supplementary food, water or shelter is artificially provided (Campbell & Croft, 2001; Hardman & Moro, 2006; Richardson *et al*., 2015). Whereas during a soft-release, the release of the animal is delayed allowing for a period of familiarisation at the recipient site in a boma, including the supplementary provisioning of food, water, and shelter (Campbell & Croft, 2001; Hardman & Moro, 2006; Johnson *et al*., 2010; Richardson *et al*., 2015; van der Merwe, 2019). The use of the soft-release techniques for carnivore translocations has shown to decrease stress and erratic post-release movements when compared to the hard-release method (Teixeira *et al.,* 2007; Somers & Gusset, 2009; Boast *et al*., 2018).

By using the appropriate release techniques, human-mediated movements of individuals can ensure the best chance of survival for individuals. Yet, these conservation tools alone may not be adequate in maintaining wild populations and requires an integrated management plan with other interventions to avoid the local or global extinction of a species (Hayward, 2011; Pritchard *et al*., 2012; Conde *et al*., 2013). Conservation breeding programmes are an example of how such an intervention can assist in retaining a species population as a form of *ex-situ* conservation (Pritchard *et al*., 2012; Braverman, 2014). The 2002 Convention on Biological Diversity (CBD) defines "*in-situ* conservation" as the "conservation of ecosystems and natural habitats and the maintenance and recovery of viable populations of species in their natural surroundings", while "*ex-situ* conservation" is defined as "the conservation of components of biological diversity outside their natural habitats" (Engels & Engelmann, 2002; Pritchard *et al.,* 2012; Braverman, 2014). According to the IUCN Red List (Hoffmann *et al.,* 2010) the use of *ex-situ* breeding programmes followed by reintroduction was able to improve the populations of 24 species, indicating that these breeding programmes, when carefully integrated with effective conservation programs, can contribute positively to the conservation of wild metapopulations (Gusset & Dick, 2012). The use of these techniques is understudied and requires further evaluation to determine the effectiveness of such strategies. (Buehler, 2018) cautions that releasing captive-born offspring may weaken wild populations as research has shown that captive-born individuals are often maladapted and less fit than their wild-born counterparts (Wermer *et al*., 2021 i*n press*). To create a holistic management approach, *ex-situ* conservation strategies should only be developed to

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complement those of *in-situ* conservation strategies, ensuring the potential of both forms of conservation are achieved (IUCN/SSC, 2014).

1.2. Cheetah conservation in South Africa

1.2.1. Species overview

Of all large carnivores in Africa, cheetah (*Acinonyx jubatus*) are widely recognized for their speed, achieving top speeds of 110 km/h in short bursts (Marker & Dickman, 2003). This is a result of their aerodynamic build and specific physiological adaptations such as binocular vision and enlarged nasal turbinates for increased oxygen flow (Ewer, 1973). Cheetah are thus open landscape specialists, but can utilise a wide variety of habitats including savannah, woodland, and deserts (van der Merwe *et al*., 2016; Durant *et al*., 2017). Cheetah prey upon species that range from birds and small mammals, such as scrub hare (*Lepus saxatilis*) and springhare (*Pedetidae capensis*), up to the young of large ungulates such as kudu (*Tragelaphus strepsiceros*), zebra (*Equus burchellii*), gemsbok (*Oryx gazella*) and even eland (*Taurotragus oryx*) as well as adult ostrich (*Struthio camelus*) (Caro, 1994; Mills & Mills, 2017). Very small prey may be killed with a bite to the skull. Cheetah are unable to suffocate larger prey, so one cheetah must control the prey by the throat, while others inflict damage to the abdominal area (Mills & Mills, 2017). Hence, larger prey are a speciality of sibling groups and male coalitions (Mills *et al*., 2004; Hayward *et al*., 2006; Mills & Mills, 2017; L.L. Marker *et al*., 2018).

The global cheetah population has declined dramatically over the last century and was estimated at 7,100 individuals in 2017 (Buk & Marnewick, 2010; Durant *et al*., 2017). Historically, cheetah roamed the majority of Africa, India, the Middle East, and southwest Asia (Marker & Dickman, 2003; Durant *et al*., 2017). To avoid competition with other large carnivores, they actively seek areas with low densities of competing predators (Durant, 1998). Consequently, 77% of current cheetah range is located outside of PAs (Durant *et al*., 2017), where the occurrence of human-wildlife conflict is elevated. A study of west and central African PAs found that there was a 73% site extinction of cheetah due to low prey densities, persecution along borders, and disease (Brugière *et al*., 2015). This decline has resulted in the extinction of this unique felid in over 13 countries (Marker & Dickman, 2003; Durant *et al*., 2017).

Southern Africa retains the largest global proportion of historical cheetah range at 22% (Durant *et al*., 2015; RWCP & IUCN/SSC, 2015; Durant *et al*., 2017). The historical population within the southern Africa region once spanned five countries (Angola, Namibia, Botswana, South Africa, and Mozambique) with a combined estimated population of 4,021 individuals (RWCP & IUCN/SSC, 2015). The African Wide Cheetah Conservation initiative (CCI), previously known as The Range Wide Conservation Program of Cheetah and African Wild Dogs (RWCP), has assisted in the development of regional strategies and national conservation action plans that use the IUCN Species Survival Commission (SSC) strategic planning process (Durant *et al*.,

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2015; RWCP & IUCN/SSC, 2015), to improve cheetah management plans and legislations, reduce habitat loss, and provide education regarding human-wildlife conflict solutions (IUCN / SSC 2015).

1.2.2. The Cheetah Metapopulation Project (CMP)

From 1965 to 2009, cheetah from the free-roaming populations in Namibia and South Africa, were translocated into fenced game reserves in South Africa (Marnewick *et al.,* 2009; Boast *et al*., 2018; Buk *et al*., 2018; van der Merwe, 2019). This attempted to reduce human-wildlife conflict by removing 'problem' or Damage-Causing Animals (DCA) individuals from farmlands, although it was only a temporary solution, as trapping of cheetahs continually occurred in the same sites (Marnewick *et al*., 2009). In total, 343 free-roaming cheetahs were relocated, usually via a hard-release and without any over-arching conservation plan, into fenced game reserves from 1965 to 2009, yet the population of cheetah within these reserves was only estimated at 281 live cheetahs by 2009 (Marnewick *et al*., 2009; Buk *et al*., 2018). As a result of poor survival rates and performance among free-roaming cheetah relocated into fenced reserves, coupled with the persisting human-wildlife conflict on farmlands, the translocation of free-roaming cheetah into fenced reserves stopped at the end of 2009 (Boast *et al*., 2018; Buk *et al*., 2018; van der Merwe, 2019).

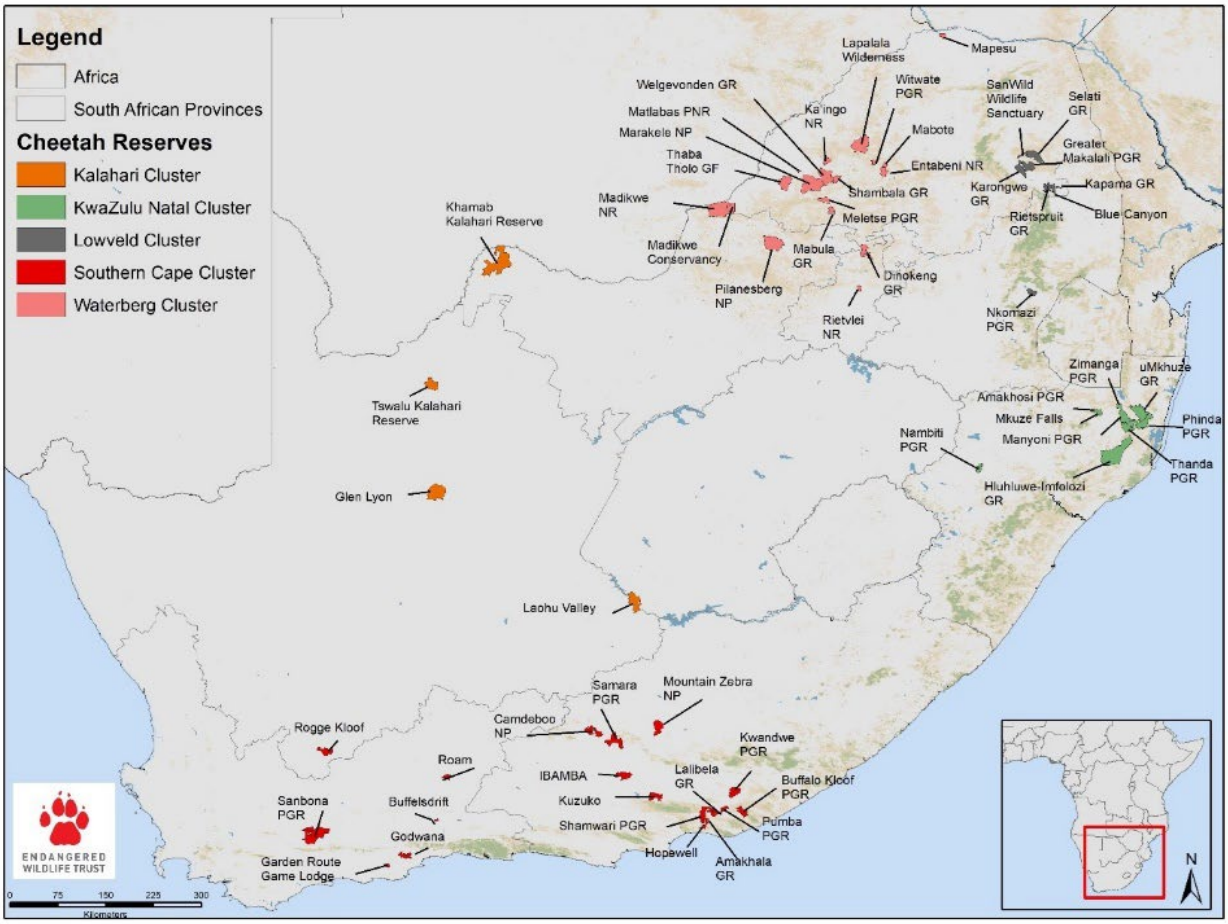

Figure 1.2.A. The reserves in the South Africa cheetah metapopulation and the five clusters of reserves. EWT, unpublished data; © Samantha Page and Vincent van der Merwe.

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The cheetah population within these fenced reserves decreased to 217 individuals in 37 fenced reserves by 2012 (Boast *et al*., 2016; Buk *et al*., 2018). To better conserve this diminishing population, the Endangered Wildlife Trust (EWT), established a Cheetah Metapopulation Project (CMP) in 2011 to manage the demographic and genetic integrity of cheetahs within fenced reserves in South Africa (Boast *et al.,* 2018; Buk *et al*., 2018; van der Merwe, 2019). This was achieved through reintroductions and translocations, allowing for suitable individuals to be moved to appropriate reserves that form part of the managed metapopulation (Buk *et al*., 2018; van der Merwe, 2019). By July 2020, the CMP had increased the cheetah population to 413 individuals in 58 fenced reserves in South Africa, consisting of five cluster groups (Figure1.2.A. and Figure 1.2.B.), and 2 fenced reserves located in Malawi (EWT, unpublished), thus increasing the cheetah population by 196 individuals over an eight-year period. During this time, the number of reserves associated with the project increased by 23 properties, further increasing the amount of natural habitat available in protected areas (van der Merwe, 2019).

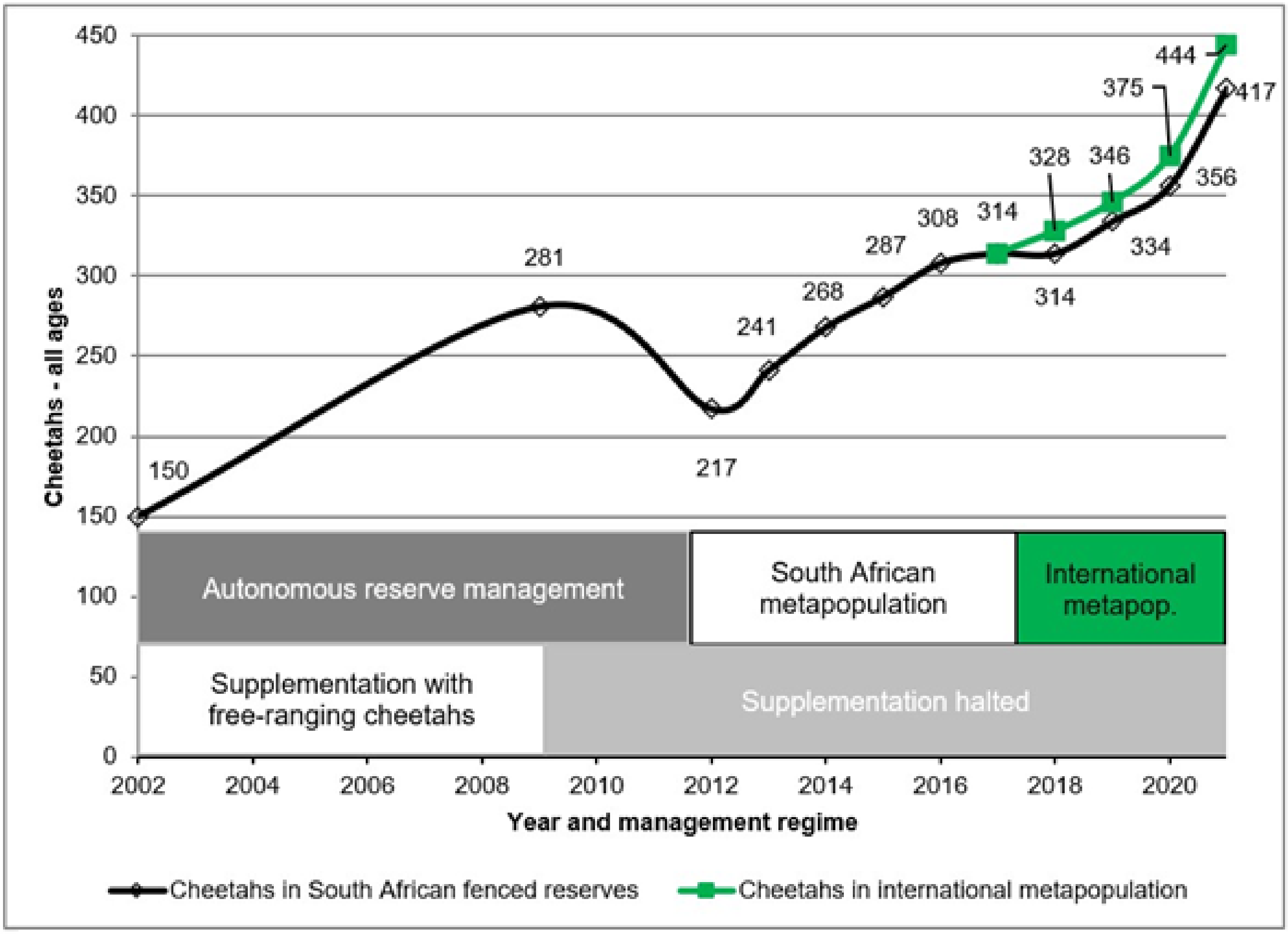

Figure 1.2.B. The number of cheetah in fully fenced reserves in South Africa during different types of management and in the internal metapopulation. Sources: Buk *et al*., 2018 and EWT records.

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To theoretically prevent inbreeding and ensure genetic viability, a thousand individuals are required for a sustainable population, with a minimum of four translocations per year involving individuals from outside of the metapopulation (Frankham, 2010; Buk *et al*., 2018; van der Merwe, 2019). Therefore, in theory, the current metapopulation does not meet these requirements and a source population is needed for genetic supplementation of unrelated individuals. Previous attempts to use the free-roaming population as a source population for the metapopulation in fenced reserves, had shown to be ineffective (Marnewick *et al*., 2009), and the use of cheetah from other African countries is theoretically not feasible due to their limited and decreasing populations (Buk *et al*., 2018; van der Merwe, 2019). Therefore, to ensure an optimal population is reach for the CMP, a reliable and viable source population of unrelated cheetah is needed.

1.2.3. Captive cheetah population

Cheetahs face many threats, among these, is the capture and trade of live cheetah from wild populations (Durant *et al*., 2017; Marker *et al*., 2018). Until the early 1960s, cheetah were initially sourced for captivity from East Africa until the populations in Kenya and Somalia became scarce, and Namibia became the main supplier (Marker *et al*., 2018). In total, over a 59 year period, 2223 wild-born cheetah were imported into global zoological institutes (Marker *et al.,* 2018b).The last major importation of cheetah to captivity in South Africa from Namibia occurred in 1974 as the CITES restricted the trade of wild cheetah from Namibia thereafter (Marker *et al*., 2018). This led to improved captive breeding programmes and by 2014, 87% of the global captive population was derived from captive breeding (Marker *et al*., 2018; Schwartz *et al.,* 2018).

The global captive cheetah population consisted of an estimated 1,762 individuals (859 females, 889 males and 14 of unknown sex), across 283 known facilities in various regions as of 31 December 2015 (Marker & Johnston, 2016). This *ex-situ* metapopulation is managed by zoological associations that make use of the international cheetah studbook allowing for breeding programmes that aims to maximise demographic and genetic integrity (Marker *et al*., 2018; Schwartz *et al*., 2018). South Africa and Namibia held 227 cheetah of the captive population (109 males and 118 females) across 10 facilities, in 2014 (Marker *et al*., 2018). Although captive breeding has seen recent improvements, the global captive population only experienced a 2% annual growth rate (excluding importations) between 2000 to 2014 (Marker *et al*., 2018). The captive population in Southern Africa (South Africa and Namibia) is the only self-sufficient captive population, as their growth rate is not dependant on importations from other regions (Marker *et al*., 2018).

Currently there is a lack of scientific information with regards to rewilding and reintroduction of captive-born cheetah (Houser *et al*., 2011). Previous reviews suggest that reintroduced captive-born carnivores are less likely to survive due to starvation, predation, and disease (Fischer & Lindenmayer, 2000; Jule *et al*., 2008). However, more recent studies by (Houser *et al*., 2011) and (Maruping *et al*., 2011) indicate that captive-raised cheetahs exhibit similar hunting techniques and behaviour to wild-born cheetah, but are just as vulnerable to threats associated with human conflict and predation by larger predators (Vebber *et al*., 2020). The need

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to combine *ex-situ* and *in-situ* conservation efforts has been emphasised by Pritchard *et al.,* (2012) and Conde *et al.,* (2013) and applies increasingly to cheetah as the wild population continues to decline .

1.3. Rewilding and phased-release methodology

1.3.1. Rewilding

The term "rewilding" has evolved to represent many different definitions which are influenced by reference time and geography (Jørgensen, 2014). The term was first used as a scientific reference by the North American Wilderness Recovery Strategy (Wildlands Project of 1991) to restore wilderness areas of the environment by removing human activity (U.S. Wilderness Act 1964; Public Law 88-577). As with many conservation terms, their definitions alter, for the purposes of this study, the term 'rewilding' signifies the process of releasing captive-born animals to wilderness areas (Jørgensen, 2014; Gammon, 2018).

The use of rewilding as a tool for conservation has been documented in previous studies (Ji *et al*., 2013; Jiang *et al*., 2016; Baker and Winkler, 2020). One such example is the use of rewilding in the recovery of Pere David's deer (*Elaphurus davidianus*), where in 1985 and 1987 a total of thirty-eight (5 males, 33 females) deer were reintroduced from herds in England into Beijing Milu Park, where the population had been declared locally extinct (Jiang *et al*., 2016). It was later found that by April 2014, the population within Beijing Milu Park had reached over 140 individuals (Jiang *et al*., 2016). Ji *et al*., (2013) also discuss how captive breeding of Przewalski's horses (*Equus ferus przewalskii*) for over twenty years has allowed for their successful reintroduction into the Mt. Kalamaili Ungulate Nature Reserve in China. Both studies demonstrate the application of rewilding for the reintroduction of captive-born individuals into their historical habitat range, from where they were extirpated. Although the principles of rewilding and reintroduction programs have merit, the practicality of such projects are often not feasible due to prohibitive costs, logistical difficulties, and the shortage of suitable habitat (Kleiman, 1989). There are concerns that releasing captive-born offspring may negatively impact wild populations, as research has shown that captive-born individuals are often maladapted and less fit than their counterparts (Buehler, 2018). Kleiman, (1989) indicates that such reintroduction programs are dependent on robust self-supporting captive populations, the presence of protected and managed suitable habitat identified by research studies, effective transportation and release methods, post-release monitoring of individuals, and overall education regarding the species. Therefore, by structuring and prioritizing these aspects (Kleiman, 1989), reintroduction programs are more likely to achieve a successful outcome.

1.3.2. Phased-release methodology

To improve on prior programmes, Ashia Cheetah Conservation (ACC; Paarl, Western Cape Province), in association with Kuzuko Lodge (Eastern Cape Province), established a "Rewilding and Release Programme"

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for cheetah in 2019 (Ashia Management Plan, unpublished). The programme is structured around a phased-release method that differs from the traditional soft- and hard-release method, as it consists of various phases which allow for an in-depth and adaptive evaluation of individuals to ensure they are ready to progress in the programme. This phased-release method consists of two distinct phases: 1) the rewilding phase and 2) the release phase with the rewilding phase including a critical skills-development step that historically has been omitted from past attempts (Figure 1.3.). A soft-release approach is used throughout, ensuring a gradual transition between the two distinct phases.

During the rewilding phase, individuals are introduced into a predator-free fenced area on Kuzuko Lodge following a period (± 3 weeks) in a boma, with a size ranging from 100m x 100m to a minimum of 50m x 50m, to acclimatize to the new surroundings. These 'wilding sections' range between 300–600 ha and are stocked with natural prey species, thus allowing for the development of behavioural and hunting skills in a controlled and relatively 'natural' environment. Daily monitoring ensures that individuals are evaluated and are supplementary fed if required. Once an individual has hunted successfully at least twice a week and does not require further supplementary feeding, they transition to the release phase of the programme.

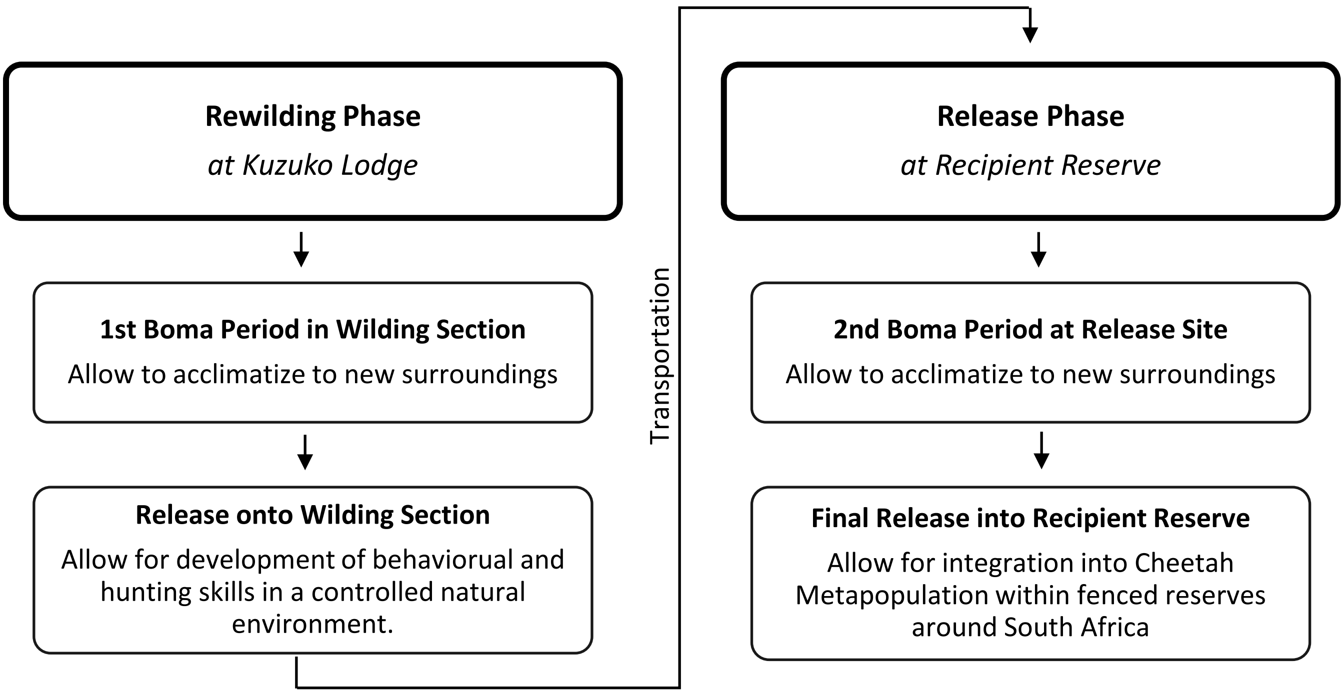

Figure 1.3. Flow chart depicting the Rewilding and Release programme that involves the use of a phased-release methodology

During the release phase of the programme, individuals are released onto pre-selected game reserves where they are initially once again placed (± 3 weeks) in a boma (see details above) to acclimatise. Pre-release

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and post-release monitoring during this phase ensures that management strategies are adapted based on the information received from these observations. Monitoring of individuals is done following the guidelines set by the IUCN, allowing for the formation of a comprehensive database recording the behavioural, spatial, and foraging ecology of captive-born cheetah during the post-release stages (IUCN/SSC, 2013). This allows for an accurate evaluation of the rewilding and release programme.

This rewilding and release programme ensures that individual cheetah progress at their own pace and can feasibly address the demographic and genetic requirements of the metapopulation as the maintained genetic studbook ensures that individuals undergo a genetic evaluation to confirm they are genetically sound for release (Ashia Management Plan, unpublished). By providing a course for the metapopulation, demand from reserves for females or strong coalition groups can be met.

1.4. Literature review

When applying such a rewilding and reintroduction programme to captive-born carnivores, previous literature suggests that these projects are less successful than the translocation of wild-born animals (Jule *et al.,* 2008). Bauer, (2005) suggests this is a result of under-developed or lack of opportunity to develop hunting skills, and a greater habituation to humans. Yet more recent studies reveal that improved techniques used in these rewilding and reintroduction programmes have led to positive outcomes (Houser *et al*., 2011; Maruping *et al*., 2011; Vebber *et al*., 2020).

A study by Houser *et al*., (2011) details the release of three confiscated cheetah cubs and an orphaned leopard (*Panthera pardus pardus*) cub, through a rehabilitation programme. This programme allocated a period in an enclosure that stocked two prey species and allowed for the free movement of smaller prey species through warthog holes, to encourage the development of hunting skills without the presence of a mother figure (Houser *et al*., 2011). Post-release monitoring data indicated that all individuals were able to hunt successfully, and exhibited behaviours seen in their wild counterparts. However, all three cheetah were later killed by farmers on surrounding farmlands at the recipient sites, as is often the case with wild cheetah (Marnewick *et al*., 2009; Houser *et al*., 2011). The number of animals within the study (n = 3) did not allow for in-depth statistical analyses but did provide descriptive conclusions based on observations.

The AfriCat Foundation in Namibia has, on several occasions, attempted to reintroduce captive-raised cheetah into the Okonjima Nature Reserve (Vebber *et al*., 2020). These are considered hard-releases, as the study by Vebber *et al*., (2020) depicting the hunting skills of these released captive-raised cheetah, did not mention the use of a phased-release or soft-release methodologies. The origin of these cheetah was also not mentioned and raises concerns about the overall fitness of these individuals and whether they were suitable candidates for release (Vebber *et al*., 2020). In the study, the authors indicated that post-release, these captive-raised cheetah were able to hunt successfully but received supplement feeding for an extended period after release and required constant monitoring. The importance of predator awareness was noted as

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some individuals were killed by leopards in the reserve post-release (Vebber *et al*., 2020). As a result of these deaths, all captive-raised cheetah that were released in this programme were recaptured in 2019 and placed back into captivity (Vebber *et al*., 2020).

A study by Maruping *et al*., (2011) investigated the use of a soft-release method for reintroducing captive-born cheetah into a 'soft' recipient reserve between 2007 and 2009. A 'soft' reserve is considered to have a low density of predators that complete with and kill cheetah, while a 'hard' reserve has a high density of these known predators (van der Merwe, 2019). During a three-month period in an enclosure, these cheetahs were fed venison carcasses, habituated to field researchers, and allowed to acclimatise to the surrounding habitat. The study investigated home-range establishment, habitat selection, prey selection, and human interventions (e.g., treatment of injury and supplementary feeding) as criteria to determine the success of the releases. Of the six individuals that were released, only three were still alive 20 months after release at the end of the study, and the overall project was declared unsuccessful due to the intensity of injuries sustained during hunting and the high degree of human intervention required (Maruping *et al.,* 2011).

All three of the above-mentioned studies, highlight that captive cheetah, either originating from captivity or orphaned, can hunt without being taught by a mother figure (Houser *et al*., 2011; Maruping *et al*., 2011; Vebber *et al*., 2020). The rehabilitation programme used in the Houser *et al*., (2011) study appeared more effective in the release of captive-raised cheetah when compared to both studies by Vebber *et al.,* (2020) and Maruping *et al*., (2011), although all the released cheetahs face the same threats as the wild cheetah population. Statistical analysis of data was limited in both (Houser *et al*., 2011; Vebber *et al*., 2020) studies and lacked diversity in evaluating the release programmes as they focused solely on hunting and prey selection of the released individuals. The Maruping *et al.,* (2011) study provided substantial criteria to measure short term success despite the small sample size, but the methodology they employed did not produce desirable results, linked to the type of release methodology employed.

The success of reintroductions is reliant on the following short and long term factors: the survival of the released individual, the ability to reproduce by the released individual and subsequent offspring; and the continuation of this re-established population (Seddon, 1999; Gusset, 2009; IUCN/SSC, 2013). Currently there is a lack of comprehensive evaluation criteria to measure the success of a reintroduction program for the release of captive-born cheetah, as previous studies only refer to survival rate as a measure of success and disregard other, equally important ecological factors (Houser *et al*., 2011; Vebber *et al*., 2020).

To determine the success rate of a rewilding and release programme is a lengthy, extremely costly, and complex process (Gusset, 2009), where the ends do not often justify the means. Before survivability rates can be used to determine the success of these programmes, ecological factors that contribute to the short-term success must be investigated. When wild-born cheetahs are reintroduced or translocated, they are evaluated in terms of their behavioural, spatial, and foraging ecology, to determine if individuals display behaviours expected of wild individuals of the species (Johnson *et al*., 2010; Boast *et al*., 2018; Buk *et al*.,

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2018; van der Merwe, 2019; Sievert, 2020). Bastille-Rousseau *et al.*, (2016) state that a dispersed individual is considered stable once daily movements settle, indicating an established HR, and are geographically confined. Therefore, by investigating movement patterns and habitat usage, stability of these individuals can be established. By investigating the overall stability of these ecological aspects, the short-term goals for a successful reintroduction or translocation can be established. The process of evaluating short term success of wild-born cheetah reintroduction or translocations can be applied to the reintroduction of captive-born cheetah to provide an evaluation that not only allows for the use of data analyses to determine success but also allows for a comparison between multiple measurable criteria for wild-born cheetah and captive-born cheetah.

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1.5. Aims and objectives

The overall aim of this study was to provide an evaluation of a phased-release methodology for the reintroduction of captive-born cheetah in South Africa. This was achieved by determining the behavioural, spatial, and foraging ecology of each captive-born cheetah released following a phased-release approach, and determining if stability, as defined by Bastille-Rousseau *et al.,* (2016), was reached for these aspects. Therefore, the primary objectives of this study were to determine:

1. The post-release movements and home-range establishment of each phase-released cheetah by:
    a. *Determining post-release exploration and home-range size at specific time intervals for each individual.*
    b. *Comparing changes between home-range size at specified time intervals for each individual.*
    c. *Investigating factors affecting post-release exploration and home-range size of specified time intervals of each individual.*
2. The spatial distribution and utilisation density of each phase-released cheetah by:
    a. Determining spatial distribution and utilisation densities of specified time intervals of each individual.
    b. Comparing changes between spatial distribution and utilisation densities of specified time intervals of each individual.
    c. Investigating factors affecting spatial distribution and utilisation densities of specified time intervals of each individual.
3. Prey consumption and body condition of each phase-released cheetah by:
    a. Determining monthly prey consumption through observed kill sites, feeding records and belly index observations.
    b. Determining body condition using the body condition score index during the study period.
    c. Comparing changes between monthly prey consumption and monthly changes in body condition scores.
    d. Investigating factors affecting changes between monthly prey consumption and monthly changes in body condition scores.
4. The post-release performance of phase-released captive-born cheetah in terms of behavioural, spatial, and foraging ecology by:
    a. Comparing post-release data of phase-released cheetah with literature on wild-born cheetah.
    b. Comparing post-release data of phase-released cheetah with literature of soft and hard release methods.

The results of this study will be used to refine the phased-released methodology and to adapt management strategies to increase the success of reintroducing captive-born cheetah into the metapopulation. By establishing baseline values, the success of reintroductions can be determined at a finer scale rather than just by using a survivability value. This research aims to fill the knowledge gap of captive-born cheetah being released into the metapopulation and will therefore contribute to the conservation of the species.

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CHAPTER 2

Methods for evaluating phased-release reintroduction success

2.1. Ethical clearance

Ethical clearance was obtained through Stellenbosch University for the use of collar data as a third-party user (ethical clearance reference number: ACU-2020-18790).

2.2. Introduction

To provide accurate information regarding the phased-release method, indicators of behaviour, spatial and foraging ecology must be analysed to provide an evaluation at an individual level and allow for comparisons between different captive-born releases and wild-born individuals. By using methods and data analyses that are already used for wild cheetah, these comparisons can be made. This chapter provides information on how the following criteria: 1) post-release movement and home-range establishment, 2) habitat utilisation, 3) prey consumption and 4) body condition scores, which will be used to provide information for the evaluation of phased-release reintroduction success at the individual level.

2.3. Study areas

Seven game reserves formed part of this study, all of which are part of the Endangered Wildlife Trust's (EWT) Cheetah Metapopulation Project (CMP). Four of the reserves were in the Eastern Cape Province, while the remaining three were in the Limpopo, North-West and KwaZulu Natal Provinces (Figure 2.3.). Vegetation maps of each reserve was obtained from the respective reserve management and are verified by the CMP. Annual game count surveys were conducted by each reserve either aerially or by vehicle, as these regular censusing surveys assist with management of species within these Protected Areas (PAs).

Amakhala Game Reserve (Reserve 1, Figure 2.3.), is located in the Eastern Cape province of South Africa. A fenced section of Amakhala, known as Carnarvon Dale Area, was 1 713 hectares in size and consists primarily of grassland vegetation which covers 49% of the area. Thicket and karroid vegetation cover 25% and 12% of the area, respectively. The remaining 14% is made up of a combination of savanna, riverine thicket, and old farmlands. A game count survey in 2020 recorded 566 animals across 17 species, and of these 13 were ungulate species (Appendix 2.A.). The dominant herbivore species were red hartebeest (*Alcelaphus buselaphus caama*), springbok (*Antidorcas marsupialis*), and common warthog (*Phacochoerus africanus*). This section of Amakhala was considered to be a soft reserve as it lacks other large predators.

Buffalo Kloof Game Reserve (Reserve 2, Figure 2.3.) is located in the Eastern Cape province of South Africa. This reserve has a total size of 11 647 hectares, with Albany valley thicket vegetation occupying 57% of the area. Grahamstown grassland thicket and Albany mesic thicket vegetation covers 28% and 11% of the

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area, respectively. The remaining 4% of the reserve is a combination of Suurberg quartzite fynbos, Bhisho thornveld, and Suurberg shale fynbos. A game count survey in 2020 counted 3 540 animals across 23 species, and 18 species were ungulates (Appendix 2.A.). The dominant herbivore species were impala (*Aepyceros melampus*), greater kudu (*Tragelaphus strepsiceros*) and common warthog. There were signs of leopard in the area, but these were not substantial enough to indicate the reserve is occupied by a resident leopard population (as opposed to a transient leopard). Therefore, the reserve was also considered to be a soft reserve.

Mount Camdeboo Game Reserve (Reserve 3, Figure 2.3.) is located in the Eastern Cape province of South Africa. The fenced northern section of the reserve was 8 120 hectares in size, all covered in Karroo escarpment grassland vegetation. A game count survey in 2020 revealed 1 350 animals across 20 species, and of these 16 species were ungulates (Appendix 2.A.). The dominant herbivore species were common eland (*Taurotragus oryx*), red hartebeest (*Alcelaphus buselaphus caama*) and gemsbuck (*Oryx gazella*). As this northern section of Mount Camdeboo does not contain any large predators it is considered to be a soft reserve.

Magic Hills Game Reserve (Reserve 4, Figure 2.3.) is located in the Eastern Cape province of South Africa. The fenced section of the reserve set aside for the release was 11 388 hectares in size, 59% of which was covered in Sunday's thicket vegetation while the remaining 41% consists of the great fish thicket vegetation. A game count survey in 2020 revealed 1 500 animals across 30 species, and of these 18 species represented ungulates (Appendix 2.A.). The dominant herbivore species were springbuck, greater kudu, and common eland. As this section of Magic Hills did not contain large predators it was considered a soft reserve.

Khamab Game Reserve (Reserve 5, Figure 2.3.) is located in the North-West province of South Africa. This reserve was 90 000 hectares in size, with open woodlands on sand occupying 55% of the total area. Closed woodlands on sand and dense woodlands on sands occupy 21% and 19% of the area, respectively. The remaining 5% was comprised of pans, old cattle posts, and variations of woodland vegetation. A game count survey in 2021 counted 9 451 animals across 18 species, of which 12 species were ungulates (Appendix 2.A.). The dominant herbivore species were blue wildebeest (*Connochaetes taurinus*), gemsbuck, and Burchell's zebra (*Equus quagga burchellii*). This reserve was considered to be a hard reserve as other large predators such as lion and leopard were present.

Ka'ingo Game Reserve (Reserve 6, Figure 2.3.) is located in the Limpopo province of South Africa. This reserve was 15 468 hectares in size, with central sandy bushveld vegetation occupying 43% of the area. Western sandy bushveld and Waterberg Mountain bushveld vegetation covered the remaining 35% and 22% of the area, respectively. A game count survey in 2021 revealed 2 341 animals across 23 species, of which 15 species represented ungulates (Appendix 2.A.). The dominant herbivore species were impala, Burchell's zebra, and blue wildebeest. This reserve was considered to be a hard reserve as other large predators such as lion and leopard were present.

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Mun-Ya-Wana Conservancy, previously known as Phinda Game reserve, (Reserve 7, Figure 2.3.) is located in the North-West province of South Africa. This reserve was 29 000 hectares in size, with Zululand lowveld savanna occupying 21% of the area. Southern Lebombo woodlands and sand veld woodlands covered 17% and 18% respectively. The remaining 44% was comprised of bush clump thickets, floodplain grasslands, mixed acacia woodlands, palm veld, riparian, and sand forest vegetation. A game count in 2020 revealed 12 935 animals across 15 species, and seven of these species were ungulates (Appendix 2.A.). The dominant herbivore species were impala, nyala (*Tragelaphus angasii*) and common warthog. This reserve was considered to be a hard reserve as other large predators such as lion and leopard were present.

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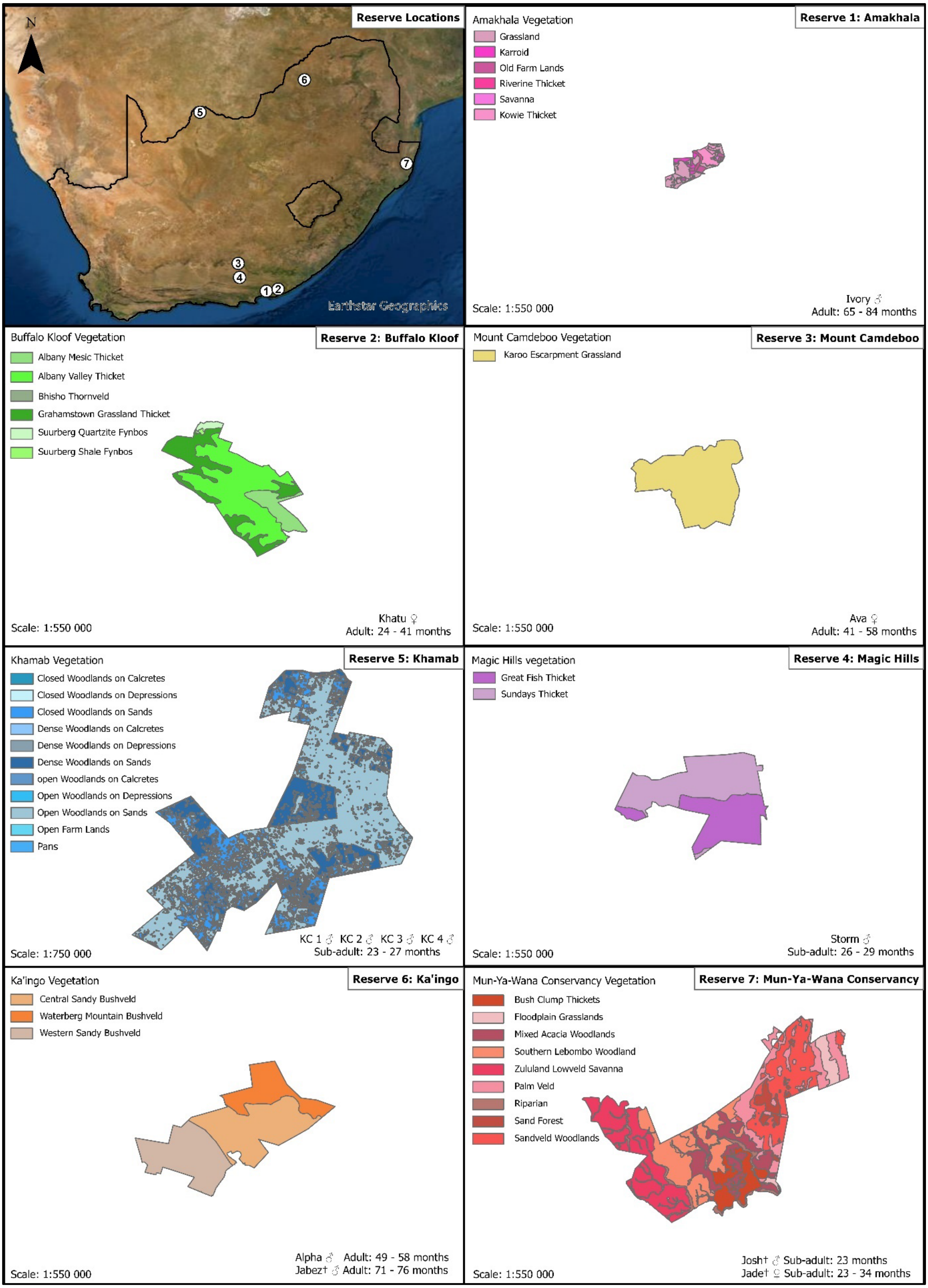

Figure 2.3. Map of each study reserves depicting size and vegetation types as well as their locations in South Africa

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2.4. Study animals

Between October 2019 and May 2021, twelve captive-born cheetah, three females and nine males, were released into seven reserves within South Africa, following a phased-release method in coordination with the EWT (Table 2.1.). All individuals originated from captive facilities within South Africa and had been genetically cleared for reintroduction into the wild cheetah metapopulation (Ashia Cheetah Conservation, unpublished data).

Each individual was released into their respective recipient reserves as either single individuals or in coalitions according to their social structures. Ava, Khatu, and Ivory were released as single individuals into their recipient reserves at 41.5 months, 24.3 months, and 65.5 months of age, respectively. Jade and Josh were released together as a brother and sister sibling coalition at 23.5 months of age. Alpha and Jabez were released as a bonded coalition of unrelated captive males at 49.1 and 71.9 months of age, respectively. Storm was bonded to an adult wild male within a boma and released at 26.3 months of age as a bonded coalition of unrelated males. The exact age of this wild male was unknown. KC1, KC2, KC3, and KC4 were released as a male sibling coalition at 23.4 months of age.

Of these twelve individuals, five were fitted with Iridium (GPS) satellite collars (African Wildlife Tracking, Pretoria, South Africa), one was fitted with an ultra-high frequency (UHF) GPS tracking collar (African Wildlife Tracking, Pretoria, South Africa), three were fitted with very high frequency (VHF) tracking collars (African Wildlife Tracking, Pretoria, South Africa), and three were fitted with Iridium Terrestrial System (GPS) collars (Telonics, Arizona, United States of America). The fitting of collars was dependant on the availability and accessibility of collars. Therefore, collars were fitted either during the transportation of individuals from the wilding section to the recipient reserve, where individuals were sedated to allow for safe handling and movement into transport crates, or individuals were sedated during the second boma acclimatization period at the recipient reserve to allow for the safe fitting of the collars. GPS collars were programmed to collect GPS locations at predetermined time intervals based on the monitoring needs of each reserves management team (Table 2.1.).

The number of cheetah observed during the study period varied as a result of births and deaths. In total, 28 cheetah were identified between October 2019 until September 2021, with five birthing events and nine mortalities. Of the mortalities observed, three formed part of the original study group, while six were offspring of members of the original study group. Of the 12 released individuals, all but one had adequate data available at the end of the study for analysis. Where possible, information is provided for the 12 individuals but only 11 are considered for analysis and discussions.

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Table 2.1. The biological and translocation details of each of the twelve cheetah that took part in the phased-release programme.

Identity	Sex	Date of Birth	Size of Wilding Camp (ha)	Rewilding Period (months)	Age at Release (months)	Recipient Reserve	Hard or Soft Reserve	Size of Recipient Reserve (ha)	Period in Boma (months)	Release Date	Birthing Events [# of cubs]	Collar Type	Collar Interval (hours)	Status (September 2021)	Date of Death	Days Released Before Death
Ava	F	15 10 2016	300	8.3	41.5	Mount Camdeboo	Soft	8 120	1.3	02 04 2020	1 [2[e]]	Satellite	4	alive		
Khatu	F	23 03 2018	300	6.1	24.3	Buffalo Kloof	Soft	11 647	0.4	31 03 2020	2 [2[†],6]	Satellite	6	alive		
Jade[a†]	F	29 09 2018	300	4.8	23.5	Mun-Ya-Wana Conservancy	Hard	29 000	1.2	12 09 2020	1 [4[†]]	Satellite	0.5	dead	05 08 2021	327
Josh[a†]	M	29 09 2018	300	4.8	23.5	Mun-Ya-Wana Conservancy	Hard	29 000	1.2	12 09 2020	N/A	VHF	N/A	dead	22 09 2020	10
Ivory	M	07 05 2014	600	9.1	65.5	Amakhala	Soft	1 713	1.1	21 10 2019	1 [2]	VHF	N/A	alive		
Alpha[b]	M	15 10 2016	300	4.8	49.2	Ka'ingo	Hard	15 468	0.7	20 11 2020	N/A	Satellite	3	alive		
Jabez[b†]	M	24 11 2014	300	4.8	71.9	Ka'ingo	Hard	15 468	0.7	20 11 2020	N/A	VHF	N/A	dead	02 04 2021	133
Storm[c]	M	15 03 2019	300	7.3	26.3	Magic Hills	Soft	11 388	2.3	23 05 2021	N/A	Satellite	9	alive		
KC 1[d]	M	24 05 2019	600	7.6	23.4	Khamab	Hard	90 000	1.3	04 05 2021	N/A	Satellite	9	alive		
KC 2[d]	M	24 05 2019	600	7.6	23.4	Khamab	Hard	90 000	1.3	04 05 2021	N/A	Satellite	9	alive		
KC 3[d]	M	24 05 2019	600	7.6	23.4	Khamab	Hard	90 000	1.3	04 05 2021	N/A	Satellite	6	alive		
KC 4[d]	M	24 05 2019	600	7.6	23.4	Khamab	Hard	90 000	1.3	04 05 2021	N/A	Satellite	8	alive		

[a] Released as sibling coalition. [b] Paired as sub-adults in the rewilding phase and release together. [c] Paired with a wild male in the boma and released together. [d] Male coalition (full siblings).[e] Dispersed from mother, not confirmed dead or alive. [†] Deceased.

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2.5. Post-release monitoring and data collection

Post-release monitoring data were collected through direct observations of each individual by a monitoring team from the recipient reserve, using a monitoring assessment form (Appendix 2.B.) adapted for this study based on the EWT cheetah observation, hunt, and kill forms (EWT, unpublished). Monitoring guidelines, which were adapted from the guidelines set by the IUCN for reintroductions and translocations (IUCN/SSC, 2013), were given to each reserve's monitoring team at the beginning of the study. Each reserve's monitoring team implemented an active, adaptive monitoring approach, allowing for monitoring strategies to be adapted during the duration of the study. Monitoring of each cheetah was carried out on average three times a week, either on foot or by vehicle. Decisions on supplementary feeding of individuals was were determined by each reserve's monitoring team.

Data captured during monitoring included: GPS location of the sighting, the presence of coalition members or offspring, notable behavioural aspects, climate, body condition scores, belly index scores, and the presence of a kill. The locations of cheetahs fitted with satellite GPS collars were automatically recorded at set intervals. The time interval between points for each individual is shown in Table 2.1 above. Movement over time was quantified and standardized by number of days since release to compare behaviour across individuals, and by a standard time frame to quantify landscape utilization.

When females were denning, monitoring of the den sites occurred only once within the first two weeks of denning, in order to assess litter size and cub survival (Sievert, 2020). This was undertaken by one of the reserves monitoring team while the female was away from the den site, and without getting too close or ever handling the cubs to minimize disturbance (Laurenson & Caro, 1994; Sievert, 2020).

2.6. Post-release movements and home-range establishment

To determine the spatial distribution and dispersal patterns, home-range estimates (size, centroid, utilisation density, and overlap) were calculated using auto-correlated kernel density estimates (ADKEs; (Fleming et al., 2015). This was done at month (30-day) intervals, from the day of release until the final month interval contained a full 30 days, for each individual in the study. Standardising the time intervals at 30-days for all individuals allowed for comparisons to be made between each consecutive month for each individual. This also allows for patterns between individuals and time since release to be compared. An ANOVA was used to identify significant differences in home-range size within individuals of different spatial sampling types (observations, GPS, and VHF). Confidence intervals of 95% were used as they are generally considered the closest approximation of total range size (Sievert, 2020). These 95% AKDEs are considered strong for comparisons between different spatial data types (Fleming *et al.,* 2015; Naude *et al*., 2020; Silva *et al*., 2021). Variogram calculations, movement model fits, and home-range estimations were implemented in the *ctmm*

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package (Fleming *et al.,* 2015; Calabrese *et al*., 2016). Home-range centroids were estimated as the geometric mean of coordinates used to fit the AKDE contours.

Estimated semi-variance was plotted as a function of timespan (month) to visually inspect the autocorrelative structure of the location data (Fleming *et al*., 2014). Brownian motion (BM) or Ornstein–Uhlenbeck (OU) movement models were used at zero to short time lags, where a linear increase in the semi-variance corresponded with uncorrelated velocity, whereas integrated OU (IOU) or OU with foraging (OUF) was used where upward curvature at these time lags indicated autocorrelation in the velocity. If plotted semi-variance did not approach an asymptote, individuals were not considered to be range residents; these cheetahs were either not monitored for long enough or did not exhibit behaviours that meet the definition of range residents and were removed from further analyses. Thereafter, space use was investigated by assessing behaviour across longer time lags, where range residents are expected to reach an asymptote on a timescale that corresponds to the home-range crossing time (Calabrese *et al*., 2016; Fleming *et al*.,2014). Maximum-likelihood model fits (Fleming *et al*., 2014) were ranked by AICc (Calabrese *et al*., 2016).

Home-ranges were estimated conditionally on the fitted and selected model per individual. OU models are described using two parameters (home-range crossing time in days and variance in km^2), while OUF models are described using three (home-range crossing time in days, velocity autocorrelation timescale in hours, and variance in km^2). OU models provided home-range and crossing time estimates, where OUF models provided these metrics as well as the velocity autocorrelation timescale and average distance travelled per individual. Finally, volumetric space-time utilisation density (UD) and home-range overlap (HRO) (Bhattacharyya's coefficient) were estimated based on these selected models (Fieberg & Kochanny, 2005; Winner *et al*., 2018). All analyses were conducted in R (R Core Team, 2018), QGIS (QGIS 3.20.2; GQIS Development Team, 2020) and ArcGIS Pro (ArcGIS Pro, 2.8.1, Environmental Systems research institute, 2020).

2.7. Habitat utilisation

Habitat utilisation metrics at month intervals for each individual were determined to investigate if habitat selection altered between successive month intervals. Habitat selection was analysed at the reserve and home range levels for each individual. 95% utilisation density (UD) estimates were used to represent the home-range of each month interval per individual (Bissett & Bernard, 2007). To calculate the habitat selection at a reserve level, digital vegetation maps of each reserve were used to compare the different vegetation types in the home-range. QGIS geoprocessing point sampling tool (QGIS 3.20.2; QGIS Development Team 2020) with a grid set at 500m was used to determine the proportion of each vegetation type within the 95% UD raster layer (Tatman *et al*., 2000).

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2.8. Prey consumption and body condition index

2.8.1. Prey consumption

The amount of energy an individual cheetah requires daily is influenced by the size of their social group, presence of cubs, age, and maturity of the individual (Caro, 1994; Durant, 2000; Mills *et al*., 2004). Therefore, previous studies have estimated that the daily consumption requirements range from 1.4kg/day to 2.8 kg/day (Frame, 1999; Mills *et al*., 2004; Lindsey *et al*., 2011), although females with older cubs have been known to consume as little as 0.4 kg/day (Mills *et al*., 2004). Following a study by (Lindsey *et al*., 2011), we assume that the average consumption requirements for cheetah is 2.1 kg/day (Mills & Biggs, 1993; Owen-Smith & Mills, 2008). These daily energy requirement values were converted to monthly (30-day) values to ensure standardization across all analyses. Therefore, the monthly energy requirement for cheetah range between 42 kg/month to 84 kg/month, with an average requirement of 63 kg/month. To determine if each individual cheetah was able to meet their monthly energy requirements once released, prey consumption estimates were calculated as (Mills, 1992) indicated that direct observations were more accurate in terms of consumption rates, killing frequency, and prey selection than other methods.

During the monitoring period, individuals were often found with obvious signs, e.g., blood present on the face or body and an enlarged abdominal/belly size, indicating they had made a kill and fed within the past 24 hours. To quantify these sightings where a kill site could not be identified, referred to as an 'increase in fullness', a value of 10 kg was given for each sighting. In order to record an 'increase in fullness' event, the physical appearance of the individual had to show obvious distention of the abdominal area, indicating they had fed and reached stomach capacity. A value of 10 kg was used as literature states this is the maximum amount one individual can consume in a single sitting (Phillips, 1993; Apps, 2012). Therefore, monthly prey consumption was calculated using data collected at observed kill sites, supplement feeding records, and physical appearance during monitoring observations, where kill observation and supplement feed events are divided by the number of individuals in a coalition to account for multiple feeding at a carcass. This was not considered for females with cubs as it cannot be accurately determined when the cubs began feeding on the carcasses.

$$\text{prey consumption (kg / month)} \\ = (\text{kills}/\#\text{ in coalition}) + \text{increase in fullness} + (\text{supplement feed}/\#\text{ in coalition})$$

In order to calculate the contribution of weight consumed by observed kills per month, the edible portion of each carcass was estimated following (Bissett & Bernard, 2007) and (Lindsey *et al*., 2011), who suggested cheetah consume: 100% of prey items < 5 kg; 90% of prey items between 5-80 kg; and 67% of prey items > 80 kg. Therefore, the total weight consumed for kill observations per month for each individual was

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calculated by summing the calculated edible portions of each kill. This was calculated by multiplying the weight of prey species by the appropriate consumption percentage as shown below.

$$\Sigma\, edible\ portion\ of\ kills\ (kg) = animal\ live\ weight\ (kg)\ \times\ consumption\ \%$$

The weight of each prey item, observed at a kill site, was obtained from (Apps, 2012) and (Mills *et al.*, 2004) (Appendix 2.C.). The influence of sex on a species weight was only considered to alter the weight of the adult age category, where weights are available for male, female, and unknown sex. Where weights could not be found for an age category, they were calculated as follows; juvenile weights were calculated at 0.25 of the average adult weights, while the subadult age category was calculated as 0.66 of the average adult weight (Bissett & Bernard, 2007; Lindsey *et al.*, 2011; Mills & Mills, 2014)

During supplement feeding events, the prey species supplied, and portion fed to an individual was recorded by reserve monitoring team (i.e., back-leg of female impala). The weight of the provided portion was estimated as a percentage of the carcass weight (50% of the live animal weight) for the specific species provided. These portion percentages are as follow: 5% for shoulder only; 10% for front leg/shoulder, ribs, and skin; 20% for back leg/rump; 25% for neck and spine, and organs; 50% for front section and back section, as shown below (Bissett & Bernard, 2007; Lindsey *et al.*, 2011; Mills & Mills, 2014).

$$portion\ weight\ (kg) = carcass\ weight\ (kg)\ \times portion\ \%$$

In order to calculate the contribution of weight consumed by supplement feeding events per month, the edible portion of each supplement feeding event was estimated using the consumption percentages used to calculate the edible portion of kill carcasses. Therefore, the total weight consumed from supplement feeding events per month for each individual was calculated by summing the calculated edible portions of each portion fed. This was calculated by multiplying the weight of each portion fed by the appropriate consumption percentage as shown below.

$$\Sigma\, edible\ portion\ of\ supplement\ feeds\ (kg) = portion\ weight\ (kg) \times (edible\ portion\ \%)$$

These calculated prey consumption weights are reliant on consistent monitoring by reserve monitoring teams. Therefore, these values calculated do not represent the total amount of prey consumed by individuals but rather indicate the minimum values as not all prey consumption events are captured.

2.8.2. Body condition index

Body Condition Scoring (BCS) is a visual evaluation that reflects the health of an individual by assessing their physical appearance (Schiffmann *et al.,* 2017; Kongsurakan *et al.*, 2020). Visual cues can be indicators of underlying nutritional deficiencies, health problems, injury, or pregnancy (Repeprt *et al.*, 2011). BCS systems for livestock are well established and are being further developed to evaluate wildlife species in both captivity

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and wild populations (DelGiudice *et al*., 2011; Repeprt *et al*., 2011; Lane *et al*., 2014; Schiffmann *et al*., 2017). Two BCS indexes have been developed for captive cheetah (Dierenfeld *et al*., 2005; Repeprt *et al.,* 2011) using standardized photos along with physical examination data of individuals. Both BCS indexes suggest there are ten focal points of interest, namely: point of buttocks, tail head, hip angle, point of hip, topline, neck, chest, shoulder, torso, and hindleg (Dierenfeld *et al*., 2005; Repeprt *et al*., 2011). By evaluating the change in appearance of these focal points, the condition of an individual can be established.

As these BCS indexes were developed for captive cheetah appearance, we created a version of these BCS indexes that specifically focuses on wild cheetah appearance. The same focal points were used, and photographs of cheetah within the metapopulation (provided by EWT) were analysed to produce a BCS index for wild cheetah in South Africa. This BCS index uses a scoring range from one to nine: Extreme Low (1), Very Low (2), Low (3), Moderate Low (4), Moderate (5), Moderate High (6), High (7), Very High (8), Extreme High (9). A score of 1 indicates a very thin individual and a score of 9 indicates an excessively fat individual. Terms such as 'normal' or 'ideal' were avoided as this index aimed to provide a descriptive insight rather than to define the optimal condition (Repeprt *et al*., 2011). This BCS index does not represent a hard-set rule but rather provides a comprehensive guide to help understand the overall condition of each individual (Appendix 2.D.).

During monitoring observations, monitors evaluated the appearance of the individual cheetah and assigned a score based on the information provided in the BCS index. The average score assigned to an individual was calculated for each monthly interval and was evaluated with the results from the prey consumption analyses to determine if there was a relationship between change in consumption rates and the body condition of an individual.

2.9. Conclusion

Ecological factors that contribute to the short-term success can be investigated in detail by the above-mentioned criteria. By evaluating stability of home range, habitat use, and diet over time, we can verify whether the short-term goals of a successful reintroduction have been achieved. By investigating the overall stability of these ecological aspects, the short-term goals for a successful reintroduction or translocation can be established. The process of evaluating short term success of wild-born cheetah reintroduction or translocations can be applied to the reintroduction of captive-born cheetah to provide an evaluation that not only allows for the use of data analyses to determine success but also allows for a comparison between measurable criteria for wild-born cheetah and captive-born cheetah.

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CHAPTER 3

Evaluation of phased-release reintroduction success: Individual-level

3.1. Introduction

To determine the success of a phased-release method as a tool for reintroducing captive-born cheetah into the South African metapopulation, an evaluation of criteria (established in Chapter 2) was required for all monitored individuals. This chapter presents the results obtained for all individual-based analyses, specifically considering: 1) survival, breeding and demographic shifts, 2) post-release movement and home-range establishment, 3) habitat utilisation, and 4) prey consumption and body condition scores as multifaceted indices and proxies for reintroduction success.

Most individuals (92%, *n* = 11/12) had sufficient data collected for such analyses. Only one individual (Josh, ♂$_{SA}$, Mun-Ya-Wana Conservancy [Reserve 7]) did not qualify, having only been released for a period of 10 days before his death, which falls outside of the minimum monitoring period (30 days) required for adequate analyses and interpretation. Data for individual animals were interpreted independently, as this first evaluation aimed to determine if the variables under consideration and analytical methods employed in this evaluation, provide sufficient detail to confidently speak to the relative adaptation of individuals to their new respective reserves. An evaluation at this individual level allows for the establishment of baseline or standard values to which one could compare future phased-release attempts and therefore create a database to allow for the overall and continuous evaluation of such phased-release methods in cheetah and reintroductions in general.

3.2. Individual cheetah survival, breeding and demography

3.2.1. Ava (Adult ♀, Mount Camdeboo [Reserve 3])

Three weeks after Ava was first released into Mount Camdeboo reserve (April 2020), from the second boma period, she was recaptured and returned to the boma to be treated for a fungal infection. Once the infection had cleared, she was re-released into the recipient reserve (July 2020). Data related to the first three weeks of her release and the boma time to treat the infection were omitted to ensure an uninterrupted study period (see Chapter 2). Ava mated with a resident wild-born male and gave birth to a litter of cubs (*n* = 2) at the end of Month Interval (MI) 4 (November 2020). Concern was raised regarding her condition and her subsequent ability to hunt during MI 4; therefore, supplementary feeding was initiated by the reserve management team. Ava’s cubs (*n* = 2) disappeared at the end of MI 13 (July 2021) at 8-months of age, with no apparent sign that they had been killed; it was assumed they had dispersed naturally.

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3.2.2. Khatu (Adult ♀, Buffalo Kloof [Reserve 2])

Khatu was released into Buffalo Kloof reserve, from the second boma period at the end of March 2020. Khatu did not require any additional supplement feeding after her release from the second boma nor was human intervention required throughout the duration of this study. During MI 4 (end of June 2020), it was confirmed that she had given birth to a litter of cubs (*n* = 2), which she abandoned within seven days. Visual spoor tracks at the den site suggested a leopard had been in the area and it was concluded that the cubs were killed by this leopard. During MI 10 (January 2021), it was confirmed that Khatu had given birth to her second litter of cubs (*n* = 6). The father of both litters was a resident captive-born cheetah (Jake), who did not form part of this study group, as he was reintroduced following a soft-release method. All cubs (*n* = 6) of the second litter were still alive (7 months old) by the end of the study in August 2021 and had been observed hunting with Khatu.

3.2.3. Jade (Sub-adult ♀, Mun-Ya-Wana Conservancy [Reserve 7])

Jade was released into the Mun-Ya-Wana Conservancy, with her litter sibling Josh (Sub-adult ♂, Mun-Ya-Wana Conservancy [Reserve 7]) in September 2020. Shortly after their release (10 days), both were attacked by a coalition of two male wild-born cheetah (estimated at 2 years of age). During the attack, Josh sustained fatal injuries and Jade was severely injured. She was returned to the boma to recover and receive treatment for her injuries. After Jade was cleared by a veterinarian, she was released back into the reserve at the end of October 2020. Over the next month (October 2020 – November 2020) Jade was relocated twice as she had entered a staff camp, after being chased by a pride of lions, and then escaped the reserve boundary. She was returned to the reserve on both occasions. Data captured between September 2020 and November 2020 were omitted to ensure an uninterrupted study period (see Chapter 2). Therefore, data analysis for Jade began at the end of November 2020 until August 2021, as this monitoring period was uninterrupted. During MI 6 it was confirmed that Jade had given birth to a litter of cubs (*n* = 4). The father was assumed to be a wild-born male as there were no other captive-born cheetah on the conservancy at the time. Jade's carcass was found in what was identified as a den site by the monitoring team in early MI 8. It is believed that lions killed Jade and her cubs at the den site. This was not the original den site observed during MI 7 but was believed to have been her second den site. As monitoring during this period was suspended to not disturb the den site due to the high density of predators within Mun-Ya-Wana Conservancy, the exact details surrounding her death are unknown.

3.2.4. Josh (Sub-adult ♂, Mun-Ya-Wana Conservancy [Reserve 7])

Josh was released into the Mun-Ya-Wana Conservancy, with his litter sibling Jade (Sub-adult ♀, Mun-Ya-Wana Conservancy [Reserve 7]) in September 2020. Shortly after their release (10 days), both were attacked by a coalition of two wild-born cheetah (see 3.2.3.). During the attack, Josh sustained fatal injuries and Jade was

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severely injured. Data collected for Josh only covered 10-day period post-release, which proved insufficient for most data analysis, however, where possible, values are presented and described for Josh with Jade.

3.2.5. Ivory (Adult ♂, Amakhala Game Reserve [Reserve 7])

Ivory was released into Amakhala Game Reserve, from the second boma period at the end of October 2019. Within the first 10 days of release, Ivory was seen with the resident wild-born female cheetah (Hope, four years of age) for a 3-day period and was observed mating during this interaction. The female gave birth to a litter of cubs (*n* = 2: ♀ ♂) in February 2020. Both cubs were still alive by the end of the study in August 2021 (MI 23) at 18 months of age. Ivory received supplementary feeding during the first 30 days post-release, as the reserve management was concerned about his hunting ability, after which he was left to hunt independently. It is noted that during MI 23 (August 2021) he was treated for an infection and received this medication in small cuts of meat (total weight = 0.6 kg).

3.2.6. Alpha (Adult ♂, Ka'ingo Game Reserve [Reserve 6])

Alpha and his slightly older coalition mate Jabez (Adult ♂, Ka'ingo Game Reserve [Reserve 6]), were released into Ka'ingo Game Reserve, from the second boma period at the end of November 2020. During the first four MIs, the coalition received supplementary feeding as the management team was concerned that they were not hunting. The coalition was then chased by a pride of lions that resulted in a coalition split (2 April 2021). Shortly thereafter, Jabez was found dead (MI 5), which subsequently changed Alpha's social group structure, and therefore his behaviour, to that of a lone male. Alpha was the only cheetah present on the reserve between MIs 5–10 (April – August 2021). A wild-born female cheetah (information unknown) was scheduled to arrive during the study, but permitting restrictions delayed her arrival.

3.2.7. Jabez (Adult ♂, Ka'ingo Game Reserve [Reserve 6])

Jabez and his slightly younger coalition mate Alpha (Adult ♂, Ka'ingo Game Reserve [Reserve 6]), were released into Ka'ingo Game Reserve, from the second boma period at the end of November 2020. During the first 4 MIs, the coalition received supplementary feeding as the management team was concerned that they were not hunting. The coalition was split after being chased by lions (see 3.2.6. above) and soon thereafter, Jabez was found dead in April 2021 (MI 5). Starvation was determined to be the cause of death, as a broken front leg, sustained during their confrontation with the lion pride, would have prevented Jabez from hunting, although this was not investigated further.

3.2.8. Storm (Sub-adult ♂, Magic Hills [Reserve 6])

Storm was artificially bonded to a wild-born male cheetah (roughly 4 years of age) during the second boma period on Magic Hills game reserve. This process occurred over a two-months, slightly lengthening the typical phased-release period. The males were released together into the reserve in May 2021 and stayed together

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as a coalition pair (MI 1). They did not require any form of supplementary feeding or human intervention throughout the duration of the study.

3.2.9. KC coalition (Four Sub-adult ♂s, !Khamab Kalahari Reserve [Reserve 5])

Four sub-adult brothers (KC1, KC2, KC3, and KC4), known collectively as the 'KC coalition', were released into !Khamab Kalahari Reserve (KKR), from the second boma period in May 2021. The coalition remained together, requiring supplementary feeding for the first MI, after which they did not require further feeding or human intervention for the duration of the study period.

3.3. Post-release movement and home-range establishment of individual cheetah

In total, 98 MI home-ranges (HR; 95% and 50% isopleths in km^2) were successfully estimated for 11 cheetahs ($n_{females}$ = 3; n_{males} = 8) throughout the study period (23 MIs). The differences in HR estimates at MIs were investigated to determine if significant HR stability was achieved (Figure 3.3.A.), as a proxy for phased-release reintroduction success, as 'settled' individuals were expected to show consistency in site fidelity (Bastille-Rousseau *et al.*, 2016). The shortest study duration obtained for an individual was four consecutive MIs (Storm, KC1, KC2, KC3, and KC4) while the longest duration was 23 consecutive MIs (Ivory; Figure 3.3.A). HRs at 95% isopleths varied between 3.61–5149 km^2, with the core area of use (50% isopleths) ranging from 0.48–1224 km^2 (Appendix 3.A. and 3.B.). Significant variation (α = 0.05) between sequential pairwise MIs for HR size (both 95% and 50% isopleths) occurred in three females (Ava, Khatu, and Jade) and two males (Ivory and Alpha; Figure 3.3.A.).

In total, 87 MI HR Overlap (HRO) proportions (95% isopleth Bhattacharyya Coefficient [BC; %]) were successfully estimated for 11 cheetahs ($n_{females}$ = 3; n_{males} = 8) throughout the study period (23 months; Figure 3.3.B.). The lowest proportion of estimated within-individual pairwise MI HRO was 3% (Storm, KC1, KC2, KC3 and KC4) while the largest pairwise proportion for an individual was 23% (Ivory; Figure 3.3.B.). Significant variation (α = 0.05) between sequential pairwise MIs for HRO proportions (at 95% isopleths) occurred in two females (Ava and Khatu) and coincided with significant variation seen in the HR estimates of the same MIs, for these two individuals.

3.3.1. Ava (Adult ♀, Mount Camdeboo [Reserve 3])

GPS collar data collection for Ava on Mount Camdeboo occurred over a 14-month interval period (July 2020 - August 2021), although monitoring data only began from MI 6 onwards. The size difference between home-ranges for the first three MI of Ava's release varied significantly (month 1: 207.53 km^2, month 2: 23.39 km^2, month 3: 199.93 km^2, α = 0.05) (Figure 3.3.A.). Results from (Sievert, 2020) indicated that wild-born cheetah, reintroduced into Liwonde National Park (LNP) in Malawi following a soft release method, were considered to be settled on average 106 days post-release (3.5 MIs). As no monitoring records were collected during the first three MIs, the unstable period cannot be confidently related to behavioural aspects (injuries, denning,

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etc) and was therefore considered to be exploration movements, and not the establishment of a home-range. Although statistical analysis classified the period as unstable, per the original hypothesis, this unstable period was comparable to behaviour that was observed in wild-born cheetah (Weise *et al*., 2015; Sievert, 2020).

A significant size difference (α = 0.05) between the home-range estimates of MIs 5 and 6 (month 4: 119.96 km^2, month 5: 4.92 km^2, month 6: 35.61 km^2) was observed and was also identified for HRO (month 3v4: 0.99; month 4v5: 0.37, Figure 3.3.B.) between the same set of consecutive MIs. Both analyses identified instability during MI 5 and 6. Monitoring records indicated that towards the end of MI 4, Ava gave birth and the change in home-range size as well as HRO was therefore associated with a denning event. Both home-range size and HRO analyses classified these MIs as unstable, per the original hypothesis, this unstable period was justified as normal behaviour that was observed in wild-born cheetah as home-range size was reduced during denning events (Houser *et al*., 2009; Sievert, 2020). From MI 7 onwards, Ava's home-range and home-range overlap estimates did not differ significantly (Figure 3.3.A. and Figure 3.3.B.), indicating that during the latter portion of her release, until the end of the study in August 2021, Ava was considered to have reached stability as per the original hypothesis.

3.3.2. Khatu (Adult ♀, Buffalo Kloof [Reserve 2])

Data collection via GPS collar for Khatu on Buffalo Kloof Reserve, occurred over an 18-month interval period (March 2020 – August 2021), although monitoring data only began from MI 8 onwards. The size between home-ranges for the first 9 MIs of Khatu's release did not show any significant differences, although MI 4 had a decrease in home-range compared to the previous MI (month 3: 83.98 km^2, month 4: 24.25 km^2, Figure 3.3.A, Appendix 3.A.). This slight decrease was attributed to the birth of her first litter which occurred during this MI, but as she abandoned the cubs shortly after birth, the home-range for MI 4 was not statistically significant.

A significant size difference between the home-ranges of MIs 10, 11 and 12 (month 9: 196.82 km^2, month 10: 6.16 km^2, month 11: 11.37 km^2, month 12: 135.40 km^2) was observed and also identified for HRO (month 9v10: 0.51; month 10v11: 0.91, Figure 3.3.B.) between the same consecutive MIs. Both analyses identified instability during MIs 10 to 12. Monitoring records indicated that at the beginning of MI 10, Khatu gave birth to her second litter of cubs (6), and the change in home-range estimates as well as HRO estimates was therefore associated with a denning event. Both home-range size and HRO analyses classified these MIs as unstable, and per the original hypothesis, this unstable period was justified as normal behaviour that was observed in wild-born cheetah as home-range size reduces during denning events (Houser *et al*., 2009; Sievert, 2020). From MI 12 onwards, Khatu's home-range and HRO estimates did not differ significantly, indicating that during the latter portion of her release, until the end of the study in August 2021, Khatu was considered to have reached stability as per the original hypothesis.

3.3.3. Jade (Sub-adult ♀, Mun-Ya-Wana Conservancy [Reserve 7])

Data collection via GPS collar and monitoring data for Jade, occurred over an 8-month interval period (November 2020 - August 2021). The size between home-ranges for the first 6 MIs of Jade's release did not show any significant differences, although MI 2 showed a slight increase in home-range compared to the previous MI (month 1: 297.26 km^2, month 2: 874.60 km^2, Figure 3.3.A.). This slight increase in MI 2 was not statistically significant, and the increase in distance was attributed to exploration movement (Sievert, 2020), as no events (injuries, denning, etc) were noted in monitoring records during this period.

A significant home-range size was observed at MI 7 (month 6: 60.90 km^2, month 7: 17.99 km^2), indicating instability during this time period. Monitoring records indicated that during MI 6 (beginning of April 2021), Jade gave birth to her first litter of cubs (n = 4). Although MI 6 was not identified as statistically different, a decrease in home-range size from the previous month was noted (month 5: 303.69 km^2, month 6: 60.90 km^2). The HRO for this time period did change although this change was not statistically significant. Although home-range size analysis classified this MI as unstable, per the original hypothesis, and this unstable period was justified as normal behaviour that was observed in wild-born cheetah as home-range size was reduced during denning events (Houser *et al.*, 2009; Sievert, 2020). During MI 8, Jade's carcass was found in what was identified as a den site by the monitoring team, there was no sign of the cubs. It is believed that a lion(s) killed Jade and her cubs at the den site. This was not the original den site observed during MI 7 but was believed to have been the second den site. As monitoring during this period was suspended, exact details surrounding her death are unknown.

3.3.4. Ivory (Adult ♂, Amakhala Game Reserve [Reserve 7])

Ivory was not fitted with a GPS collar, therefore data relating to Ivory's movements were obtained from visual monitoring records. Monitoring of Ivory occurred over a 23-month interval period (October 2019 – August 2021). A significant size difference between the home-ranges was observed for MI 3 (month 2: 12.12 km^2, month 3: 4.60 km^2, Figure 3.3.A.), and was identified as an unstable period. Monitoring records indicated that Ivory sustained an injury to his left hip during this period. Home-range analysis classified this MIs as unstable, per the original hypothesis, and this unstable period was attributed to an injury which restricted his movements during this time period. From MI 4 onwards, Ivory's estimated monthly home-range did not alter significantly, and no significant differences were observed in the home-range overlap analysis. Thus, indicating that during the latter portion of his release, until the end of the study period, he was considered to have stabilised as per the original hypothesis.

3.3.5. Alpha (Adult ♂, Ka'ingo Game Reserve [Reserve 6])

Data collection via GPS collar and monitoring data for Alpha on Ka'ingo occurred over a 10-month interval period (November 2020 - August 2021). The size difference between home-ranges for the first 5 MIs of

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Alpha's release varied but not significantly. The pattern observed for this time period indicates that while in a coalition social group, Alpha and Jabez had a large exploration period as seen in wild-born cheetah (Weise *et al*., 2015; Sievert, 2020). The significant variation in Alpha's home-range at MI 10 indicates the effect of a gradual decrease in home-range size over a 5-month period. This is a result of the death of his coalition member during MI 5. As Alpha was the only existing cheetah on the reserve at this time of the study, his home-range size decreased to a point where it showed statistical significance at MI 10 (month 9: 19.87 km^2, month 10: 4.53 km^2, Figure 3.3.A.). No significant differences were observed in the HRO analysis for Alpha during the study period (Figure 3.3.B.).

3.3.6. Jabez (Adult ♂, Ka'ingo Game Reserve [Reserve 6])

Jabez was not fitted with a GPS collar, therefore data relating to Jabez's movements were only obtained from visual monitoring records. Monitoring for Jabez occurred over a 5-month period until his death (November 2020 – April 2021). The size difference between home-ranges for the first 5 MIs of Jabez's release varied (Figure 3.3.A.). The pattern observed for this time period indicates that while in a coalition social group, Alpha and Jabez had a large exploration period as seen in wild-born cheetah (Weise *et al*., 2015; Sievert, 2020). During MI 5, the coalition encountered a pride of lions who separated the pair, and Jabez was later found dead with what appeared to be an injured front leg.

3.3.7. Storm (Sub-adult ♂, Magic Hills [Reserve 6])

Data collection via a GPS collar and monitoring observations for Storm on Magic Hills Reserve occurred over a 4-month period (May 2021 – August 2021). The size difference between home-ranges for all 4 MIs varied but not significantly (Figure 3.3.A.). The pattern observed for this time period indicates that while in a coalition social group, Storm and the wild male cheetah had a large exploration period as seen in wild-born cheetah (Weise *et al*., 2015; Sievert, 2020).

3.3.8. KC coalition (Four Sub-adult ♂s, !Khamab Kalahari Reserve [Reserve 5])

Data collection via GPS collars and monitoring observations for the KC coalition (KC1, KC2, KC3, and KC4), on !Khamab Kalahari Reserve, occurred over a 4-month period (May 2021 – August 2021). The coalition was analysed on an individual level for home-range and HRO estimates as each member had their own GPS collar. For all four individuals, the size difference between home-ranges for all 4 MIs varied but not significantly (Figure 3.3.A.). The pattern observed for this time period indicated that, while in a coalition social group, the KC coalition had a large exploration period as seen in wild-born cheetah (Weise *et al*., 2015; Sievert, 2020).

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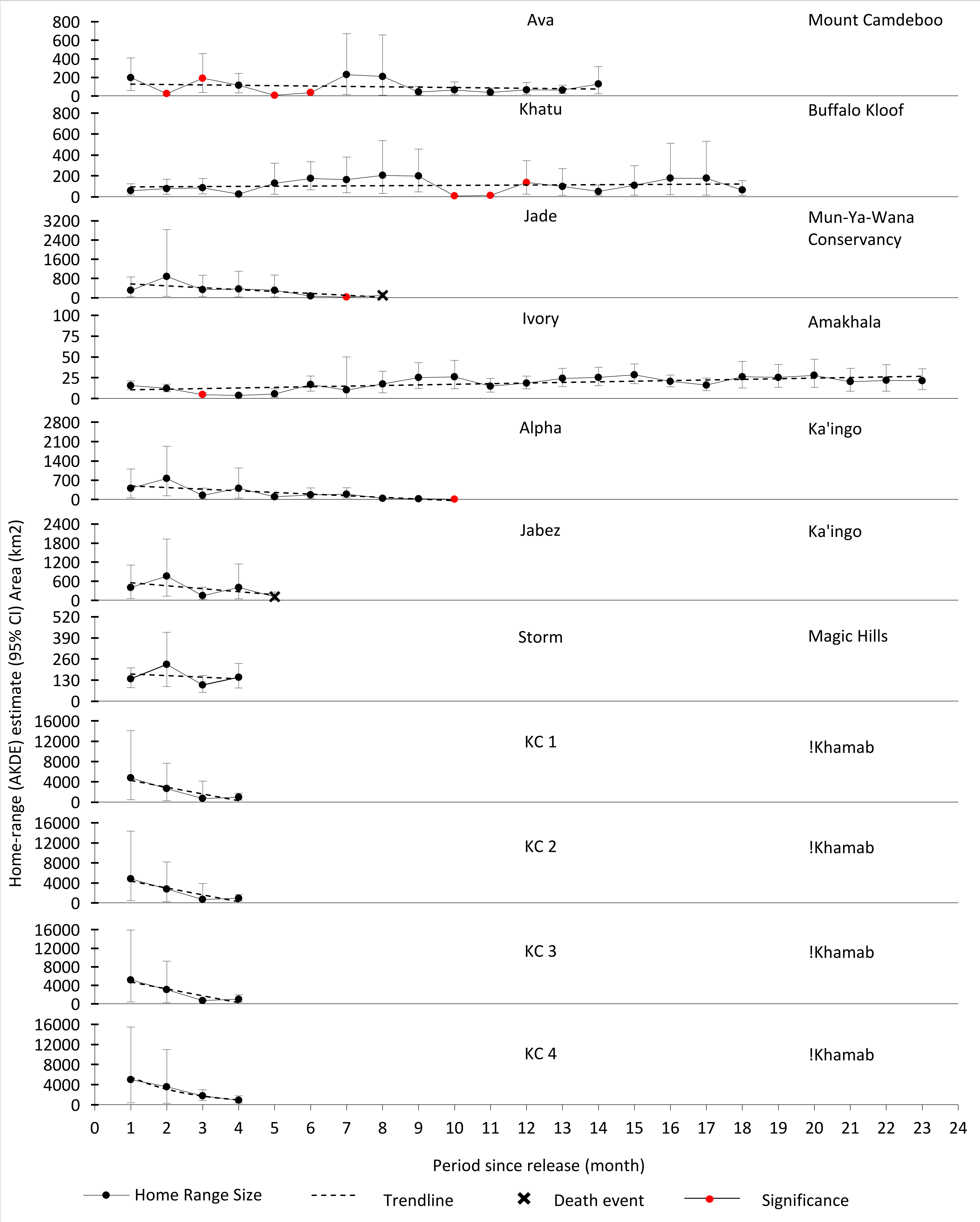

Figure 3.3.A. Home-range (AKDE) estimates (95% CI) area (km^2). **Note y-axis scales differ between individuals** and x-axis is indicative of the month intervals from release date.

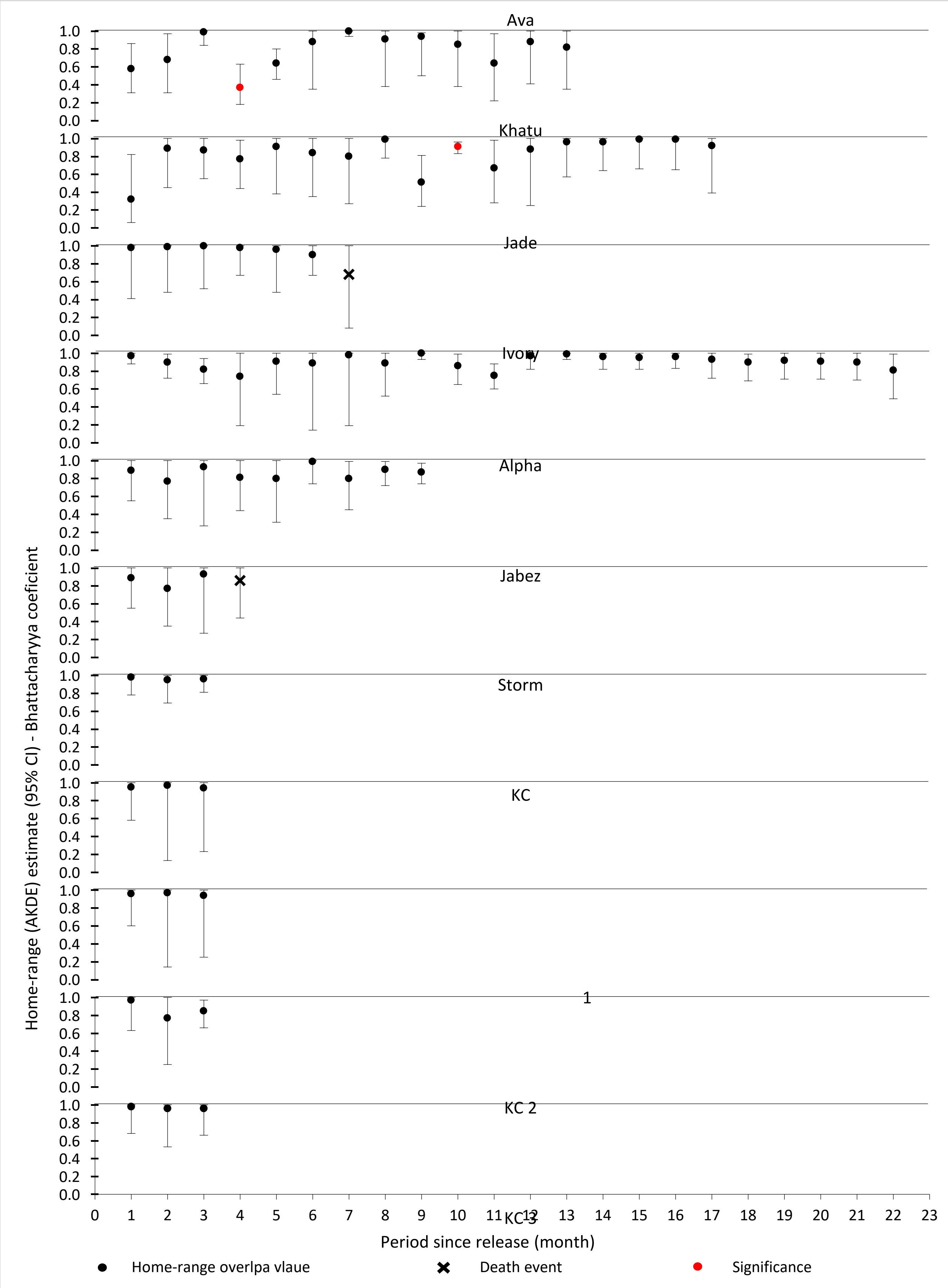

Figure 3.3.B. Home-range overlap estimates (95% CI) -Bhattacharyya coefficient.

3.4. Habitat utilisation results

Habitat utilisation per MI was calculated for 10 of the 12 cheetah. Mount Camdeboo was covered by one vegetation type (Karoo Escarpment Grassland) and the data for Josh did not meet the minimum requirements, therefore habitat utilisation could not be conducted for both Ava (released onto Mount Camdeboo) and Josh. Figures 3.4.A. to 3.4.G. visualize the change in habitat utilisation and home-range estimates per MI for each of the 10 individuals. The use of habitat for each MI per individual was discussed according to significant home-range estimates.

3.4.1. Khatu (Adult ♀, Buffalo Kloof [Reserve 2])

During the study period, Khatu was shown to enter all of the available vegetation types but mainly selected for 2 vegetation types, Albany valley thicket and Grahamstown grassland thicket, which appear in every MI during the study. During MIs 4, 10 and 11, Khatu avoided Bhisho Thornveld completely (Appendix 3.D.), which was normally utilised to some extent during the other months. These MIs were associated with a decrease in home-range estimates (Figure 3.4.A.) and were known for denning events. The same was seen for Albany Mesic thicket, which was not utilised during MI 10 and 11, where denning events occurred for a longer period of time.

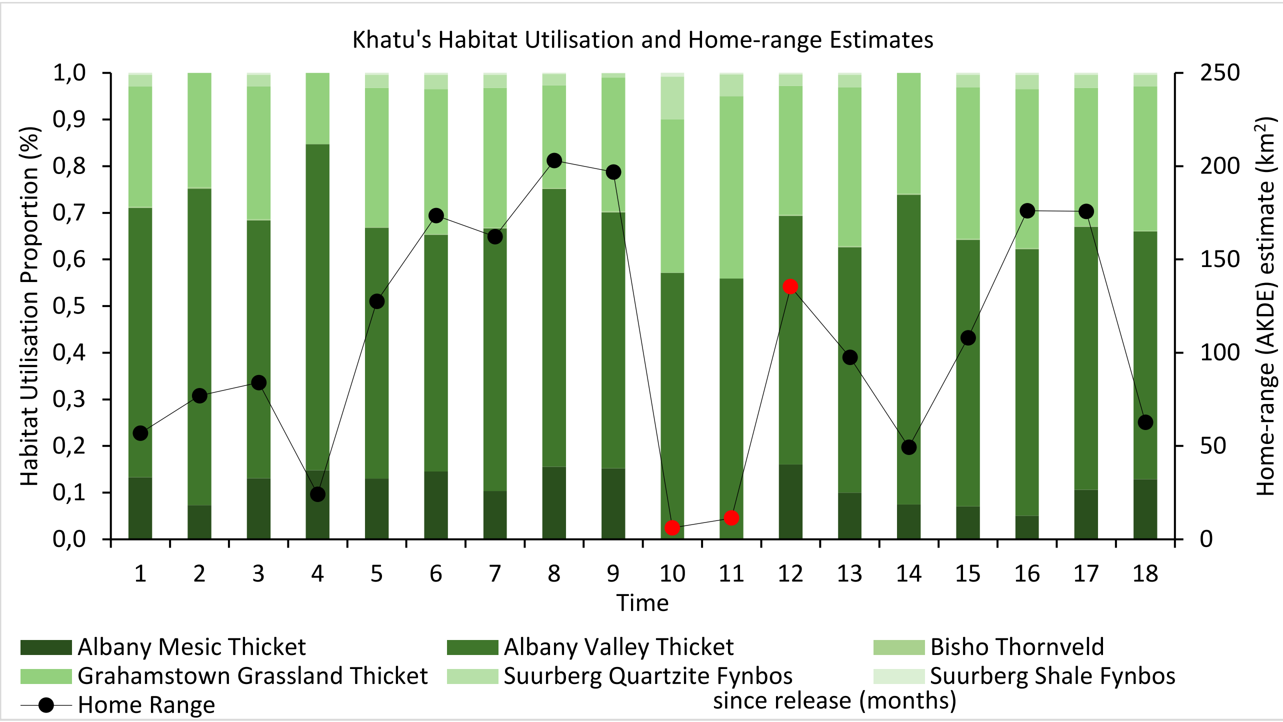

Figure 1.4.A. Khatu's Habitat Utilisation and Home-range Estimates

3.4.2. Jade (Sub-adult ♀, Mun-Ya-Wana Conservancy [Reserve 7])

Between MIs 1 to 5, Jade was seen utilising all available vegetation, although the proportion of vegetation utilisation for each available vegetation type altered for each MI (Figure 3.4.B.). During this period Jade's

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home-range estimates were seen changing, although not significantly, indicating that this period was a possible exploration phase as her home-range estimates begin to plateau at MI 3 to 5 where the vegetation type utilisation was seen to stabilize. During MI 6 to 8, there was a large shift and 3 vegetation types (Floodplain Grasslands; Sand Forest; and Sandveld Woodlands) were completely avoided. This period was associated with a significant change in home-range size which was attributed to a denning event.

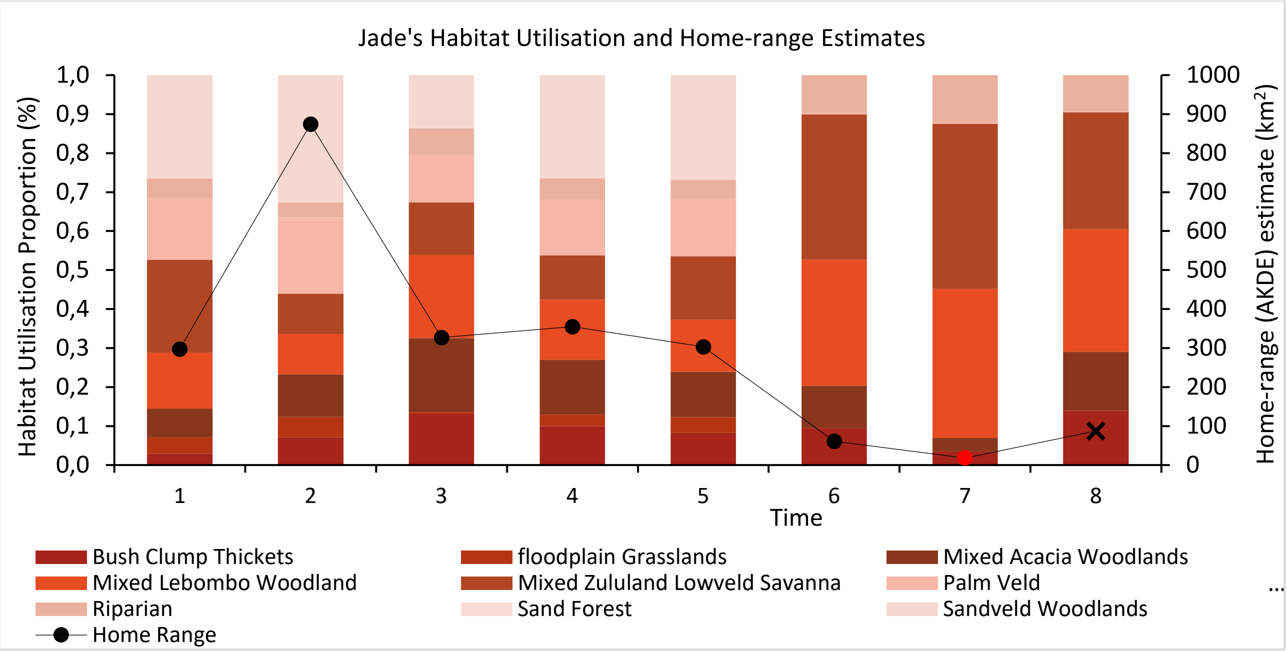

Figure 3.4.B. Jade's Habitat Utilisation and Home-range Estimates

3.4.3. Ivory (Adult ♂, Amakhala Game Reserve [Reserve 7])

During the study period, Ivory was seen utilising all available vegetation, although the proportion of vegetation utilisation for each available vegetation type altered for each MI (Figure 3.4.C.). During MI 3, a significant change in home-range size was observed and a change in the utilisation proportion of vegetation was seen for MI 3. From MI 7 onwards, Ivory's home-range estimates follow a pattern until MI 23, indicating he had settled with regards to movements, and this is seen in his habitat utilisation patterns which even out over the same time span.

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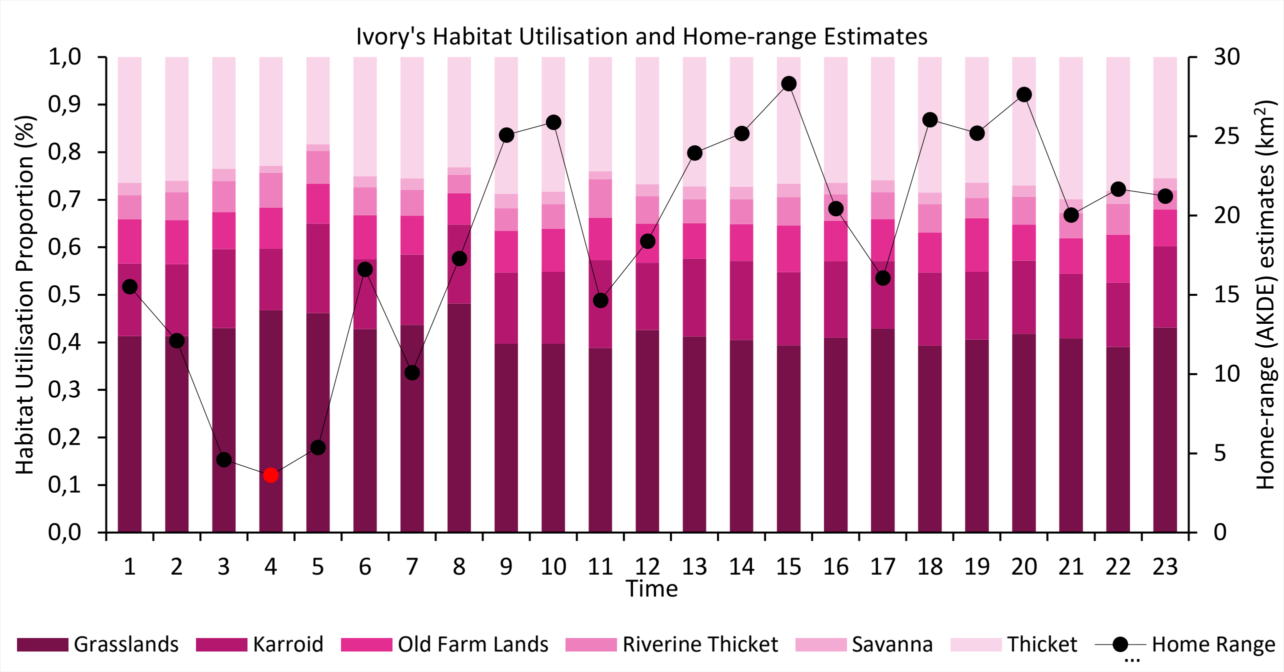

Figure 3.4.C. Ivory's Habitat Utilisation and Home-range Estimates

3.4.4. Alpha (Adult ♂, Ka'ingo Game Reserve [Reserve 6])

Between MIs 1 to 5, Alpha and Jabez were seen utilising all available vegetation types, although the proportion of vegetation utilisation for each available vegetation type altered for each MI (Figure 3.4.D.). During MI 5, Alpha's coalition mate, Jabez, was separated from him and died shortly thereafter. Thus, Alpha's change in habitat utilisation following MI 5 was attributed to the change in social structure, as he transitioned from a coalition social structure (month 1-5) to a lone male social structure (month 6-9). Furthermore, Alpha was the only cheetah present on the reserve during this time frame (month 6 -9), he retreated to a small area within the reserve and was seen to only utilise one type of vegetation (Western Sandy Bushveld). The lack of individuals of the same species and the presence of other competing predators such as lion and leopard, was attributed to this significant change.

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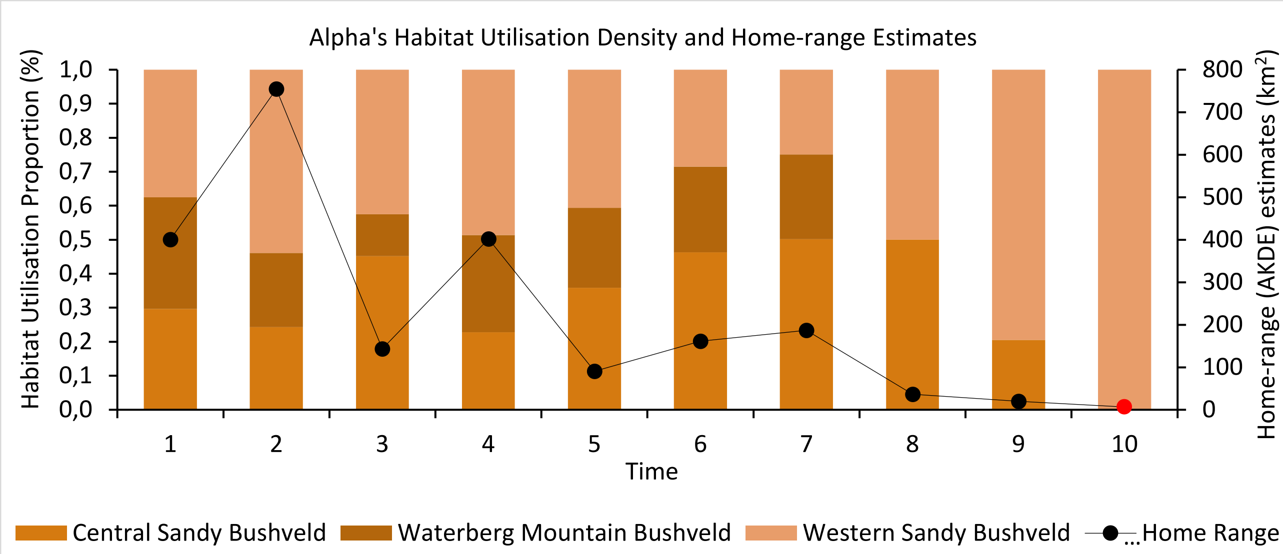

Figure 3.4.D. Alpha's habitat Utilisation and Home-range Estimates

3.4.5. Jabez (Adult ♂, Ka'ingo Game Reserve [Reserve 6])

Between MIs 1 to 5, Jabez and Alpha were seen utilising all available vegetation type, although the proportion of vegetation utilisation for each available vegetation type altered for each MI (Figure 3.4.E.). During MI 5, Jabez separated from Alpha and was found dead shortly thereafter.

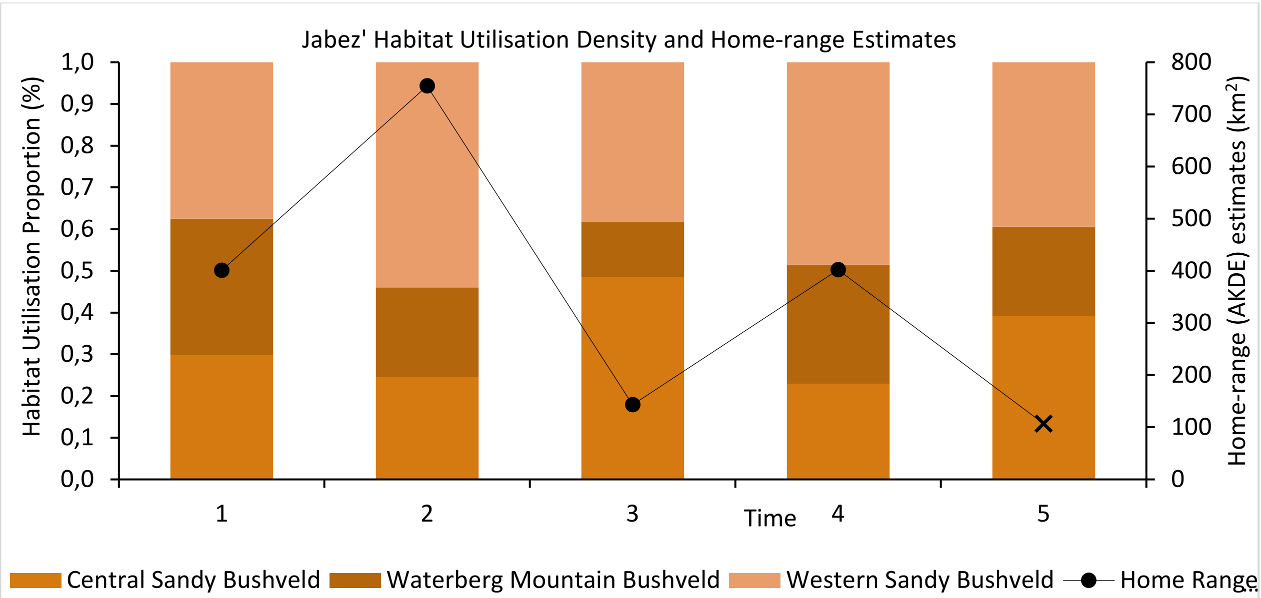

Figure 3.4.E. Jabez' Habitat Utilisation and Home-range Estimates

3.4.6. Storm (Sub-adult ♂, Magic Hills [Reserve 6])

Between MIs 1 to 4, Storm, and his wild-born cheetah coalition mate, were seen utilising all available vegetation types, although the proportion of vegetation utilisation for each available vegetation types altered for each MI (Figure 3.4.F.).

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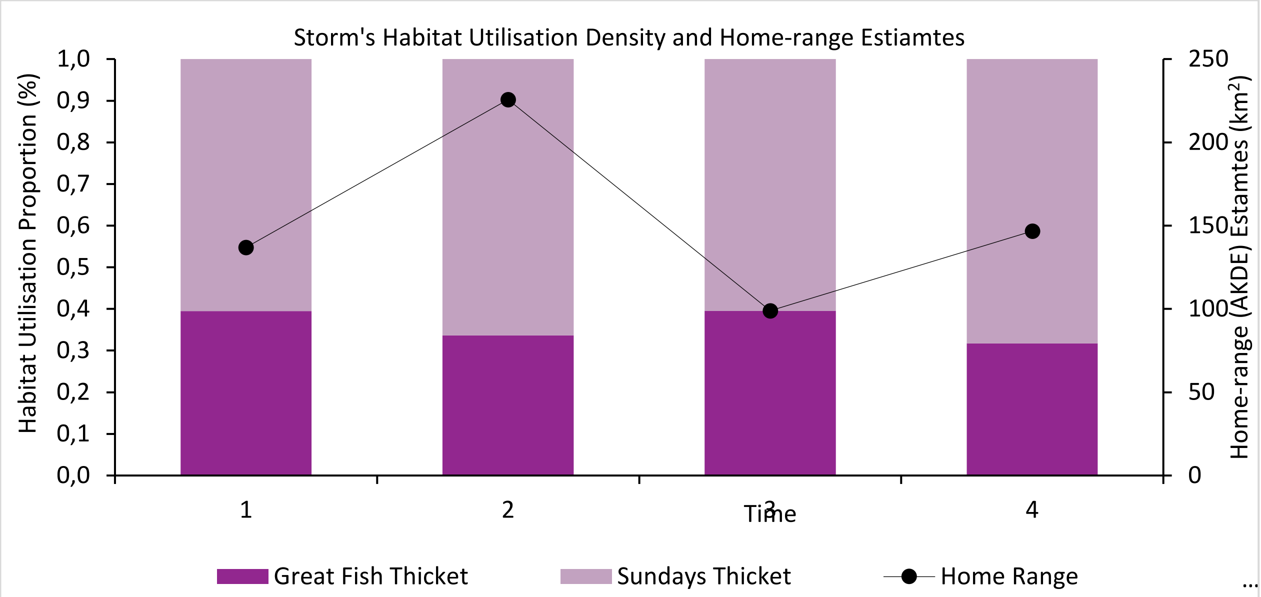

Figure 3.4.F. Storm's Habitat Utilisation and Home-range Estimates

3.4.7. KC coalition (Four Sub-adult ♂s, !Khamab Kalahari Reserve [Reserve 5])

During the study period, the KC coalition was shown to enter all of the available vegetation types but mainly selected for 3 vegetation types; namely open woodlands on sands, closed woodlands on sands, and dense woodlands on sands, although the proportion of vegetation type utilisation altered for each MI (Figure 3.4.G.). Although each of the four brothers had slightly different home-range estimates, they showed the same overall trend and thus the same vegetation type utilisation as they remained in their coalition group throughout the study period.

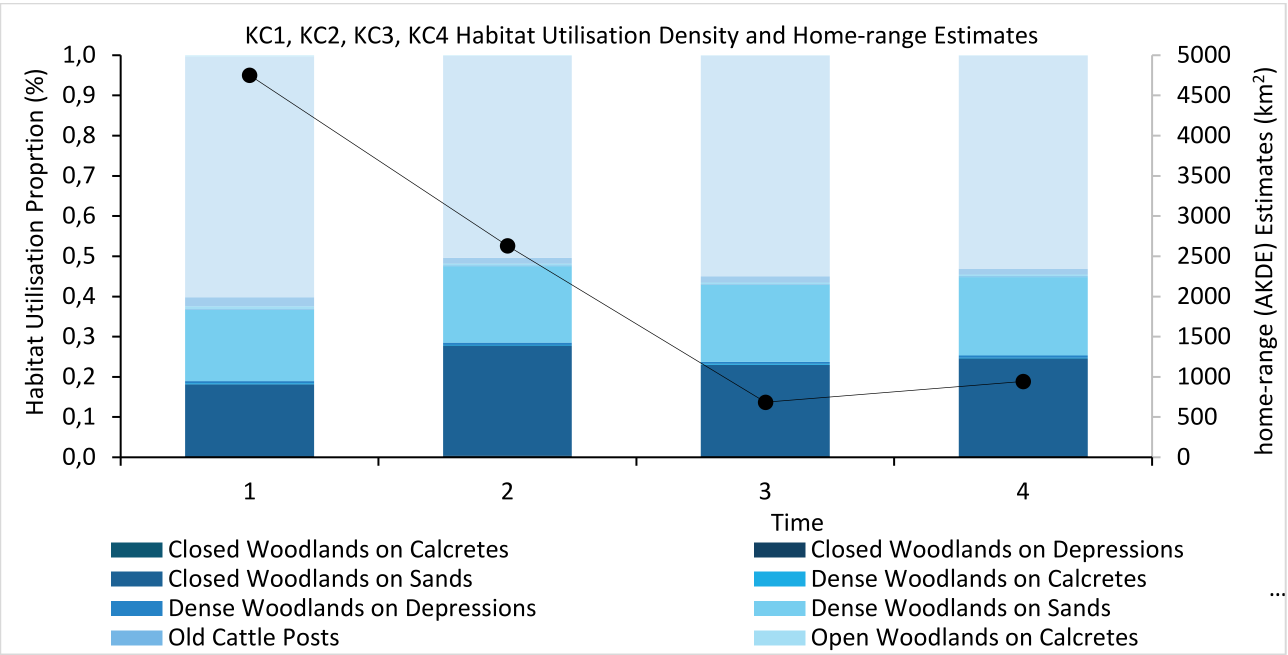

Figure 3.4.G. KC coalition Habitat Utilisation and Home-range Estimates

3.5. Prey consumption and body condition score results per individual cheetah

In total, 128 kills consisting of 19 prey species were observed during the study period (Appendix 3.F.). A total of 57 'increase in fullness' events were noted across all individuals, while 26 supplement feeding events occurred for 9 individuals (Ava, Jade, Ivory, Alpha, Jabez, KC1, KC2, CK3, KC4) once released. Body condition scores were noted for all individuals during their respective post-release monitoring period until the end of the study period in August 2021 and were visualized for each MI (Figure 3.5.A. to 3.5.G.).

3.5.1. Ava (Adult ♀, Mount Camdeboo [Reserve 3])

Monitoring observations for Ava occurred over a 9-month period (December 2020 – August 2021). During this time period Ava's monitoring data revealed 33 prey consumption events, consisting of 27 kill observations, 3 'increase in fullness' observations, and 3 supplement feeding events (Appendix 3.F.). The kill observations consisted of 9 different species, with kudu making up the bulk of these observations (48%). Sixty-seven percent of all observed kills fell in the juvenile weight class range, of unknown sex. The remaining kills observed were classified into weight classes; 15% subadult and 18% adult, and sex classes; 22% female and 11% male. Supplement feeding occurred twice in MI 6 and once in MI 7. During MI 6 a total of 6.9 kg of meat was supplied while in MI 7, a total of 23 kg of meat was supplied. From MI 7 onwards, Ava did not receive additional supplement feed and was self-sufficient during the remainder of the study period. Three 'increase in fullness' observations were noted in total, two occurring in MI 7 and one in MI 11. On average Ava consumed 92.63 kg/month, ranging from a minimum of 14.40 kg/month (month 13) to 184.89 kg/month (month 11). It must be noted that during MI 11, Ava was competing with her cubs and although she would

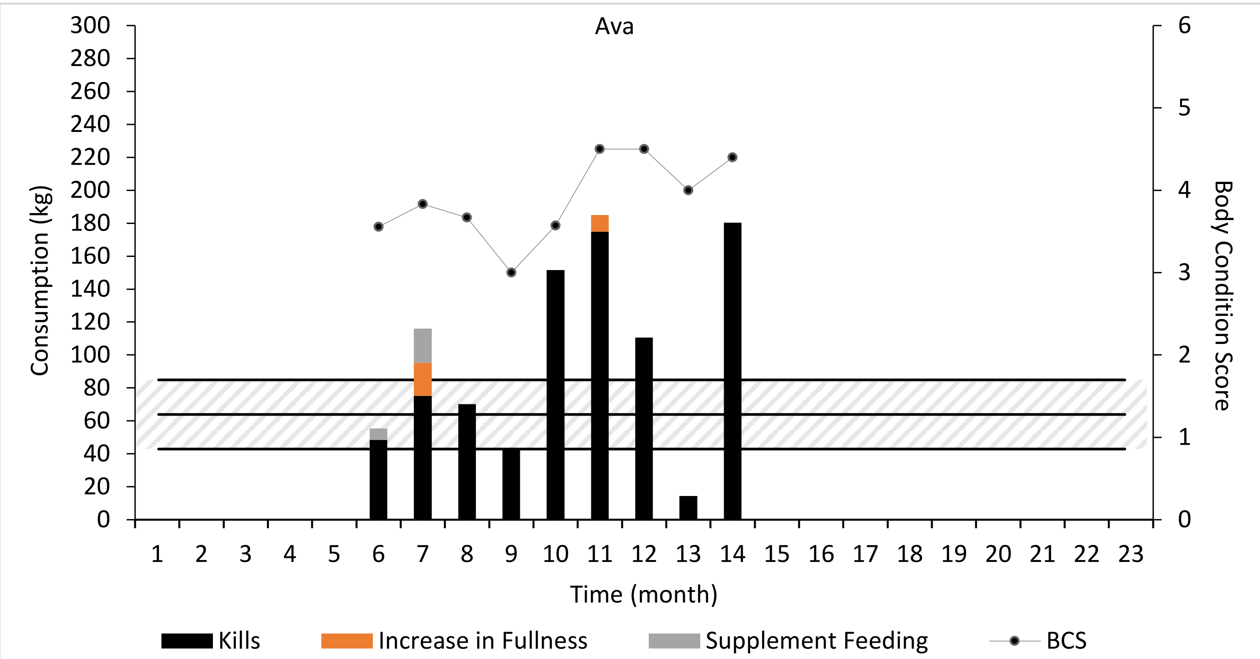

Figure 3.5.A. Ava's Prey Consumption (kg) and Body Condition Scores

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not have consumed the full 184.89 kg/month, she was observed to have provided this amount for all three individuals to consume. These monthly prey consumption values are visualized in Figure 3.5.A.

For MI 6 and 7, Ava's kill observations indicated that she consumed a total of 48.42 kg/month and 75.30 kg/month, respectively. For MI 7, the 'increase in fullness' observations accounted for an additional 20 kg/month for MI 7. The total quantity of prey consumed by kills and 'increase in fullness' observations for both MI 6 and 7 (48.42 kg/month and 95.3kg/month) were within the monthly energy requirement range. The MI 6 consumption was considered on the lower portion of this range as it did not meet the average monthly requirement (63 kg/month) and supplement feed was therefore considered applicable as Ava had young cubs during this period. However, MI 7 indicated that Ava's prey consumption was well over the maximum monthly energy requirement when considering only weights obtained from kill and 'increase in fullness' observations. The supplement feeding events for this month were not justified as observation data indicated that Ava was able to achieve and indeed surpass the monthly energy requirement. Figure 3.5.A. illustrates a decline in monthly prey consumption between MI 7 to 9, followed by an increase from MI 9 to 11.

Ava was observed returning to the den site to tend to her cubs during MI 7 and 8. Her home-range estimates for these respective months was estimated to be large (month 7: 240.61 km^2, month 8: 219.88 km^2), indicating that she was moving large distances from the den site to hunt. Although a decline of total prey consumption was observed during this time period, the total amount of prey consumed by observed kills was still within the range for monthly energy requirements. As Ava was moving large distances, the possibility of missing a kill event was higher and attributed to the decline in observed kills. Monitoring data revealed that the cubs (two) were present at the kills and were observed feeding on the carcasses from MI 9 onwards. Wild-born cheetah females are known to increase their prey consumption rate to meet the nutritional requirements of the dependant cubs (Schaller, 1968; Sievert, 2020). Therefore, the increase in monthly prey consumption, which was well above the maximum monthly energy requirement (month 10: 11.49 kg/month, month 11: 184.89 kg/month) was justified. During the period between MI 12 to 14, Ava moved to an inaccessible section of the reserve, therefore few monitoring records were captured for this time period. The monthly prey consumption estimated does not provide an accurate representation for this time period.

During this 9-month period (December 2020 - August 2021), a total of 50 monitoring observations occurred where body condition scores were obtained. Scores obtained for Ava ranged between 3 to 5, with an overall average of 3.9. These body condition scores are shown in Figure 3.5.A. along with monthly prey consumption weights. The relationship between the body condition scores and prey consumption weights was apparent as they changed during the same time period. Between MIs 6 and 7, Ava had given birth and was not carrying cubs internally, although her condition revealed a slight increase in condition. The excessive supplement feed provided during this time period could be the factor that caused this increase in condition.

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There was a decrease in condition from MI 7 to 9. During this period Ava was observed moving greater distances, as determined by the estimated home-ranges, and was producing milk to nourish her litter of cubs. Milk production and an increase in daily movement can be attributed to the decline in body condition during this time period. Between MI 9 to 12, an increase in condition was observed. This increase in condition is attributed to the correlated increase in prey consumed during this time period. During the period between MI 12 to 14, Ava moved to an inaccessible section of the reserve, therefore few monitoring records were captured for this time period. Therefore, the body condition score represents only two observations and not an accurate monthly average. Despite the low data collection for this period, mainly MIs 12 and 13, the change in body condition score and prey consumption occurred simultaneously, further reinforcing the relationship between the two variables and indicating the accuracy of using body condition scoring as an effective tool for determining overall health of an individual.

3.5.2. Khatu (Adult ♀, Buffalo Kloof [Reserve 2])

Monitoring observations occurred over a 10-month period for Khatu (November 2020 - August 2021). During this time period Khatu's monitoring data revealed 28 prey consumption events, consisting of 25 kill observations and 3 'increase in fullness' observations, while no supplement feeding was provided (Figure 3.5.B.). The kill observations consisted of 8 different species, with impala making up the bulk of these observations (36%). Sixty percent of all observed kills fell in the adult weight class, with subadults and juveniles representing 12% and 28%, respectively. Forty-four percent of kills were of an unidentified sex class, while the 32% represented females and 24% represented males. Three 'increase in fullness' observations

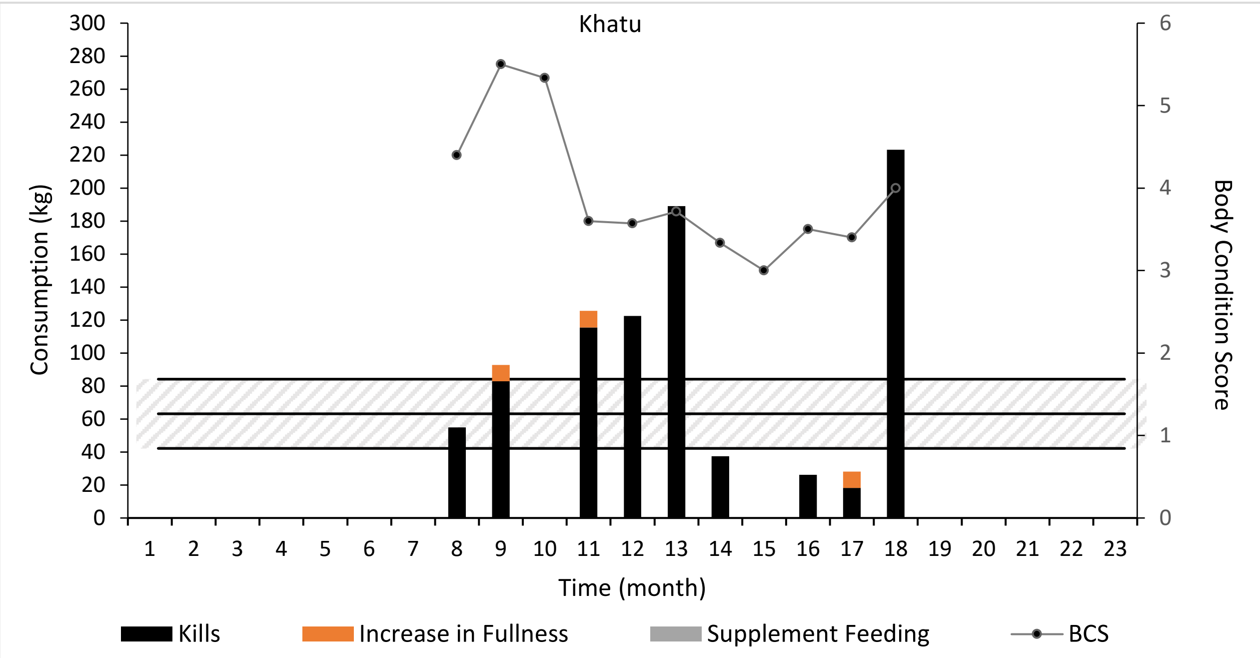

Figure 3.5.B. Khatu's Prey Consumption (kg) and Body Condition Score

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were noted for MIs 9,11, and 17. On average Khatu consumed 99.97 kg/month, ranging from a minimum of 26.10 kg/month (MI 16) to a maximum 223.19 kg/month (MI 18).

There was an increase in monthly prey consumption between MI 8 to 13, followed by a sharp decrease from MI 14 to 17, and a rapid increase at month 18. This rapid decrease observed for Mis 14 to 17, was the result of a reduced number of monitoring events that occurred for these MIs. In total, only 12 monitoring events were recorded for this 4-month period. Therefore, the monthly prey consumption estimated for Khatu, does not provide an accurate representation for this time period.

Khatu's kill and 'increase in fullness' observations from MI 8 to 13, indicated that her overall prey consumption steadily increased (month 8: 54.90 kg/month, month 9: 92.80 kg/month, month 11: 125.55 kg/month, and month12: 122.55 kg/month, month 13: 189.13 kg/month). During MI 10, there was no kill or 'increase in fullness' observations, as monitoring was limited in order to not disturb the den site due to Khatu previously abandoning of her first litter. Despite this, when monitoring resumed in MI 11, records indicated she was still able to hunt successfully. The total amount of prey consumed by kills and 'increase in fullness' observations for this time frame, exceed the monthly energy requirement range. Monitoring data revealed that the cubs (*n* = 6) were present at the kills and were observed feeding on the carcasses from MI 12 onwards. Wild-born cheetah females are known to increase their prey consumption rate to meet the nutritional requirements of the dependant cubs (Schaller, 1968; Sievert, 2020). Therefore, the increase in monthly prey consumption, which was well above the maximum monthly energy requirement, was justified.

During this 10-month period (November 2020 - August 2021), a total of 54 monitoring observations occurred were body condition scores were obtained. Scores obtained for Khatu ranged between 3 to 6, with an overall average of 3.9. These body condition scores are shown in Figure 3.5.B. along with monthly prey consumption weights. A sharp rise in intake was seen from MI 8 to 10, as this was when she conceived her litter. Between MIs 8 to 13, Khatu had given birth and was lactating, and an increase in daily movement can be attributed to her decline in body condition during this time period. A reduced number of monitoring events during MI 14 to 17 resulted in a low number of body condition observations. Therefore, the monthly averages for prey consumption and body condition during this time period were not reliable. Despite this, her body condition and prey consumption rate still followed an overall trend, indicating the relationship between the two different analyses.

3.5.3. Jade (Sub-adult ♀, Mun-Ya-Wana Conservancy [Reserve 7])

Monitoring observations for Jade occurred over an eight-month period (November 2020 - August 2021). During this time period Jade's monitoring data revealed 17 prey consumption events, consisting of 8 kill observations, 7 'increase in fullness' observations and 2 supplement feeding events. The kill observations consisted of 2 different species; 75% impala and 25% nyala. Of the kills, 50% were classed as juveniles 12% subadult and 38% adult. Of these, 88% of all kills were of unknown sex, with one kill being identified as a

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female. Supplement feeding occurred twice in MI 3, where a total of 55.94 kg of meat was supplied. From MI 4 onwards, Jade did not receive additional supplement feed and was self-sufficient during the remainder of the study period. Seven 'increase in fullness' observations were noted in total, three during MI 1, one in MI 2 and 3, and twice during MI 7. On average Jade consumed 55.87 kg/month, ranging from a minimum of 9.35 kg/month (month 5) to a maximum 116.79 kg/month (month 3). These monthly prey consumption values are shown in Figure 3.5.C.

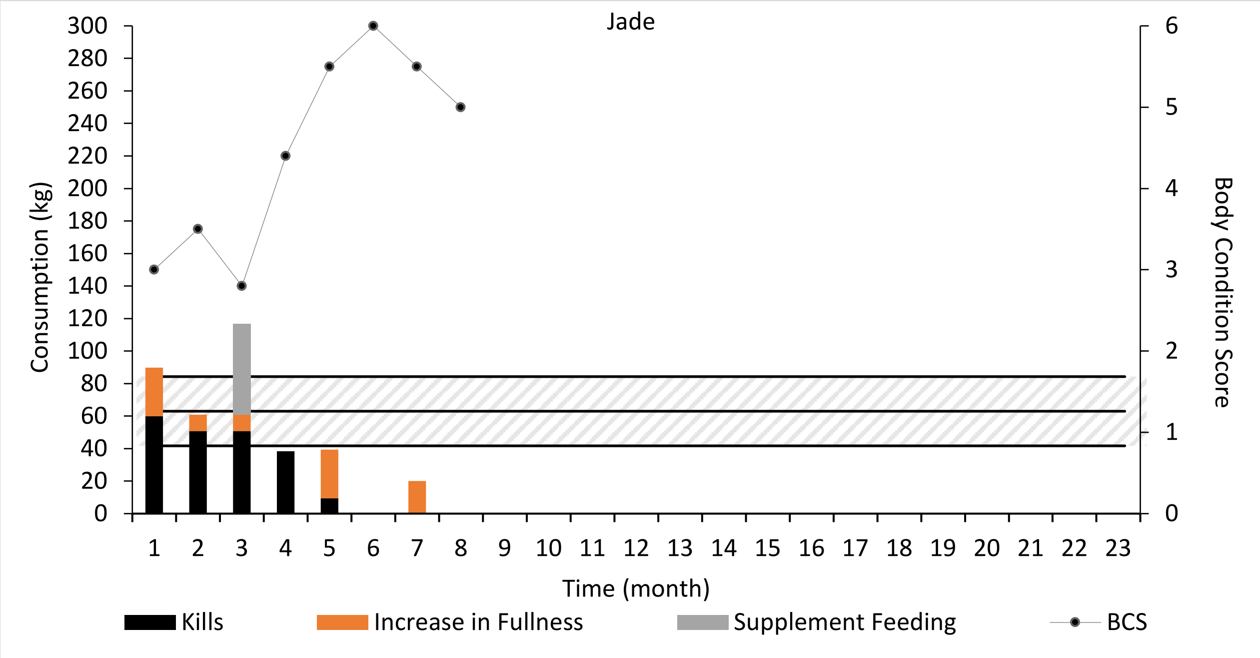

Figure 3.5.C. Jade's Prey Consumption (kg) and Body Condition Score

For MI 1 and 2, Jade's kill and 'increase in fullness' observations indicated that she consumed a total of 89.85 kg/month and 60.85 kg/month, respectively. These values indicate that she was consuming enough to remain within the range for monthly energy consumption. In MI 3, she received a substantial amount of supplement feed which equalled in weight the amount of prey she managed to kill that month (kills: 50.85 kg/month, supplement feed: 55.94 kg/month). Monitoring records indicated she had lost condition and the reserves management team made the decision to provide supplement feed. This was evident in the body condition scoring for MI 3 as there was a decrease in her score from the previous two months. MI 4 and 5 indicated that Jade was not reaching the minimum energy requirement for these respective months. During these MIs, few monitoring events occurred, therefore, the estimated monthly prey consumption does not provide an accurate representation for this time period. During MI 6, Jade was observed with a litter of cubs (n = 4) and monitoring was limited so as not to disturb the den site. As a result, no kills or 'increase in fullness' events were observed.

During this 8-month period (November 2020 - August 2021), a total of 41 monitoring observations occurred were body condition scores were obtained. Scores obtained for Jade ranged between 2.8 to 6, with an overall average of 4. These body condition scores are shown in Figure 3.5.C. along with monthly prey consumption weights. During the following MI, Jades body condition increased and continued to do so, despite her prey consumption not reaching the monthly minimum value. The reason for an increase in body condition was apparent as in MI 6, she was observed with a litter of cubs (*n* = 4). Her condition began to decrease again after giving birth as she was producing milk for her cubs. Jade was found dead at the beginning of August 2021 due to a predation event by lions.

3.5.4. Ivory (Adult ♂, Amakhala Game Reserve [Reserve 7])

Monitoring observations occurred for Ivory over a 23-month period (October 2019 - August 2021). During this time period Ivory's monitoring data revealed 84 prey consumption events, consisting of 43 kill observations, 33 'increase in fullness' observations, and 8 supplement feeding events. The kill observations consisted of 9 different species, with red hartebeest making up the bulk of these observations (51%). Sixty three percent of all observed kills fell in the juvenile weight class. The remaining kills observed were classified into the following weight classes; 9% subadult and 28% adult. Sex classes indicates a: 9% female and 7% male and 84% of unknown sex. Supplement feeding occurred four times between MI 1 and 2, and four times again in MI 23. During MI 1 a total of 101.70 kg was supplied while in MI 2, a total of 9.66 kg was supplied. From MI 3 onwards, Ivory did not receive additional supplement feed and was self-sufficient during the remainder of the study period. The supplement feeding that occurred in MI 23 totalled 0.6 kg and was used to administer medication and not as an energy source. Thirty-three 'increase in fullness' observations were noted in total. On average Ivory consumed 87.83 kg/month, ranging from a minimum of 40.50 kg/month (month 18) to a maximum of 200.72 kg/month (month 22). These monthly prey consumption values are shown in Figure 3.5.D. During MI 20, 21 and 23, few monitoring events occurred with only 9 records being captured in total

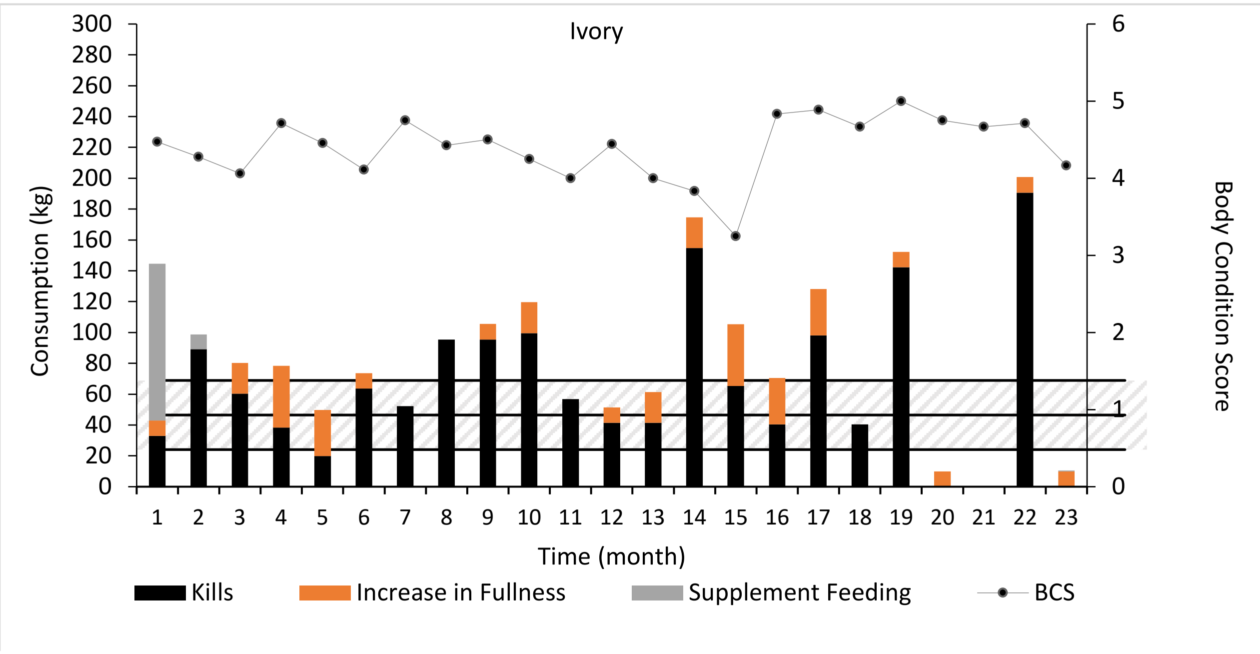

Figure 3.5.D. Ivory's Prey Consumption (kg) and Body Condition Score

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for these 3 MIs. Therefore, the monthly prey consumption estimated for MI 20, 21, and 23 does not provide an accurate representation for this time period.

For MI 1, Ivory's kills and 'increase in fullness' observations indicated that he consumed a total of 42.85 kg/month which does not meet the minimum monthly energy requirement. During this MI, Ivory was supplement fed receiving a total of 101.70 kg, which exceeded the maximum monthly energy requirement. During MI 2, Ivory's kills increased to 89.10 kg, and supplement feed for the month was only 9.66kg. From MI 2 onwards, Ivory did not receive additional supplement feed and was considered to be self-sufficient. Between MI 3 and 18, Ivory's monthly prey consumption fluctuated and only dropped below the minimum monthly energy requirement once (MI 18) while it went beyond the maximum energy requirement on seven occasions (MI 8, 9, 10, 14, 15, 17, 19). During the MIs where Ivory surpassed the monthly energy requirement, he mainly targeted adult or sub-adult prey species.

During this 23-month period (October 2019 - August 2021), a total of 484 monitoring observations were made where body condition scores were obtained. Scores obtained for Ivory ranged between 2 to 5, with an overall average of 5.0. These body condition scores are shown in Figure 3.5.D. along with monthly prey consumption weights. The monthly body condition scores fluctuated for Ivory, in a similar manner seen for Ivory's monthly prey consumption. Notably, Ivory's body condition score dropped after a month where high prey consumption occurred. Towards the end of month 14, Ivory was noted to have sustained an injury to his left front leg, which persisted for 2 weeks. This resulted in a sharp decrease in body condition in the following MI (MI 15). This pattern was observed again in MI 22 and 23, as ivory was observed with an eye injury which he received treatment for in MI 23. The MI prior to an observed decrease in body condition, usually associated with an injury, Ivory was observed targeting prey usually in the adult or subadult age category. The injuries ivory sustains could therefore be as a result of targeting larger prey species relative to his body size.

3.5.5. Alpha (Adult ♂, Ka'ingo Game Reserve [Reserve 6])

Monitoring observations for Alpha occurred over a 9-month period (November 2020 - August 2021). During this time period Alpha's monitoring data revealed 21 prey consumption events, consisting of 7 kill observations, 4 'increase in fullness' observations, and 10 supplement feeding events. The kill observations consisted of 3 different species, with impala making up the bulk of these observations (57%) with 71% of all observed kills in the adult weight class. The remaining kills observed were classified into weight classes, 15% subadult and 14% juvenile. Sex classes indicated 43% female, 28% male and 28% of unknown sex.

Supplement feeding occurred six times in MI 1, with a total of 170.10kg being provided for Alpha. This alone was double the maximum monthly energy requirement for an individual. During MI 2, supplement feeding was reduced to a total of 56.70kg. Between these 2-MI, Alpha and Jabez reduced their movements and thus home-range size decreased. Due to the excessive supplement feed they were provided with, the

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coalition did not explore further, but rather seemed to stay in the area where they were being fed. Monitoring events between MI 2 and 4 reduced to a total of 10 events over a 2-month period. Therefore, only three kill sites were observed and only two 'increase in fullness' events were recorded. Despite the lack of monitoring, supplement feeding still persisted, until MI 4. During MI 5 a dramatic increase in kill observations were noted, and the coalition were able to reach their monthly energy requirements without being supplement fed. During this MI, Jabez separated from Alpha and was killed. All kills from MI 6 onwards were therefore kills by Alpha. From MI 6 to 9, Alpha was observed reaching and surpassing his monthly energy requirements on two occasions (MI 6 and MI 9). During MIs 7 and 8, monitoring events were reduced and no kill sites were found during this time period. Therefore, the monthly estimated prey consumption does not provide an accurate representation for this time period.

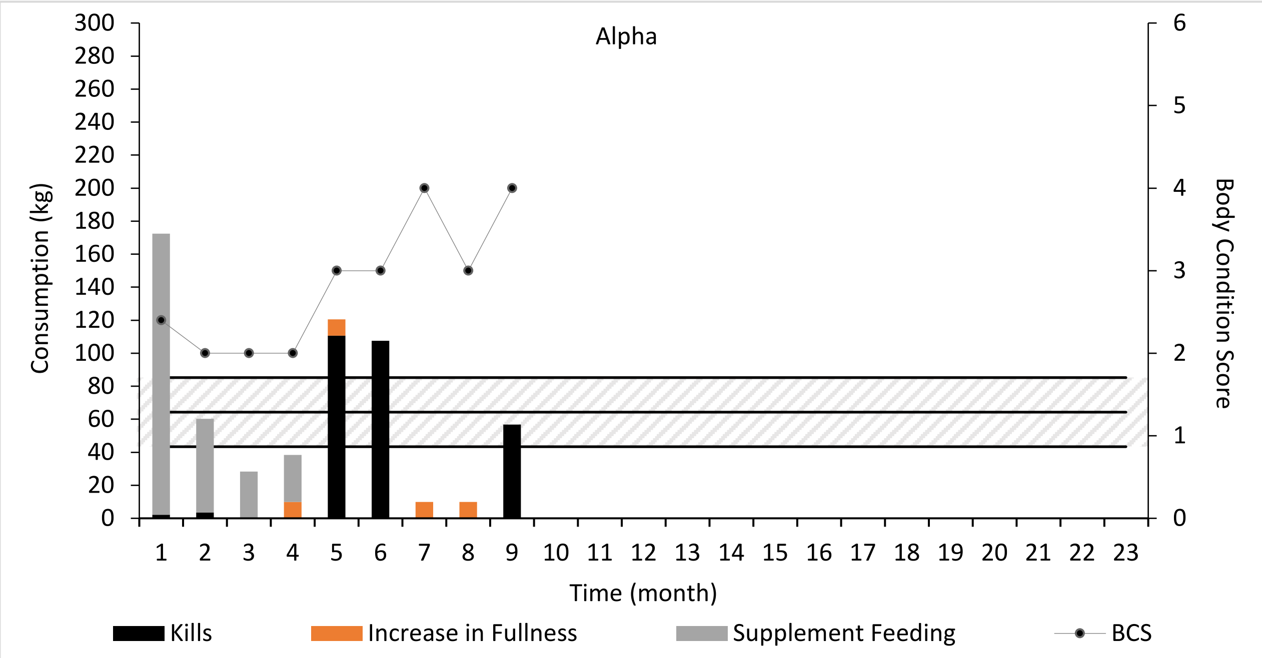

Figure 3.5.E. Alpha's Prey Consumption (kg) and Body Condition Score

During this 9-month period, a total of 33 monitoring observations occurred where body condition scores were obtained. Scores obtained for Alpha ranged between 1 to 4, with an overall average of 2.5. These body condition scores are visualized in figure 3.5.E long with monthly prey consumption weights. During the first 4 MI, the body condition for Alpha was low but increased when kill observations were noted. During the first 4 MIs, Alpha and Jabez received excessive supplement feeding and did not explore the reserve as seen with other male cheetah in the study. This is attributed to the feeding events that prevent the coalition from exploring an area as they had learnt to stay and wait for feed to be provided. When the supplement feeding stopped, the coalition was observed on kills, their body condition was seen to increased. Few monitoring events during MI 7 to 8 resulted in only a few records being obtained for Alpha's body condition. Therefore, his monthly average for prey consumption and body condition during this time period were not accurate.

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Despite this, his condition and prey consumption still followed an overall trend, indicating the relationship between the two different analyses (Figure 3.5.E.).

3.5.6. Jabez (Adult ♂, Ka'ingo Game Reserve [Reserve 6])

Monitoring observations occurred over a 5-month period for Jabez (November 2020 - April 2021). During this time period Jabez's monitoring data revealed 14 prey consumption events, consisting of 3 kill observations, 1 'increase in fullness' observations, and 10 supplement feeding events. The kill observations consisted of 3 different species; impala, kudu, and klipspringer. Supplement feeding occurred six times in MI 1, with a total of 170.10kg being provided for Jabez. This alone was double the maximum monthly energy requirement for an individual. During MI 2, supplement feeding was reduced to a total of 56.70kg. Between these 2-MIs, Alpha and Jabez reduced their movements and home-range size decreased. Due to the excessive feed they received, the coalition did not explore further, but rather seemed to stay in an area where they were being fed.

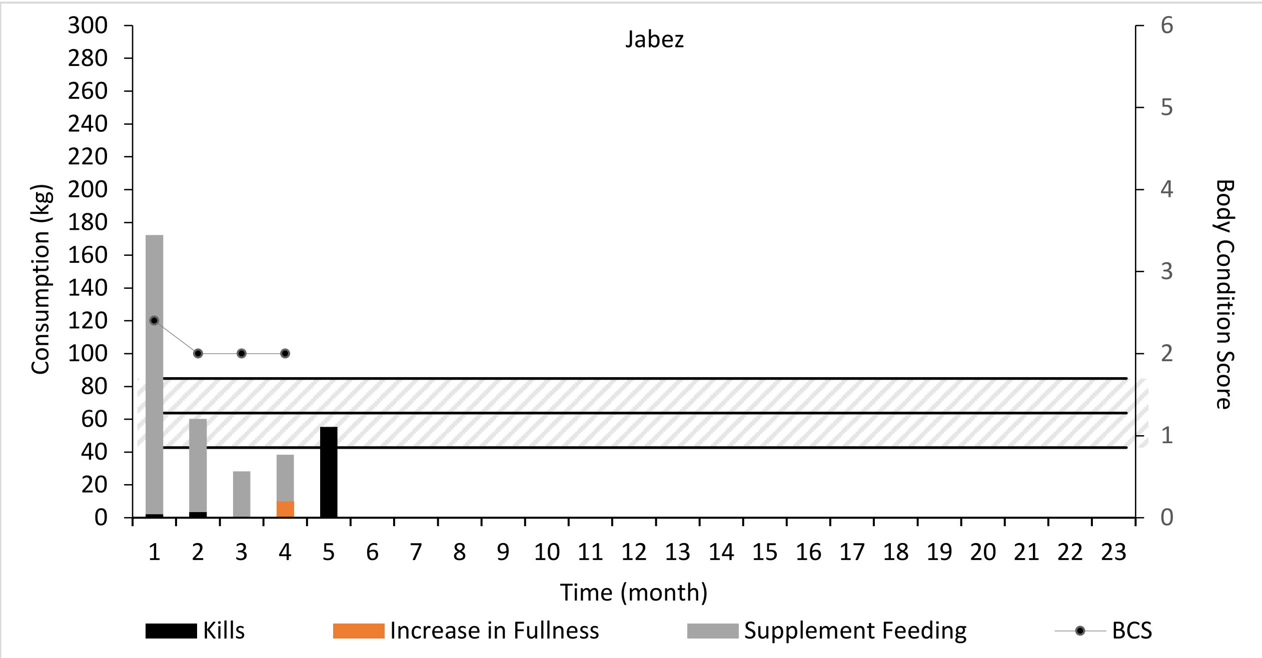

Figure 3.5.F. Jabez' Prey Consumption (kg) and Body Condition Score

During this 9-month period, a total of 23 monitoring observations occurred where body condition scores were obtained. Scores obtained for Jabez ranged between 1 to 3, with an overall average of 2.1. These body condition scores are shown in Figure 3.5.F along with monthly prey consumption weights. During the first 4 MI, the body condition for Jabez was low and stabilized at a low score. This can be linked to the excess supplement feed provided, as Jabez was not moving and maintaining a healthy body. The coalition received excessive supplement feeding and did not explore the reserve as seen with other male cheetah in the study. This is attributed to the feeding events that prevent the coalition from exploring an area as they had learned to stay and wait for food to be provided. When the supplement feeding stopped, the coalition was observed on kills. Despite this, Jabez was found dead in MI 5.

3.5.7. Storm (Sub-adult ♂, Magic Hills [Reserve 6])

Monitoring observations occurred over a 4-month period for Storm (May 2021 - August 2021), although data was only recorded for three of these MIs. During this time period Storm's monitoring data revealed 5 prey consumption events, all of which were kill observations. Eighty percent of kills were in the adult weight category, and 40% of kills were kudu. The remaining kills were a combination of springbok, impala, and waterbuck. These monthly prey consumption values are shown in Figure 3.5.G. During the 4-month study, only one body condition score was recorded for Storm, therefore body condition for this individual was not analysed.

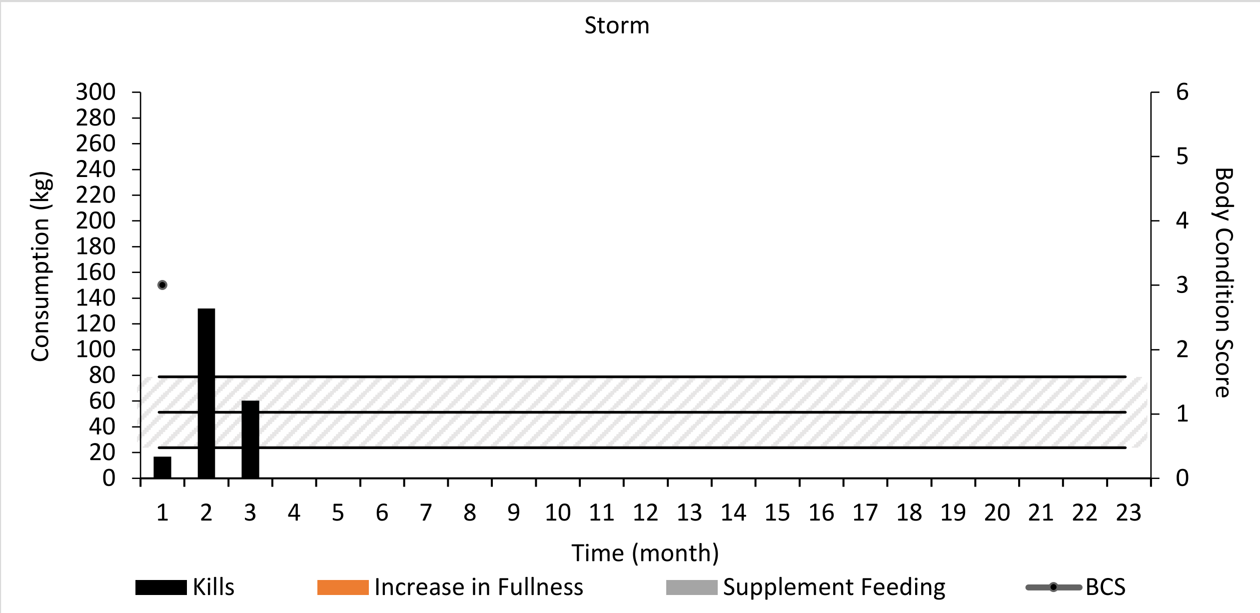

Figure 3.5.G. Storm's Prey Consumption (kg) and Body Condition Score

3.5.8. KC coalition (Four Sub-adult ♂s, !Khamab Kalahari Reserve [Reserve 5])

Monitoring observations occurred over a 4-month period for the KC coalition (May 2021 - August 2021). During this time period the KC coalition's monitoring data revealed 22 prey consumption events, consisting of 12 kill observations, 7 'increase in fullness' observations, and 3 supplement feeding events. The kill observations consisted of 5 different species, with gemsbok making up the bulk of these observations (33%) with 50% of kills in the subadult age category. The remaining kills observed were classified into weight classes, 16% juvenile and 33% adult, and 91% of all kills were of an unidentified sex. Supplement feeding occurred three times in MI 1 with a total of 24.29 kg for each individual. The KC coalition averaged 110.36 kg/month each, from a minimum of 75.49 kg/month (month 1) to a maximum of 151.11 kg/month (month 2). These

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monthly prey consumption values are shown in Figure 3.5.H. During this 4-month period (May 2021 - August 2021), a total of 50 monitoring observations occurred were body condition scores were obtained. Scores obtained for the KC coalition ranged between 3 to 4, with an overall average of 3.5. These body condition scores are shown in Figure 3.5.H. along with monthly prey consumption weights. The relationship between the body condition scores and prey consumption weights was apparent as they changed during the same time period.

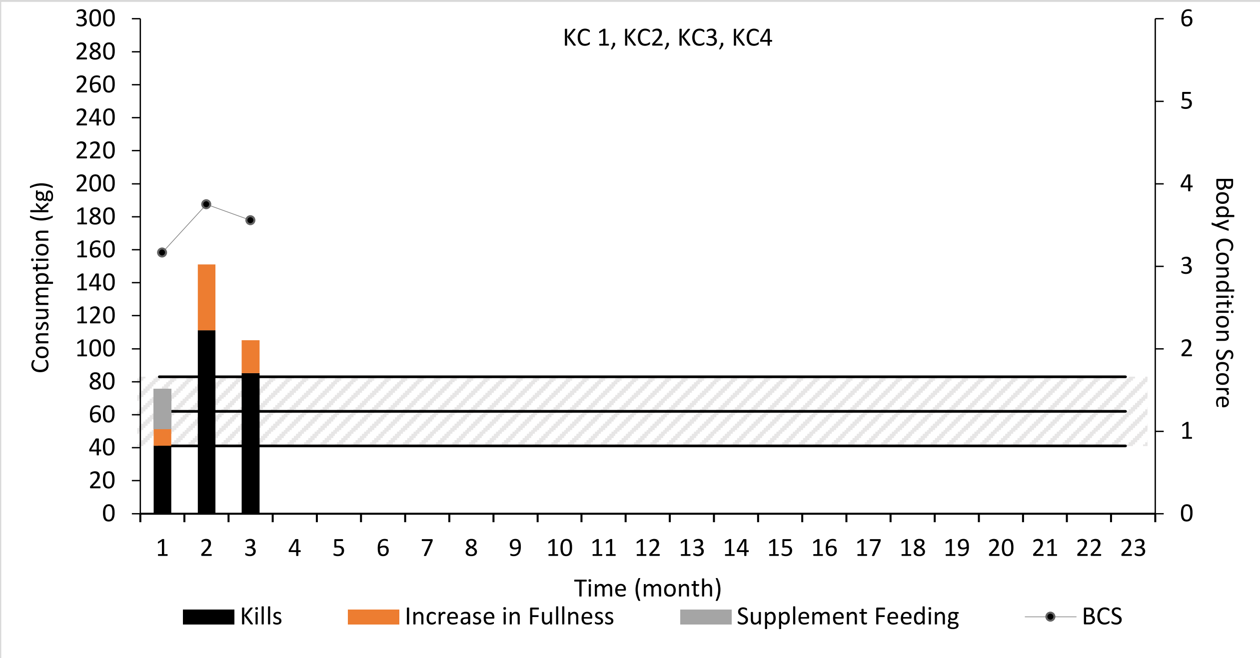

Figure 3.5.H. KC coalition Prey Consumption (kg) and Body Condition Score

3.6. Conclusion

Each individual was evaluated independently from one another to determine if the evaluation criteria was able to accurately identify periods of significant instability that could be linked to either a normal behavioural aspect (denning, injury etc) or if the period of instability required human intervention. By establishing if individuals qualified in each criteria, the success of both the individual and the use of the data analysis could be determined. Table 3.5. indicates if the criteria used in the individual evaluation was determined successful (S) or if the data analyses required attention (A), for each individual.

Of the original 12 captive-born cheetah that were released following a phased-release method, 9 were still alive by the end of the study period. All females had produced at least one litter of cubs (4 litters in total), of which one litter (*n* = 6) were still alive by the end of the study. Ivory was the only male to have fathered a litter of cubs (n = 2), with a wild-born female during this study period, who were both still alive by the end of the study. The mortalities that occurred during the study were as a result of: another cheetah attack (Josh), lion attack (Jade), and starvation due to an injury (Jabez).

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Table 3.5. Assessment of criteria used in the individual evaluation (S: successful; A: attention needed)

	Home-Range Estimates	**Home-range Overlap Estimates**	**Habitat Utilisation**	**Prey Consumption**	**Body Condition Score**
Ava	S	S	-	S	S
Khatu	S	S	S	S	S
Jade	A	A	S	S	S
Ivory	S	S	S	S	S
Alpha	S	S	S	A	A
Jabez	S	S	S	A	A
Storm	S	S	S	A	A
KC coalition	S	S	S	S	S

The monthly home-range estimates were established for all 11 individuals. The home-range estimates were accurate in determining significant changes for 5 individuals, while the remaining individuals were classified as stable during their study period. For Ivory and Alpha, the home-range estimates were able to classify significant monthly home-range changes that were associated with either an injury or could be explained due to event that occurred during the study. During denning events for 2 females, the home-range estimates identified these MIs as significant changes. However, one individual, Jade, had a denning event missed by this particular analysis. She was observed with cubs and a den site in MI 6 and the home-range analysis only classified MI 7 as being significant. Therefore, it did not accurately identify Jades monthly home-range. Home-range overlap estimates were established for all 11 individuals, and significant monthly changes were correlated to denning events for two females, and therefore was determined as natural behaviour as seen with wild-born individuals. However, Jade's den site was not found to be statistically different for her home-range overlap estimates, and therefore the home-range overlap analysis was not successful for identifying significant changes for Jade. Habitat utilisation estimates indicated that 10 individuals entered all available habitat at some point during the study period. This mainly occurred during the first few months after release when individuals were in an exploration stage. Females were seen to change habitat utilisation when denning occurred as the change in habitat utilisation correlates with a significant change in home-range estimates.

Prey consumption was established for all 11 individuals; however, the monthly values were influenced by the consistency of the monitoring records obtained from each reserve management team. Most individuals did not require supplement feeding after 4 months post release, with one or two supplement feeding events after this time period due to major events (i.e. first denning event). Therefore, if monitoring events occurred sporadically or did not achieve three monitoring per week, the estimates for both prey

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consumption and body condition were inaccurate. As a result, prey consumption and body condition scoring proved insufficient for three individuals. Despite this, the relationship between the two different analyses was evident and should be investigated further. It is noted that excessive supplement feeding influenced the accuracy of the prey consumption as individuals who were excessively fed did not appear to hunt during these MIs. Although a supplement feeding protocol had been developed, this was not followed accurately and can be seen in individuals Alpha and Jabez. The need to re-examine the current procedures and supplement feeding protocols should be further investigated.

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CHAPTER 4

Evaluation of phased-release reintroduction success: population-level

4.1 Introduction

To determine if the evaluation criteria (established in Chapter 2) were suitable for evaluating the overall process of phased-release reintroductions, the results obtained for each individual-based analyses (Chapter 3, above) were grouped according to sex and overall, to represent the phased-release process as a population of individuals (*n* = 12) across all reserves (*n* = 7). This allowed for comparisons to the literature with regards to wild-born cheetah as well as existing literature on other captive-born release attempts (of various phases). Aspects specifically considered were: 1) survival, breeding and demographic shifts, 2) post-release movement and home-range (HR) establishment, 3) habitat utilisation, and 4) prey consumption and Body Condition Scores (BCS), as multifaceted indices, and reasonable proxies for reintroduction success.

4.2. Population comparisons

4.2.1. Survival, breeding and demography

The Endangered Wildlife Trust (EWT) considers cheetah that are still alive two years post-relocation or have bred within this two-year period, a management success, as these individuals have either continued their genetic lineage or were able to provide sufficient tourism-based returns towards the survival of the species (EWT, unpublished). The cheetah in this study comprised 12 individuals and by the end of the study period, nine individuals (75%: $n_{females}$ = 2; n_{males} = 7) were still alive (August 2021). None of these individuals had yet been released for over a two-year period, so comparisons with the EWT wild-born management relocation success (56%, July 2020; EWT, unpublished)) cannot yet be determined. In (Houser *et al*., 2011), all three captive-raised cheetahs released through their soft-release rehabilitation programme, were killed by farmers within seven months of release. Of the six individuals released in (Maruping *et al*., 2011), following their soft-release method, three remained in the reserve for 20 months, two individuals died, and one was later removed as the individual was declared not suitable for release. Although it is too early to say if the phased-release individuals in the current study outperformed other captive-release individuals based solely on these mortality values, there is a positive sign as four individuals (Ava, Khatu, Ivory and Alpha) have been released for longer than seven months and at the end of the study were still alive.

Four of the released individuals in the current study, produced a total of 16 cubs in five litters (Jade [*n* = 4[†]], Khatu [*n* = 2[†],6], Ava [*n* = 2], Ivory [*n* = 2]), indicating a 33% breeding success for phased-release individuals (3 of 3 females, 1 of 9 males). By the end of the study (August 2021); six cubs (38%) were killed by competing

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predators within the first two months; two cubs (12%) dispersed at 8-months of age; and eight cubs (50%) were still alive, although none were classified as having reached independence yet. Figures from the EWT indicate that the breeding success of relocated wild-born cheetah was 51% in July 2020 (EWT, unpublished). Although the phased-release group has a lower breeding success, it must be noted that not all individuals have been released for a long enough period to consider this as an accurate estimation of the breeding success for phased-release individuals, and some male individuals were on reserves where no females were present during periods of this study. Moreover, wild-born release cheetah in the metapopulation are paired with potential mates in recipient sites to foster growth in the population, this was not the primary focus in these captive-born, phased-release individuals. Instead, these values should be interpreted in terms of time since release, because as mentioned above, none of the phased-release individuals had yet been released for over a two-year period.

4.2.2. Movement and home-range establishment

The average monthly HR size for females (n = 3) was estimated at 133.72 km^2 while the males (n = 8) had a larger average HR size estimate at 261.66 km^2 which is seen in wild-born cheetah (Broomhall *et al*., 2003; Marnewick & Somers, 2015). The change in monthly home-range size for females does not follow a uniform trend when shown as a group (Figure 4.2.A.). The initial increase in the first 2-Month Intervals (MIs) indicates an exploration period as previously demonstrated for wild -born cheetah (Weise *et al*., 2015). It must be noted that during MIs 4, 5, 7, and 10, denning events were observed which resulted in a decrease in HR size estimates for those individuals as seen in wild-born counterparts (Houser *et al*., 2009). All females conceived within the first four months post-release, when considering a gestation period of 90-95 days (Bissett & Bernard, 2011; Sievert, 2020). The HR size estimates for females after these denning events, can therefore be considered as settled or established HRs due to this breeding event success (Bissett & Bernard, 2007; Houser *et al*., 2009; Marker *et al*., 2018).

The average monthly HR size estimates for males decreased over the study period, from an initial large exploration period during the first 4 MIs to a reduced size towards the end of the study period (Figure 4.2.B.). All significant monthly changes (see individual-level HR establishment) were accounted for as either an exploration event or a behavioural event, such as a change in social structure as previously seen for wild-born cheetah (Durant, 2000; Marnewick & Somers, 2015; Weise *et al*., 2015).

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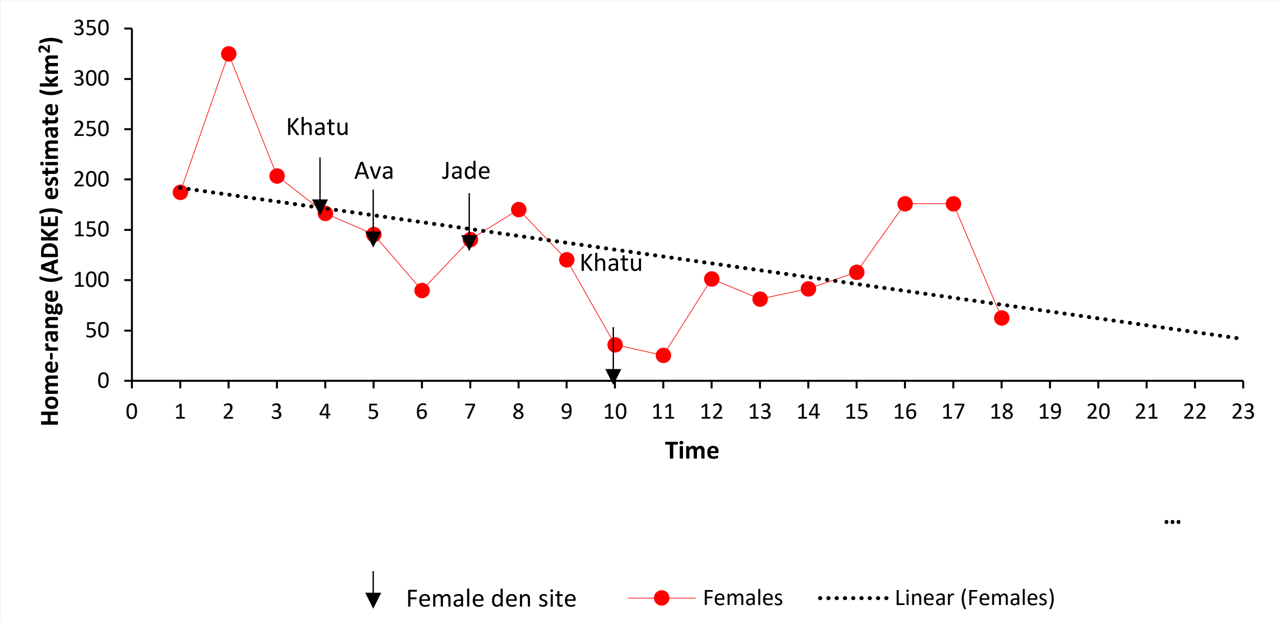

Figure 4.2.A. Average home-range estimates (95% CI) for all females

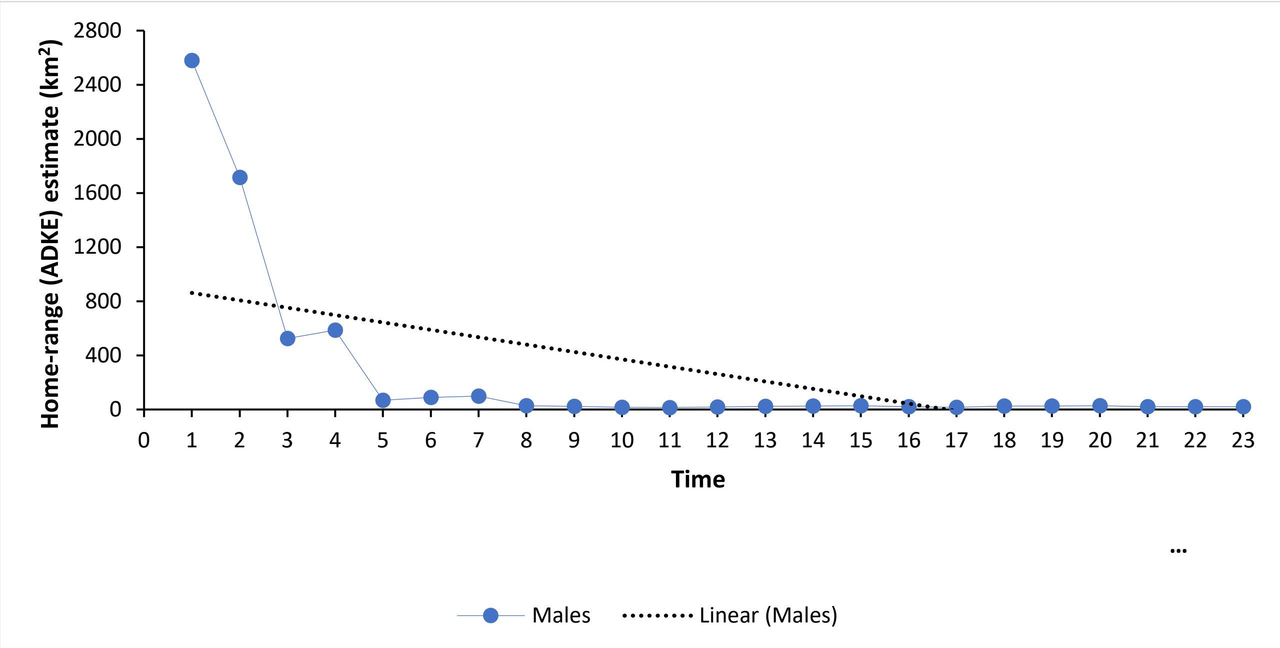

Figure 4.2.B. Average home-range estimates (95% CI) for all males

4.2.3. Habitat utilisation

Regarding habitat selection and utilisation, both males and females initially made use of all vegetation types available to them. Once the females had conceived, they specifically selected habitat within their respective reserves, during and potentially biased by the denning process. This occurred regardless of the reserve being a hard or soft reserve (presence or absence of predators respectively). It is known that denning site influences the survival of cubs as it not only provides protection against the elements but provides a safe area to avoid predators (Schaller, 1968; Laurenson, 1993; Bissett & Bernard, 2007; Sievert, 2020).

Of the four litters that were born to females during the study period (Jade [*n* = 4†], Khatu [*n* = 2†,6], Ava [*n* = 2]), two litters (Jade [*n* = 4†], Khatu first litter [*n* = 2†]), were killed by predators in the den site (leopard and lion, respectively). Khatu's second den site was established in a different area and these cubs (*n* = 6) were all still alive (18 months of age) by the end of the study period. The social structure for the males influenced the habitat utilised during each month as previously demonstrated for wild-born cheetah (Broomhall *et al.*, 2003; Bissett & Bernard, 2007) as seen by the individual male 'Alpha', who changed habitat utilisation after his coalition mate died, though, with limited observations, such trends are descriptive until this database is expanded upon, and active habitat selection can be modelled.

4.2.4. Prey consumption and body condition

Females (*n* = 3) consumed (including both kills and 'increase in fullness' events) on average 75.6 kg/month, while males (*n* = 8) were consuming (including both kills and 'increase in fullness' events) on average 71.3kg/month (Figure 4.2.C.), both within the monthly energy requirement ranges established in the literature for wild cheetah (Frame, 1999; Mills *et al.*, 2004; Lindsey *et al.*, 2011). The females were seen to consume slightly more prey, but this is attributed to the number of dependant cubs. Body Condition Scores (BCS) identified health concerns for some individuals and indicated other expected physical changes that followed natural event cycles (e.g., pregnancy driven BCS increase and loss in condition due to milk production).

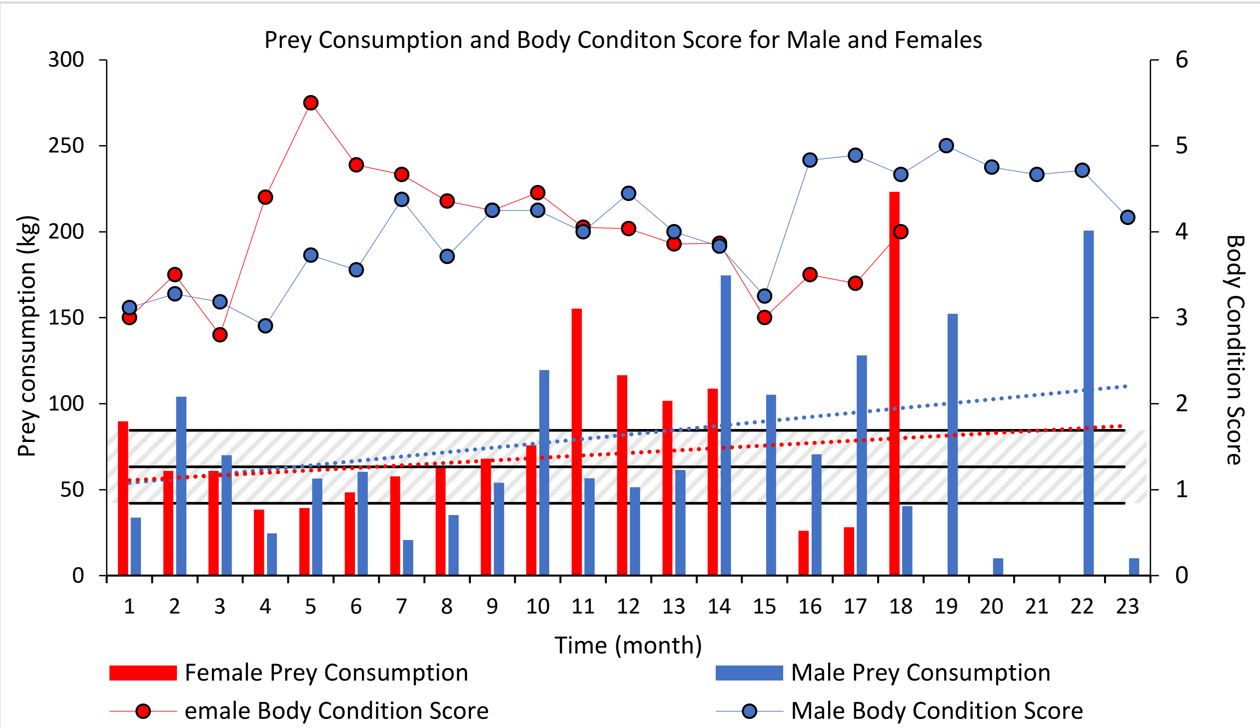

Figure 4.2.C. Prey Consumption (kills and 'increase in fullness' events) (kg) and Body Condition scores for males and females.

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Inconsistent monitoring during a few MI's resulted in some data collection being incomplete and therefore an accurate or effective analysis for some individuals was not possible and these values should be interpreted with caution (Ava [MI:12, 13, 14], Khatu [MI: 10, 14, 15, 16, 17], Jade [MI: 6, 7], Ivory [MI: 20, 21, 23], Alpha [MI: 2, 3, 4, 7, 8], Jabez [MI: 2, 3, 4], Storm [MI: 1, 2, 3, 4]). The excessive supplementary feeding observed for some individuals (Ava [MI: 7], Ivory [MI: 1], Alpha [MI: 1, 2, 3, 4], Jabez [MI:1, 2, 3, 4]), was also seen to affect the number of kills observed and altered BCSs during these periods.

4.5. Conclusion

In Chapter 3, it was determined to what extent the criteria for an evaluation of behavioural, spatial, and foraging ecology, proved successful on an individual level for these captive-born phased-release cheetah translocated into hard recipient reintroduction reserves. There were aspects of these indices (mostly monitoring effort and consistency) that needed attention to improve the overall reliability and value of the analysis. Overall, however, these evaluation criteria at least provided novel fine-scale information useful to adaptively managing these individuals or at most, provided evidence to support reintroduction success in captive-born phased-release cheetah into hard recipient reintroduction reserves. These criteria could therefore be considered for between group comparisons and to compare the success of the overall phased-release method to wild-born cheetah and other captive-release data.

Despite this, when comparing the overall phased-release method in terms of the criteria used to values obtained from wild populations, these criteria for reintroduction success indicated that, although complete success cannot be fully proven, the current trend seen in both individuals and between the two sexes is at least equivalent to those of wild-born cheetah. Furthermore, when comparing these results to the values of previous attempts to release captive cheetah, the criteria indicate that individuals that undergo a phased-release, can outperform individuals that undergo other release methods. Having said this, the data obtained for the phased-release individuals and population, are critically dependent on reliable monitoring data and strategic of supplementary feeding (Table 4.5.). Therefore, further investigation into prey consumption and BCS should be prioritized to ensure future real-time evaluation of the phased-release method, providing current and robust data to continue building this new conservation management tool.

Table 4.5. Assessment of the criteria to determine if they were successful/ indicated positive aspects (+) or if the data analyses required attention (A).

		Home-range	Home-range Overlap	Habitat Selection and Utilisation	Prey Consumption	Body Condition Score
Individuals	**Females**	+	+	+	+	+
	Males	+	+	+	A	A
Phased-Release Method		+	+	+	A	A

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CHAPTER 5

Research summary and management implications

5.1. Research findings

Variables used as criteria to determine or approximate ecological stability and therefore reintroduction success have shown to be valuable not only at an individual level, but also when applied to the entire population, beyond just captive-born phased-release individuals and for monitoring of any cheetah population (captive, metapopulation or wild). These criteria identified events that related to both natural processes (e.g., denning, temporary changes in behaviour such as courting or more permanent changes in social structure, including conflict and coalition shifts), as well as periods of instability where human intervention was needed (e.g., injury or other health concerns). These criteria further emphasise how success should be defined differently for distinct levels (i.e., individual versus reserve or population level). Therefore, to achieve overall success, individuals must succeed at each level throughout the identified stages of phased-release for the overall reintroduction to be considered successful. Accordingly, these definitions of success needed to be defined by behavioural, spatial, and foraging ecology of cheetah at these distinct levels.

5.2. Methods and limitations

During the study there were limitations due to the nature of multi-reporter observation-based research. The number of individuals included in the study was disproportionate in terms of sex ratios (females =3, males = 8), as well as by social groupings (i.e., singletons versus coalition groups). Although comparisons could be made between sex and groupings these must be interpreted with caution, and viewed as a possible early trend, rather than a set value defining a group or sex. Another limitation was the duration of the study (though monitoring is ongoing and should mitigate this concern in future evaluation), as 42% (*n* = 5/12) of individuals had only been released for a period of four months during the study period. Literature suggests that this timeframe could only exhibit exploration movement and not necessarily the establishment of home-ranges (HRs) (Weise *et al*., 2017). Prey consumption and Body Condition Scores (BCS) depend on accurate and consistent monitoring, as well as decisions made by reserve management regarding supplementary feeding. These analyses indicated that they could be useful, and they should be included in the overall evaluation of the programme, but the execution needs to be investigated to improve the strategic use of such intervention (both in timing and extent) by reserve management and monitoring teams. The traditional use of survival rate as a criterion to evaluate the success of a reintroduction program cannot be included at this stage, as the data does not allow for an accurate representation with regards to overall survival over

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time. This can only be considered when the offspring of the original study group reach sexual maturely and begin to reproduce themselves.

5.3. Management Implications

During the study, it was found that reserve management were concerned about the hunting ability of certain individuals and were providing supplementary feeding which exceeded individual daily consumptive requirements in some cases. Beyond concerns over the wasteful use of resources (e.g., cost, time, and welfare), this can negatively impact release programs, as individuals learned to stay within the area where they were being fed, which prevented natural exploratory behaviour and opportunistic hunting. A study by (Warmenhove *et al*., 2021) indicated that a five-day feeding interval for young, orphaned cheetah (±7.5 months of age) proved effective in ensuring sufficient feeding support. If hunting occurred within the five-day interval, the supplementary feeding was delayed. Therefore, we propose the use of a supplementary feeding protocol with individual-specific meat portions calculated and provided to ensure individuals meet their minimum daily calorific intake requirements as a function of literature-based recommendations and recent BCS trends. This is essential, as during this study it became apparent that some individuals were being fed beyond their necessary energy requirement which affected their observed BCS and offset potential kills during and immediately after supplementation. Therefore, the following calculation is proposed for future management intervention (Frame, 1999; Mills *et al*., 2004; Bissett and Bernard, 2007; Lindsey *et al*., 2011).

$$supplement\ feed\ amount = \frac{\big((number\ days\ without\ feed) \times 2.1\big)}{(weight\ consumption\ \%)}$$

To determine the appropriate amount of meat to provide to an individual, multiply the total amount of days without any feeding events by the standard daily energy requirements, 2.1. This value must be divided by the appropriate weight consumption percentage (see Chapter 2), to ensure the total amount of meat provisioned to an individual allows for them to consume enough to meet the energy requirements for the number of days they have been without food. To ensure this calculation is used correctly, the following protocol steps must be followed (Figure 5.4.). This protocol ensures in-depth evaluation and adaptive monitoring of the individual to ensure that supplementary feeding is based on the individual's physiological requirements, health, BCS and direct observed kill number (or lack thereof) during an intense monitoring period.

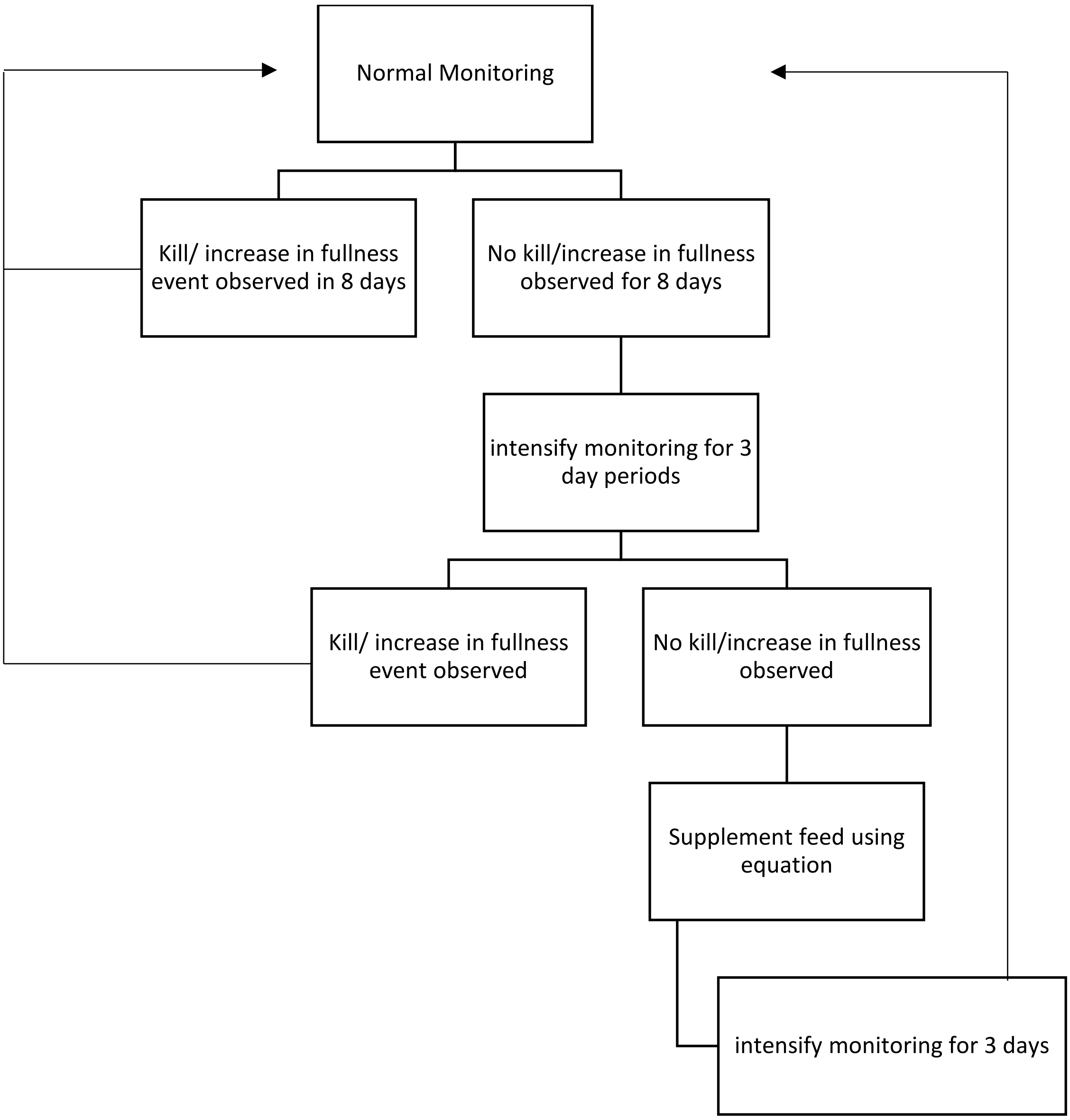

Figure 5.3. Supplementary feeding protocol

5.4. Recommendations

Further investigation and research are required to create an evaluation process that not only provides accurate and robust data for these analyses but ensures consistent and high-quality data collection as well. This will ensure that such adaptive monitoring is done effectively and is a reliable form of data collection for many individuals, but also as a metapopulation across many small, fenced reserves. The development and application of a minimum supplementary feeding intervention protocol will ensure that no individuals are fed wastefully at random, as the provisioned amount is calculated to meet individual needs, while maximising natural exploratory behaviour and opportunistic hunting fostered through phased-release. Through data-driven and individual need-based optimisation, this phased-release program ensures that captive-born individuals who progress though this release method are at least as well-equipped to survive in recipient metapopulation reserves as their wild- or metapopulation-born counterparts. This program can be used to

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provide injured wild individuals with an option to be returned to these populations through a process that is focused on evidence-based evaluation and phased-release that maximises the chances (within the bounds of reserve management capacity and control) of reintroduction success.

There are considerable costs and strict logistical needs that need to be met to replicate such phase-releases in cheetah and a cost-risk analysis is crucial to ensure such interventions can be conducted appropriately, successfully, and sustainably. The cheetah conservation community at large, do not expressly recommend such a venture be performed by any captive or semi-captive facility without substantial consultation with phased-release experts and organisations. The extensive financial means and logistical support required to carry out such captive-bred to metapopulation or wild recipient reserve reintroductions of cheetah to an ethical and sustainable level of welfare and ecological competency that will not compromise such efforts for other organisations committed to cheetah conservation. Finally, this will also allow a formal link to be established with the Cheetah Metapopulation Programme (CMP), bridging the gap between *ex-situ* and *in-situ* conservation for these carnivores, and providing the CMP with a new source of cheetah demographic and genetic variability to help maintain and grow the diversity of the metapopulation population.

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Appendices

Appendix 2.A. Game Count Survey for 2020/2021 of each game reserve in the study, obtained from each reserve.

Species	**Amakhala**	**Buffalo Kloof**	**Mount Camdeboo**	**!Khamab**	**Magic Hills**	**Ka'ingo**	**Mun-Ya-Wana Conservancy**
Aardvark					15		
Baboon troops			20		15	23	
Bat-eared Fox	3				15		
Black Wildebeest	24		122		16		
Black-backed Jackal	3	30	2		25	3	
Blesbuck	47	50	83		37		
Blue Wildebeest		100		3023	14	264	995
Bontebok		45					
Buffalo		278	15		28	75	396
Burchell Zebra	46	70	35	1786	73	429	866
Bushbuck		260			15	3	
Bushpig					30		
Cape Fox					10		
Cape Mountain Zebra			23				
Caracal		20			15		
Cheetah	4	3	1	15	2	1	23
Crocodile						17	
Duiker	2		4	346	50	14	
Eland	49	75	421	1097	199	1	
Elephant		present		15		29	117
Gemsbuck	14	12	127	2199	35	1	
Giraffe	22	200		148	31	54	170
Hippopotamus		10					79
Impala	62	650		3	56	885	4169
Klipspringer			9			3	
Kudu	4	350	98	50	218	241	200
Leopard				10			32
Lion				32		7	40
Mountain Reedbuck	2	65	2		10		
Nyala		185			10	12	3908
Ostrich		10	6		37		
Red Hartebeest	116	45	198	456	9		
Roan		40					
Sable		40	75		14	46	
Spotted Hyena				12		5	40
Springbuck	68	55	23	211	471		
Steenbuck					50	13	
Tesessebe						3	
Vaal Rhebuck			27				
Vervet Monkey					50		
Warthog	81	700	52	27	30	149	1800
Waterbuck	19	250	8	5	73	64	100
Wild dog				16			
Total	566	3543	1351	9451	1653	2341	12935

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Appendix 2.B. Monitoring Form supplied to each reserve management team

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Insert reserve logo here

[Insert reserve name]

Monitoring Form

ENDANGERED WILDLIFE TRUST

ASHIA CHEETAH CONSERVATION

DAILY MONITORING

General Information

Cheetah ID				Cheetah Sex	F	M
Cheetah Age	Cub	Sub-adult	Adult	GPS Coordinates		
Part of a Coalition	Yes	No		Coalition Members	(____) F	(____) M
Coalition Members ID						
Female with Cubs	Yes	No		Litter Size	(____) F	(____) M
Date				Time		
Section of Reserve				Name of Monitor		

Comments:

- *Mating Pair :*
- *Unusual Interactions :*

Vegetation

Biome	Savanna	Grassland	Thicket	Nama Karoo	Succulent Karoo	Fynbos
Habitat	Open Grass	Medium Bush	Thick Bush	Not Visible		

Weather

Clear Skies	Partly Cloudy	Overcast	Raining	
Calm	Slight Breeze	Strong Breeze	Windy	
Cold	Cool	Mild	Warm	Hot (______°C)

Cheetah Behaviour and Appearance

Behaviour Type

Position	Lying Down	Crouching	Sitting	Standing		
Activity	Still	Rolling	Walking	Pacing	Trotting	Running
General Behaviour	Resting	Vigilant	Playing	Searching	Hunting COMPLETE HUNT SECTION	Feeding COMPLETE KILL SECTION

Appearance

Body Condition Score	Score 1	Score 2	Score 3	Score 4	Score 5	Score 6	Score 7	Score 8	Score 9
Belly Index Score	Not eaten (1)	Empty-Hungry (2)	Full (3)	Just Eaten (4)					

Comments:

- *Note any injury :*

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CHEETAH KILL/ FEEDING SECTION

Carcass Information

Prey/ Kill Information				
Name Prey/ Kill Species				
Age of Animal	Juvenile	Sub-adult	Adult	Unknown
Sex of Animal	F	M	Unknown	
Location	In Open	Near Tree/ Bush	Under Tree/ In Bush	
Comments:				
Supplement Feeding (IF DONE)				
Species Provided		Carcass Portion Provided		
Slaughter/ Kill Method Used				
Age of Carcass When Supplied		Date and Time of Feeding		
Feeding Interval	1 – 3 days	5 – 7 days	9 – 11 days	unknown
Comments:				

Carcass Appearance

General Appearance								
Carcass Opened At	Groin	Rump	Stomach	Ribs	Armpit	Back	Neck/Head	Unknown
Carcass Percentage	Full Carcass	Half Carcass	Torso Only	Limbs Only	Unknown			
Strangulation								
Bite Marks	Neck / Head	Torso	Rear	Limbs	Not Present	Unknown		
Comments: - *Predators present (Y / N):*								

CHEETAH HUNT/ CHASE SECTION

Chase Details

Chase Abandoned After Short Distance	Y / N	Prey Successfully Brought Down	Y / N			
If Abandoned Tick Explanation	Seen by Prey	Prey Moved Off	Physical Exhaustion	Injury	Predator Interference	Other (explain below)
Rate Kill Technique	Accidental (1)	Beginner (2)	Practise (3)	Experienced (4)	NA	
Comments: - *Approx. distance run:* - *Duration of hunt:* - *Prey species targeted:* - *Predators / scavengers visible:*						

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Appendix 2.C. Prey species weight for different age categories (juvenile, subadult, and adult) as well as sex weight for adult category (Bissett and Bernard, 2007; Lindsey *et al*., 2011; Mills & Mills, 2014)

Species	**Unknown Sex**			**Male**	**Female**
	Juvenile	**Subadult**	**Adult**	**Adult**	**Adult**
Red Hartebeest	11.5	95.0	142.5	146.5	120.5
Klipspringer	1.0	7.8	11.6	10.0	13.3
Warthog	0.7	46.0	69.0	81.5	56.5
Mountain Reedbuck	3.0	20.0	30.0	30.0	24.8
Springbuck	3.8	25.0	37.5	40.0	35.0
Blesbok	6.5	43.7	65.5	70.0	61.0
Eland	29.0	215.5	600.0	740.0	460.0
Kudu	16.0	144.2	216.3	267.5	165.0
Impala	5.0	37.7	56.5	63.0	50.0
Plains Zebra	32.5	196.7	295.0	315.0	275.0
Blue Wildebeest	22.0	130.8	196.3	195.0	197.5
Grey Duiker	1.6	13.0	19.5	18.0	21.0
Springhare	0.3	1.9	3.4	-	-
Bushbuck	3.8	23.5	35.3	41.5	29.0
Bontebok	6.5	-	-	61.0	-
Nyala	4.9	57.0	85.5	109.5	61.5
Waterbuck	56.3	150.0	225.0	270.0	180.0
Scrub Hare	0.7	1.8	2.7	3.2	2.2
Gemsbok/Oryx	57.5	153.3	230.0	250.0	210.0

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Appendix 2.D. Body Condition Scoring Index developed for this study

Body Condition Scoring

Body Condition Scoring (BCS) is a visual evaluation of body fat reserves of an individual, and influence's performance, reproduction, and health. Thinness or fatness can be an indicator of underlying nutritional deficiencies, health problems, injury, or pregnancy. To ensure this tool is accurate, it must be used regularly and include behaviour and movement assessments. Images/videos alone are not enough to make a conclusive decision. This is not a hard-set rule but rather a comprehensive guide to help understand the overall condition of each individual.

The Body Condition Scoring Scale:

BCS uses a 9-point scale. A score of 1 indicates a very thin individual and a score of 9 indicates an excessively fat individual. The BCS scale focuses on six specific body areas: 1. neck, chest, and shoulders; 2. ribs; 3. abdominal tuck; 4. spine; 5. Tail head; 6. hind leg and pelvic area. Normal body conditions for individuals may range between scores (i.e. an individual may range between score 3 and 5). Changes that occur outside of this "normal range" could indicate a problem (i.e. pregnancy, lactating mother, disease, etc.).

How to use this index:

To assess an individual follow the steps below:

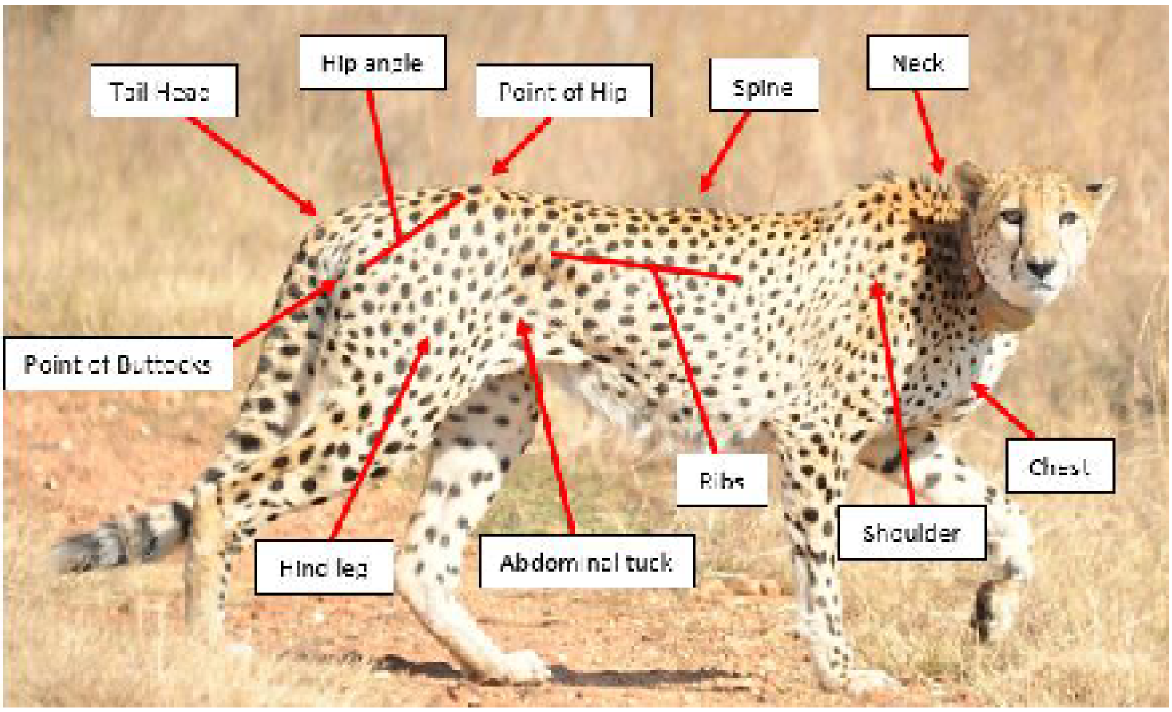
1. Ensure assessment is done from both the side and rear/front view.
2. Evaluate the hind leg and pelvic area, and tail head first, followed with the abdominal tuck and spine, lastly evaluate the ribs and neck, chest, and shoulders.
3. When evaluating a specific body section assign a score based on the description found in the BCS table solely based on that specific section's description. If a body section falls between two scores assign a half score (i.e. falls between score 3 and 4, score 3.5).
4. Re-evaluate the assigned scores including all body sections. This will allow for an overall average score to be determined. (i.e. if the majority of the body sections are a score 3, but one or two sections are scored a 4, the overall final score of the individual will be a 3).

Belly size:

Belly size is a different evaluation to Body Condition Scoring. Belly size estimation is part of training provided by the Serengeti Cheetah Project. Belly size is scored on an increasing scale from 1 to 14 where 1 is starvation, and 14 is a cheetah that looks like it has swallowed a basketball. The belly of a cheetah at size 8 neither goes in nor goes out but is smoothly in line with the cheetah's silhouette. In the absence of training, key points to note are that size 8 is hunting size thin - i.e. there is no bulge to the belly at all, and a cheetah will start to hunt at this point. Cheetahs with belly size less than 3 are rarely seen – with 5-8 being the 'hungry' norm, as cheetahs usually manage to find something to eat before they get too thin.

Supplied by Prof. Sarah Durant

Illustration of Focal Points used to determine BCS



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Score	Body Condition Scoring Table								
	1 – Extreme Low	2 – Very Low	3 – Low	4 – Moderate Low	5 – Moderate	6 – Moderate High	7 – High	8 – Very High	9 – Extreme High
Overall	Emaciated, skeletal appearance + poor coat condition	Minimal fat cover with muscle wastage	Lean, exaggerated limbs, poor muscling	Lean + muscular appearance	Lean + muscular appearance	Muscular in appearance	Fat present on inner thigh, hip, and stomach	Fat visible	Fat visible + no definition between shoulder-ribs-hip
Hind leg and pelvic area	Hip + buttocks points sharply prominent Femur + muscle wastage visible Concaved hip angle	Hip + buttocks points sharply prominent Femur visible + slight muscle wastage Concaved hip angle	Hip + buttocks points visible with slight covering Femur visible + thigh muscle obvious while walking Visible hip angle	Hip + buttocks points visible with some covering Femur slightly visible + thigh muscle obvious while walking visible hip angle	Hip + buttocks points slightly visible + round Femur not visible + obvious thigh muscle Rounded hip angle	Hip angle, hip + buttocks points are rounded, barely visible Rump has moderate fat covering	Hip angle, hip + buttocks points rounded + peaks not visible Rump has fat covering	Hip angle, hip + buttocks points well rounded and filled-in, peaks not visible Rump has excessive fat covering	Hips, hind legs, rump completely rounded + bulging in appearance Rump has excessive fat covering
Tail head	Tail head sharply apparent + tail bones visible	Tailhead visible, protrudes fully above hip + buttocks	Tailhead visible, protrudes above hip + buttocks	Tail head visible but blending smoothly into hip at tail base	Tail head slightly visible but is rounded in appearance	Tail head barely visible, blends smoothly into rump	Tail head not visible, blends continuously with hips	Tail head not visible, blends continuously with hips	Tail head not visible, blends continuously with hips
Abdominal tuck	Severe	Prominent	Prominent	Visible	Visible	Slightly visible	Not visible + abdomen rounded	Abdomen rounded	Abdomen bulging + fat hind leg
Spine	Individual vertebrae sharply visible	Vertebrae visible	Vertebrae visible + barely covered	Vertebrae covered + barely visible	Vertebrae not visible + smooth in appearance	Smooth, flat, in appearance	Smooth, flat, rounded in appearance	Smooth, wide, flat in appearance	Continuous with neck + shoulders + hip
Ribs	Ribs visible + no covering Sharp shoulder-ribs-hip transitions	Ribs visible + slight covering Sharp shoulder-ribs-hip transitions	Ribs not visible Obvious shoulder-ribs-hip transitions	Ribs not visible Obvious shoulder-ribs-hip transitions	Ribs rounded Smooth Shoulder-ribs-hip transitions	Ribs rounded Smooth shoulder-ribs-hip transitions	Ribs rounded with fat Continuous shoulder-ribs-hip transitions	Ribs rounded with fat Continuous shoulder-ribs-hip transitions	Ribs bulging with fat No distinct shoulder-ribs-hip transitions
Neck, chest, shoulders	Thin neck Hollow chest Muscle wastage at shoulders + visible bone structure	Thin neck Hollow chest Slight muscle wastage at shoulders + visible bone structure	Thin neck Slightly rounded chest Prominent Shoulder bones	Normal neck Slightly rounded chest Muscle definition + shoulder bones visible	Normal neck Rounded chest Muscle definition + shoulder bones visible	Thick neck Rounded chest Shoulder rounded + bones visible	Thick neck Bulging chest Shoulders bulging behind	Neck blending into shoulders Bulging chest Shoulders bulging behind	Neck blending into shoulders Bulging chest Shoulders bulging behind

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Appendix 3.A. Home-range (AKDE) estimates at 95% confidence interval for each individual in the study over month

Identity	ID	Model Type	DOF Area	DOF Bandwidth	Quantile	Area (km²)	Area Lower	Area Upper
Ava								
Ava_month01	1	OUF anisotropic	5.10	6.58	95	207.53	68.02	418.97
Ava_month02*	2	OUF anisotropic	12.19	19.55	95	23.39	12.57	37.36
Ava_month03*	3	OU isotropic	3.32	3.70	95	199.93	45.80	465.50
Ava_month04	4	OUF anisotropic	4.88	6.16	95	119.96	38.28	247.45
Ava_month05*	5	OUf anisotropic	94.30	125.54	95	4.92	3.97	5.96
Ava_month06*	6	OUF anisotropic	15.35	20.02	95	35.61	20.09	55.51
Ava_month07	7	OUF isotropic	1.91	1.89	95	240.61	26.97	682.67
Ava_month08	8	OU anisotropic	1.60	1.61	95	219.88	17.99	667.93
Ava_month09	9	OUF isotropic	3.13	3.95	95	44.16	9.53	104.83
Ava_month10	10	OUF isotropic	3.32	3.59	95	65.78	15.07	153.14
Ava_month11	11	OUF anisotropic	4.03	5.95	95	39.11	10.72	85.54
Ava_month12	12	OU isotropic	4.13	5.23	95	67.24	18.82	145.93
Ava_month13	13	OU anisotropic	7.98	6.62	95	65.24	28.13	117.69
Ava_month14	14	OUF isotropic	3.01	3.20	95	133.85	27.72	321.90
Khatu								
Khatu_month01	1	OU anisotropic	4.21	4.13	95	56.96	16.18	122.92
Khatu_month02	2	OU isotropic	4.26	5.35	95	76.97	22.09	165.48
Khatu_month03	3	OUF isotropic	4.83	5.48	95	83.98	26.59	173.80
Khatu_month04	4	OUF anisotropic	14.83	18.83	95	24.25	13.52	38.06
Khatu_month05	5	OUF isotropic	2.68	2.99	95	127.61	23.10	319.64
Khatu_month06	6	OUF isotropic	6.28	7.67	95	173.59	65.50	333.43
Khatu_month07	7	OU anisotropic	3.31	4.42	95	162.28	37.11	378.06
Khatu_month08	8	OUF anisotropic	2.31	2.57	95	203.05	30.35	536.43
Khatu_month09	9	OUF anisotropic	3.40	4.04	95	196.82	46.19	454.56
Khatu_month10*	10	OU anisotropic	54.37	72.48	95	6.16	4.64	7.91
Khatu_month11*	11	OUf anisotropic	67.49	78.56	95	11.37	8.82	14.23
Khatu_month12*	12	OU anisotropic	2.57	2.77	95	135.40	23.35	343.92
Khatu_month13	13	OUF isotropic	2.08	2.19	95	97.57	12.54	267.92
Khatu_month14	14	OU isotropic	3.62	4.28	95	49.32	12.29	111.60
Khatu_month15	15	OU isotropic	2.09	2.16	95	108.01	14.02	295.83
Khatu_month16	16	OU anisotropic	1.81	1.79	95	176.10	18.00	510.21
Khatu_month17	17	OU anisotropic	1.63	1.81	95	175.82	14.96	529.80
Khatu_month18	18	OU anisotropic	2.88	3.06	95	62.70	12.34	153.20
Jade								
Jade_month01	1	OUF anisotropic	1.83	2.02	95	297.26	31.19	856.19
Jade_month02	2	OUF anisotropic	1.37	1.40	95	874.60	51.94	2824.39
Jade_month03	3	OUF anisotropic	1.92	1.70	95	327.30	37.08	926.32
Jade_month04	4	OUF anisotropic	1.54	1.44	95	355.35	26.93	1096.12
Jade_month05	5	OU anisotropic	1.54	1.53	95	303.69	22.99	936.95
Jade_month06	6	OUF anisotropic	9.44	15.04	95	60.90	28.47	105.45
Jade_month07*	7	OUF anisotropic	22.82	34.17	95	17.99	11.38	26.08
Jade_month08	8	OU anisotropic	2.50	3.17	95	87.36	14.50	224.32
Josh								

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Josh_month1	1	OUF anisotropic	1.31	1.31	95	376.19	20.99	1228.42
Ivory								
Ivory_month01	1	IID anisotropic	36.39	37.00	95	15.53	10.90	20.96
Ivory_month02	2	OU anisotropic	27.33	25.27	95	12.12	8.01	17.07
Ivory_month03*	3	OUf anisotropic	16.51	15.78	95	4.60	2.65	7.06
Ivory_month04	4	OU anisotropic	29.37	25.28	95	3.61	2.42	5.02
Ivory_month05	5	IID anisotropic	4.23	30.00	95	5.38	1.54	11.59
Ivory_month06	6	OUf anisotropic	12.74	12.54	95	16.62	8.78	26.91
Ivory_month07	7	IID anisotropic	0.52	10.00	95	10.10	0.01	49.79
Ivory_month08	8	IID anisotropic	6.63	14.00	95	17.30	6.74	32.74
Ivory_month09	9	IID anisotropic	9.88	10.00	95	25.08	11.96	42.96
Ivory_month10	10	IID anisotropic	8.69	9.00	95	25.89	11.64	45.73
Ivory_month11	11	IID isotropic	12.00	13.00	95	14.65	7.57	24.03
Ivory_month12	12	IID anisotropic	22.00	23.00	95	18.38	11.52	26.81
Ivory_month13	13	OUf anisotropic	18.24	19.06	95	23.96	14.26	36.14
Ivory_month14	14	OUf anisotropic	19.97	18.85	95	25.19	15.38	37.38
Ivory_month15	15	OUf anisotropic	21.74	19.97	95	28.34	17.71	41.44
Ivory_month16	16	IID anisotropic	32.02	29.00	95	20.44	13.99	28.11
Ivory_month17	17	IID anisotropic	17.17	18.00	95	16.07	9.39	24.51
Ivory_month18	18	OUΩ anisotropic	10.15	11.10	95	26.06	12.57	44.36
Ivory_month19	19	IID anisotropic	12.74	13.00	95	25.21	13.32	40.83
Ivory_month20	20	IID anisotropic	10.09	11.00	95	27.64	13.30	47.13
Ivory_month21	21	IID isotropic	8.00	9.00	95	20.05	8.65	36.14
Ivory_month22	22	OUf anisotropic	6.93	7.50	95	21.68	8.66	40.56
Ivory_month23	23	IID anisotropic	10.97	9.00	95	21.24	10.59	35.53
Alpha								
Alpha_month01	1	OUF anisotropic	2.07	2.50	95	400.60	51.26	1101.17
Alpha_month02	2	OUF anisotropic	2.55	2.92	95	754.43	128.77	1921.93
Alpha_month03	3	OUF anisotropic	1.90	1.79	95	143.34	15.98	407.17
Alpha_month04	4	OUF anisotropic	1.91	1.92	95	402.18	45.33	1139.55
Alpha_month05	5	OUF anisotropic	5.45	7.83	95	90.50	31.22	180.77
Alpha_month06	6	OUF anisotropic	2.48	3.48	95	161.27	26.51	415.22
Alpha_month07	7	OUF anisotropic	3.68	3.91	95	186.79	47.26	420.41
Alpha_month08	8	OUF anisotropic	13.94	21.46	95	36.67	20.02	58.29
Alpha_month09	9	OUF isotropic	28.72	47.07	95	19.87	13.28	27.78
Alpha_month10*	10	OU anisotropic	33.26	58.85	95	6.57	4.53	8.98
Jabez								
Jabez_month01	1	OUF anisotropic	2.07	2.50	95	400.90	51.16	1102.76
Jabez_month02	2	OU anisotropic	2.55	2.92	95	754.37	128.76	1921.80
Jabez_month03	3	OUF anisotropic	1.90	1.79	95	143.32	15.98	407.10
Jabez_month04	4	OUF anisotropic	1.91	1.92	95	402.15	45.33	1139.48
Jabez_month05	5	OUF anisotropic	3.05	3.90	95	106.77	22.44	255.60
Storm								
Storm_month01	1	OUF anisotropic	19.20	21.09	95	136.88	82.65	204.56
Storm_month02	2	OUF isotropic	6.85	9.18	95	225.67	89.66	423.35
Storm_month03	3	OUF anisotropic	13.75	19.29	95	98.92	53.74	157.65

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Storm_month04	4	OU anisotropic	14.26	17.80	95	146.67	80.70	232.02
KC1								
KC1_month01	1	OU anisotropic	1.71	1.68	95	4751.93	440.73	14062.58
KC1_month02	2	OUF isotropic	1.80	1.95	95	2629.95	266.23	7635.98
KC1_month03	3	OU anisotropic	0.34	78.00	95	685.28	0.03	4118.18
KC1_month04	4	OUF isotropic	7.21	8.16	95	944.73	385.95	1749.28
KC2								
KC2_month01	1	OU anisotropic	1.67	1.64	95	4793.80	424.83	14323.87
KC2_month02	2	OUF isotropic	1.72	1.83	95	2769.72	260.00	8175.38
KC2_month03	3	OU anisotropic	0.38	79.00	95	680.28	0.08	3876.10
KC2_month04	4	OUF isotropic	7.72	8.85	95	916.71	388.46	1667.83
KC3								
KC3_month01	1	OU anisotropic	1.54	1.47	95	5149.07	389.04	15892.24
KC3_month02	2	OU isotropic	1.61	1.65	95	3033.65	250.29	9199.60
KC3_month03	3	IID anisotropic	80.87	108.00	95	704.92	559.70	866.64
KC3_month04	4	OUF anisotropic	5.46	6.45	95	977.97	337.58	1952.92
KC4								
KC4_month01	1	OUF anisotropic	1.53	1.45	95	4993.89	375.01	15431.83
KC4_month02	2	OU anisotropic	1.54	1.54	95	3550.80	269.91	10946.22
KC4_month03	3	OU isotropic	10.33	12.91	95	1746.75	849.26	2962.38
KC4_month04	4	OUF anisotropic	5.76	6.85	95	895.27	320.14	1760.90

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Appendix 3.B. Home-range (AKDE) estimate at 50% confidence interval for each individual in the study over month time period

Identity	ID	Model Type	DOF Area	DOF Bandwidth	Quantile	Area (km²)	Area Lower	Area Upper
Ava								
Ava_month01	1	OUF anisotropic	5.1	6.583	50	54.49	17.94	110.97
Ava_month02*	2	OUF anisotropic	12.189	19.551	50	5.74	3.09	9.2
Ava_month03*	3	OU isotropic	3.317	3.695	50	52.27	11.97	121.7
Ava_month04	4	OUF anisotropic	4.881	6.164	50	31.43	10.03	64.84
Ava_month05*	5	OUf anisotropic	94.304	125.536	50	0.48	0.39	0.59
Ava_month06*	6	OUF anisotropic	15.352	20.022	50	6.47	3.65	10.09
Ava_month07	7	OUF isotropic	1.906	1.886	50	55.27	6.19	156.81
Ava_month08	8	OU anisotropic	1.599	1.608	50	52.88	4.33	160.63
Ava_month09	9	OUF isotropic	3.129	3.95	50	9.95	2.15	23.62
Ava_month10	10	OUF isotropic	3.317	3.592	50	17	3.89	39.59
Ava_month11	11	OUF anisotropic	4.027	5.947	50	9.16	2.51	20.04
Ava_month12	12	OU isotropic	4.128	5.225	50	17.51	4.9	38.01
Ava_month13	13	OU anisotropic	7.981	6.62	50	16.53	7.13	29.81
Ava_month14	14	OUF isotropic	3.012	3.197	50	32.9	6.81	79.12
Khatu								
Khatu_month01	1	OU anisotropic	4.205	4.125	50	12.91	3.67	27.85
Khatu_month02	2	OU isotropic	4.257	5.35	50	19.84	5.69	42.65
Khatu_month03	3	OUF isotropic	4.829	5.476	50	19.57	6.2	40.51
Khatu_month04	4	OUF anisotropic	14.831	18.827	50	5.22	2.91	8.19
Khatu_month05	5	OUF isotropic	2.678	2.991	50	31.25	5.66	78.28
Khatu_month06	6	OUF isotropic	6.277	7.667	50	42.85	16.17	82.3
Khatu_month07	7	OU anisotropic	3.311	4.415	50	36.31	8.3	84.59
Khatu_month08	8	OUF anisotropic	2.308	2.568	50	46.98	7.02	124.1
Khatu_month09	9	OUF anisotropic	3.4	4.036	50	45.69	10.72	105.52
Khatu_month10*	10	OU anisotropic	54.374	72.476	50	0.9	0.67	1.15
Khatu_month11*	11	OUf anisotropic	67.488	78.559	50	1.48	1.15	1.86
Khatu_month12*	12	OU anisotropic	2.574	2.772	50	34.17	5.89	86.79
Khatu_month13	13	OUF isotropic	2.078	2.192	50	23.79	3.06	65.33
Khatu_month14	14	OU isotropic	3.619	4.281	50	12.57	3.13	28.43
Khatu_month15	15	OU isotropic	2.093	2.163	50	25.75	3.34	70.53
Khatu_month16	16	OU anisotropic	1.805	1.785	50	42.65	4.36	123.57
Khatu_month17	17	OU anisotropic	1.632	1.808	50	40.7	3.46	122.65
Khatu_month18	18	OU anisotropic	2.876	3.062	50	14.17	2.79	34.62
Jade								
Jade_month01	1	OUF anisotropic	1.832	2.02	50	69.97	7.34	201.53
Jade_month02	2	OUF anisotropic	1.373	1.402	50	201.32	11.96	650.13
Jade_month03	3	OUF anisotropic	1.918	1.703	50	77.48	8.78	219.28
Jade_month04	4	OUF anisotropic	1.539	1.438	50	81.33	5.42	221.06
Jade_month05	5	OU anisotropic	1.538	1.528	50	71.47	5.41	220.5
Jade_month06	6	OUF anisotropic	9.443	15.038	50	11.71	5.47	20.27
Jade_month07	7	OUF anisotropic	22.817	34.167	50	4.06	2.57	5.89

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Jade_month08	8	OU anisotropic	2.497	3.166	50	19.67	3.26	50.51
Josh								
Josh_month1	1	OUF anisotropic	1.337	1.305	50	85.84	4.79	280.32
Ivory								
Ivory_month01	1	IID anisotropic	36.385	37	50	3.8	2.67	5.14
Ivory_month02	2	OU anisotropic	27.33	25.268	50	2.35	1.56	3.31
Ivory_month03*	3	OUf anisotropic	16.509	15.778	50	0.81	0.47	1.25
Ivory_month04	4	OU anisotropic	29.365	25.283	50	0.53	0.35	0.73
Ivory_month05	5	IID anisotropic	4.233	30	50	0.76	0.22	1.63
Ivory_month06*	6	OUf anisotropic	12.735	12.542	50	3.44	1.82	5.57
Ivory_month07	7	IID anisotropic	0.521	10	50	2.71	0	13.34
Ivory_month08	8	IID anisotropic	6.63	14	50	3.66	1.43	6.93
Ivory_month09	9	IID anisotropic	9.88	10	50	6.65	3.17	11.4
Ivory_month10	10	IID anisotropic	8.69	9	50	7.03	3.16	12.42
Ivory_month11	11	IID isotropic	12	13	50	3.92	2.02	6.42
Ivory_month12	12	IID anisotropic	22.002	23	50	3.84	2.41	5.61
Ivory_month13	13	OUf anisotropic	18.242	19.063	50	6.4	3.81	9.66
Ivory_month14	14	OUf anisotropic	19.973	18.852	50	6.89	4.21	10.23
Ivory_month15	15	OUf anisotropic	21.737	19.971	50	5.2	3.25	7.6
Ivory_month16	16	IID anisotropic	32.019	29	50	4.71	3.22	6.48
Ivory_month17	17	IID anisotropic	17.174	18	50	3.3	1.93	5.03
Ivory_month18	18	OUΩ anisotropic	10.148	11.101	50	6.21	3	10.5
Ivory_month19	19	IID anisotropic	12.739	13	50	7.17	3.79	11.61
Ivory_month20	20	IID anisotropic	10.085	11	50	6.37	3.07	10.87
Ivory_month21	21	IID isotropic	8	9	50	5.43	2.34	9.78
Ivory_month22	22	OUf anisotropic	6.925	7.497	50	5	2	9.36
Ivory_month23	23	IID anisotropic	10.968	9	50	5.59	2.79	9.35
Alpha								
Alpha_month01	1	OUF anisotropic	2.073	2.501	50	90.55	11.59	248.9
Alpha_month02	2	OUF anisotropic	2.553	2.915	50	183.21	31.27	466.73
Alpha_month03	3	OUF anisotropic	1.9	1.792	50	35.85	4	101.83
Alpha_month04	4	OUF anisotropic	1.913	1.92	50	95.38	10.75	270.27
Alpha_month05	5	OUF anisotropic	5.454	7.83	50	23.71	8.18	47.36
Alpha_month06	6	OUF anisotropic	2.478	3.475	50	39.09	6.42	100.64
Alpha_month07	7	OUF anisotropic	3.68	3.905	50	49.43	12.51	111.25
Alpha_month08	8	OUF anisotropic	13.937	21.463	50	9.35	5.1	14.86
Alpha_month09*	9	OUF isotropic	28.716	47.071	50	3.34	2.23	4.67
Alpha_month10*	10	OU anisotropic	33.26	58.849	50	1.06	0.73	1.45
Jabez								
Jabez_month01	1	OUF anisotropic	2.069	2.5	50	90.58	11.56	249.17
Jabez_month02	2	OU anisotropic	2.553	2.915	50	183.19	31.27	466.69
Jabez_month03	3	OUF anisotropic	1.9	1.792	50	35.83	3.99	101.78
Jabez_month04	4	OUF anisotropic	1.913	1.921	50	95.35	10.75	270.16
Jabez_month05	5	OUF anisotropic	3.053	3.895	50	26.66	5.6	63.83
Storm								
Storm_month01	1	OUF anisotropic	19.196	21.086	50	27.48	16.59	41.07

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Storm_month02	2	OUF isotropic	6.854	9.178	50	48.94	19.44	91.82
Storm_month03	3	OUF anisotropic	13.751	19.289	50	26.6	14.45	42.4
Storm_month04	4	OU anisotropic	14.262	17.799	50	29.96	16.49	47.4
KC1								
KC1_month01	1	OU anisotropic	1.709	1.681	50	1138.83	105.62	3370.17
KC1_month02	2	OUF isotropic	1.795	1.951	50	586.97	59.42	1704.25
KC1_month03	3	OU anisotropic	0.337	78	50	161.71	0.01	971.81
KC1_month04	4	OUF isotropic	7.205	8.157	50	211.46	86.39	391.54
KC2								
KC2_month01	1	OU anisotropic	1.667	1.641	50	1147.49	101.59	3428.7
KC2_month02	2	OUF isotropic	1.72	1.828	50	620.18	58.22	1830.59
KC2_month03	3	OU anisotropic	0.379	79	50	162.77	0.02	927.43
KC2_month04	4	OUF isotropic	7.716	8.847	50	200.07	84.78	364
KC3								
KC3_month01	1	OU anisotropic	1.536	1.467	50	1224.1	92.49	3778.1
KC3_month02	2	OU isotropic	1.606	1.653	50	682.83	56.34	2070.69
KC3_month03	3	IID anisotropic	80.87	108	50	162.73	129.21	200.07
KC3_month04	4	OUF anisotropic	5.46	6.449	50	224.17	77.38	447.64
KC4								
KC4_month01	1	OUF anisotropic	1.532	1.448	50	1183.96	88.91	3658.62
KC4_month02	2	OU anisotropic	1.541	1.536	50	803.3	61.06	2476.37
KC4_month03	3	OU isotropic	10.325	12.907	50	420.81	204.6	713.67
KC4_month04	4	OUF anisotropic	5.76	6.845	50	202.19	72.3	397.69

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Appendix 3.C. Home-range (AKDE) overlap at 95% confidence interval

Identity	v1	v2	ID	CI low	Estimate	CI High
Ava						
	ava_month01	ava_month02	1	0.31	0.58	0.86
	ava_month02	ava_month03	14	0.31	0.68	0.97
	ava_month03	ava_month04	26	0.84	0.99	1
	ava_month04	ava_month05	37	0.18	0.37	0.63
	ava_month05	ava_month06	47	0.46	0.64*	0.8
	ava_month06	ava_month07	56	0.35	0.88	1
	ava_month07	ava_month08	64	0.94	1	1
	ava_month08	ava_month09	71	0.38	0.91	1
	ava_month09	ava_month10	77	0.5	0.94	0.98
	ava_month10	ava_month11	82	0.38	0.85	1
	ava_month11	ava_month12	86	0.22	0.64	0.97
	ava_month12	ava_month13	89	0.41	0.88	1
	ava_month13	ava_month14	91	0.35	0.82	1
Khatu						
	khatu_month01	khatu_month02	1	0.06	0.32	0.82
	khatu_month02	khatu_month03	7	0.45	0.89	1.00
	khatu_month03	khatu_month04	12	0.55	0.87	1.00
	khatu_month04	khatu_month05	16	0.44	0.77	0.98
	khatu_month05	khatu_month06	19	0.38	0.91	1.00
	khatu_month06	khatu_month07	21	0.35	0.84	1.00
	khatu_month07	khatu_month08	71	0.27	0.80	1.00
	khatu_month08	khatu_month09	1	0.78	0.99	1.00
	khatu_month09	khatu_month10	11	0.24	0.51*	0.81
	khatu_month10	khatu_month11	20	0.83	0.91	0.96
	khatu_month11	khatu_month12	28	0.28	0.67	0.98
	khatu_month12	khatu_month13	35	0.25	0.88	1.00
	khatu_month13	khatu_month14	41	0.57	0.96	1.00
	khatu_month14	khatu_month15	46	0.64	0.96	1.00
	khatu_month15	khatu_month16	50	0.66	0.99	1.00
	khatu_month16	khatu_month17	17	0.65	0.99	1.00
	khatu_month17	khatu_month18	55	0.39	0.92	1.00
Jade						
	jade_month01	jade_month02	1	0.41	0.98	1.00
	jade_month02	jade_month03	8	0.48	0.99	1.00
	jade_month03	jade_month04	14	0.52	1.00	1.00
	jade_month04	jade_month05	19	0.67	0.98	1.00
	jade_month05	jade_month06	23	0.48	0.96	1.00
	jade_month06	jade_month07	26	0.67	0.90	1.00
	jade_month07	jade_month08	28	0.08	0.68	1.00
Ivory						
	Ivory_month01	Ivory_month02	1	0.88	0.97	1.00
	Ivory_month02	Ivory_month03	2	0.72	0.90	0.99
	Ivory_month03	Ivory_month04	3	0.66	0.82	0.94

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	Ivory_month04	Ivory_month05	4	0.19	0.74	1.00
	Ivory_month05	Ivory_month06	5	0.54	0.91	1.00
	Ivory_month06	Ivory_month07	6	0.14	0.89	1.00
	Ivory_month07	Ivory_month08	7	0.19	0.98	1.00
	Ivory_month08	Ivory_month09	8	0.52	0.89	1.00
	Ivory_month09	Ivory_month10	9	0.93	1.00	1.00
	Ivory_month10	Ivory_month11	10	0.65	0.86	0.99
	Ivory_month11	Ivory_month12	11	0.60	0.75	0.88
	Ivory_month12	Ivory_month13	12	0.82	0.97	1.00
	Ivory_month13	Ivory_month14	13	0.93	0.99	1.00
	Ivory_month14	Ivory_month15	14	0.82	0.96	1.00
	Ivory_month15	Ivory_month16	15	0.82	0.95	1.00
	Ivory_month16	Ivory_month17	16	0.83	0.96	1.00
	Ivory_month17	Ivory_month18	17	0.72	0.93	1.00
	Ivory_month18	Ivory_month19	18	0.69	0.90	0.99
	Ivory_month19	Ivory_month20	19	0.71	0.92	1.00
	Ivory_month20	Ivory_month21	20	0.71	0.91	1.00
	Ivory_month21	Ivory_month22	21	0.70	0.90	1.00
	Ivory_month22	Ivory_month23	22	0.49	0.81	0.99
Alpha						
	alpha_month01	alpha_month02	1	0.55	0.89	1.00
	alpha_month02	alpha_month03	2	0.35	0.77	1.00
	alpha_month03	alpha_month04	3	0.27	0.93	1.00
	alpha_month04	alpha_month05	4	0.44	0.81	1.00
	alpha_month05	alpha_month06	5	0.31	0.80	1.00
	alpha_month06	alpha_month07	6	0.74	0.99	1.00
	alpha_month07	alpha_month08	7	0.45	0.80	0.99
	alpha_month08	alpha_month09	8	0.72	0.90	0.99
	alpha_month09	alpha_month10	9	0.74	0.87	0.97
Jabez						
	jabez_month01	jabez_month02	1	0.55	0.89	1.00
	jabez_month02	jabez_month03	2	0.35	0.77	1.00
	jabez_month03	jabez_month04	3	0.27	0.93	1.00
	jabez_month04	jabez_month05	4	0.44	0.86	1.00
Storm						
	storm_month01	storm_month02	1	0.78	0.98	1.00
	storm_month02	storm_month03	2	0.69	0.95	1.00
	storm_month03	storm_month04	3	0.81	0.96	1.00
KC1						
	KC1_month01	KC1_month02	1	0.58	0.95	1.00
	KC1_month02	KC1_month03	2	0.13	0.97	1.00
	KC1_month03	KC1_month04	3	0.23	0.94	1.00
KC2						
	KC2_month01	KC2_month02	1	0.60	0.96	1.00
	KC2_month02	KC2_month03	2	0.14	0.97	1.00
	KC2_month03	KC2_month04	3	0.25	0.94	1.00

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KC3						
	KC3_month01	KC3_month02	1	0.63	0.97	1.00
	KC3_month02	KC3_month03	2	0.25	0.77	1.00
	KC3_month03	KC3_month04	3	0.66	0.85	0.97
KC4						
	KC4_month01	KC4_month02	1	0.68	0.98	1.00
	KC4_month02	KC4_month03	2	0.53	0.96	1.00
	KC4_month03	KC4_month04	3	0.66	0.96	1.00

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Appendix 3.D. Habitat Utilisation for each individual in the study

Identity	Vegetation								
Khatu	Albany Mesic Thicket	Albany Valley Thicket	Bisho Thornveld	Grahamstown Grassland Thicket	Suurberg Quartzite Fynbos	Suurberg Shale Fynbos			
month 01	0.133	0.577	0.002	0.259	0.025	0.004			
month 02	0.073	0.679	0.002	0.246	0.000	0.000			
month 03	0.131	0.553	0.002	0.285	0.025	0.004			
month 04	0.148	0.699	0.000	0.153	0.000	0.000			
month 05	0.130	0.538	0.002	0.298	0.028	0.004			
month 06	0.145	0.508	0.002	0.311	0.030	0.004			
month 07	0.104	0.563	0.002	0.299	0.028	0.004			
month 08	0.156	0.596	0.002	0.221	0.024	0.002			
month 09	0.152	0.549	0.002	0.286	0.009	0.001			
month 10	0.000	0.572	0.000	0.329	0.092	0.008			
month 11	0.000	0.559	0.000	0.391	0.047	0.003			
month 12	0.161	0.533	0.002	0.277	0.025	0.003			
month 13	0.100	0.526	0.002	0.340	0.027	0.004			
month 14	0.075	0.664	0.002	0.259	0.000	0.000			
month 15	0.070	0.572	0.002	0.324	0.028	0.004			
month 16	0.051	0.571	0.002	0.341	0.031	0.004			
month 17	0.106	0.564	0.002	0.296	0.028	0.004			
month 18	0.129	0.531	0.002	0.310	0.025	0.004			
Jade	Bush Clump Thickets	floodplain Grasslands	Mixed Acacia Woodlands	Mixed Lebombo Woodland	Mixed Zululand Lowveld Savanna	Palm Veld	Riparian	Sand Forest	Sandveld Woodlands
month 01	0.030	0.042	0.073	0.143	0.238	0.158	0.050	0.001	0.264
month 02	0.071	0.053	0.109	0.104	0.104	0.196	0.037	0.001	0.326
month 03	0.131	0.005	0.189	0.214	0.134	0.121	0.070	0.001	0.135
month 04	0.099	0.030	0.140	0.155	0.114	0.142	0.056	0.001	0.263
month 05	0.082	0.040	0.116	0.133	0.164	0.148	0.049	0.001	0.267
month 06	0.095	0.000	0.109	0.323	0.373	0.002	0.099	0.000	0.000
month 07	0.035	0.000	0.035	0.382	0.423	0.003	0.121	0.000	0.000
month 08	0.139	0.000	0.151	0.315	0.300	0.001	0.094	0.000	0.000
Ivory	Grasslands	Karroid	Old Farm Lands	Riverine Thicket	Savanna	Thicket			
month 01	0.413	0.152	0.093	0.051	0.026	0.265			
month 02	0.413	0.152	0.093	0.059	0.024	0.260			

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month 03	0.430	0.166	0.078	0.065	0.026	0.235
month 04	0.467	0.129	0.087	0.073	0.015	0.229
month 05	0.462	0.188	0.083	0.069	0.014	0.183
month 06	0.428	0.146	0.093	0.059	0.024	0.250
month 07	0.437	0.148	0.081	0.056	0.023	0.255
month 08	0.482	0.166	0.066	0.039	0.015	0.232
month 09	0.397	0.150	0.087	0.048	0.030	0.288
month 10	0.397	0.151	0.091	0.052	0.026	0.283
month 11	0.389	0.184	0.089	0.082	0.016	0.240
month 12	0.426	0.141	0.082	0.057	0.026	0.268
month 13	0.413	0.163	0.074	0.051	0.027	0.272
month 14	0.405	0.166	0.077	0.053	0.026	0.273
month 15	0.394	0.154	0.098	0.060	0.028	0.267
month 16	0.410	0.161	0.085	0.056	0.023	0.265
month 17	0.429	0.143	0.088	0.057	0.025	0.259
month 18	0.393	0.154	0.084	0.060	0.024	0.285
month 19	0.406	0.143	0.112	0.043	0.032	0.264
month 20	0.418	0.153	0.076	0.058	0.023	0.270
month 21	0.408	0.136	0.075	0.053	0.029	0.299
month 22	0.390	0.135	0.101	0.065	0.027	0.281
month 23	0.431	0.171	0.077	0.041	0.025	0.255
Alpha	Central Sandy Bushveld	Waterberg Mountain Bushveld	Western Sandy Bushveld			
month 01	0.297	0.328	0.375			
month 02	0.243	0.218	0.539			
month 03	0.452	0.122	0.425			
month 04	0.228	0.285	0.486			
month 05	0.359	0.235	0.406			
month 06	0.463	0.252	0.285			
month 07	0.501	0.250	0.249			
month 08	0.500	0.000	0.500			
month 09	0.206	0.000	0.794			
month 10	0.000	0.000	1.000			
Jabez	Central Sandy Bushveld	Waterberg Mountain Bushveld	Western Sandy Bushveld			
month 01	0.298	0.327	0.375			
month 02	0.244	0.216	0.539			
month 03	0.485	0.131	0.383			
month 04	0.229	0.286	0.485			
month 05	0.392	0.214	0.394			
Storm	Great Fish Thicket	Sundays Thicket				

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month 01	0.395	0.605									
month 02	0.336	0.664									
month 03	0.396	0.604									
month 04	0.317	0.683									
KC1,KC2,KC3,KC4	Closed Woodlands on Calcretes	Closed Woodlands on Depressions	Closed Woodlands on Sands	Dense Woodlands on Calcretes	Dense Woodlands on Depressions	Dense Woodlands on Sands	Old Cattle Posts	Open Woodlands on Calcretes	Open Woodlands on Depressions	Open Woodlands on Sands	Pan Bottoms
month 01	0.001	0.003	0.179	0.002	0.006	0.177	0.002	0.007	0.022	0.599	0.004
month 02	0.001	0.003	0.274	0.002	0.005	0.190	0.002	0.005	0.014	0.503	0.001
month 03	0.000	0.003	0.227	0.002	0.005	0.192	0.002	0.004	0.015	0.549	0.001
month 04	0.001	0.003	0.242	0.002	0.005	0.195	0.002	0.005	0.015	0.530	0.001

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Appendix 3.E. Speed and Distance

Identity	Model Type	Speed			Distance			
		Speed (km/day)	Speed Lower	Speed Upper	Duration (months)	Distance Travelled (km)	Distance Travelled Lower	Distance Travelled Upper
Ava								
Ava_month01	OUF anisotropic	10.398	7.725	13.256	1.000	306.951	228.059	391.334
Ava_month02	OUF anisotropic		0	Inf	1.010		0	Inf
Ava_month03	OU isotropic		0	Inf	1.010		0	Inf
Ava_month04	OUF anisotropic	7.746	5.572	10.088	1.010	229.759	167.217	296.947
Ava_month05	OUf anisotropic	6.165	5.536	6.809	1.010	208.476	186.669	230.862
Ava_month06	OUF anisotropic	11.420	7.446	15.788	1.005	477.796	276.738	704.197
Ava_month07	OUF isotropic	3.501	2.998	4.022	1.010		Inf	
Ava_month08	OU anisotropic		0	Inf	1.010		0	Inf
Ava_month09	OUF isotropic	4.351	2.727	6.150	0.976	125.446	78.635	177.318
Ava_month10	OUF isotropic	5.501	3.200	8.091	1.009	163.894	95.323	241.044
Ava_month11	OUF anisotropic	3.705	2.400	5.142	1.008	110.234	71.398	152.980
Ava_month12	OU isotropic		0	Inf	1.007		0	Inf
Ava_month13	OU anisotropic		0	Inf	1.003		0	Inf
Ava_month14	OUF isotropic	6.194	4.516	7.996	1.010	184.791	134.727	238.553
Khatu								
Khatu_month01	OU anisotropic		0	Inf	1.011		0	Inf
Khatu_month02	OU isotropic		0	Inf	1.000		0	Inf
Khatu_month03	OUF isotropic	4.308	3.169	5.529	1.007	128.068	94.203	164.366
Khatu_month04	OUF anisotropic	8.265	6.439	10.199	0.980	239.090	186.263	295.024
Khatu_month05	OUF isotropic	6.679	5.294	8.140	1.011	199.353	158.003	242.971
Khatu_month06	OUF isotropic	6.085	5.008	7.211	1.007	180.934	148.924	214.424
Khatu_month07	OU anisotropic		0	Inf	1.007		0	Inf
Khatu_month08	OUF anisotropic	12.039	4.942	20.603	1.007	358.120	146.994	621.845
Khatu_month09	OUF anisotropic	9.113	5.146	13.602	1.007	270.919	152.994	404.389
Khatu_month10	OU anisotropic		0	Inf	1.007		0	Inf
Khatu_month11	OUf anisotropic	8.062	6.814	9.360	1.007	239.752	202.634	278.356
Khatu_month12	OU anisotropic		0	Inf	1.007		0	Inf
Khatu_month13	OUF isotropic	3.005	1.856	4.283	1.007	89.381	55.200	127.373
Khatu_month14	OU isotropic		0	Inf	1.007		0	Inf
Khatu_month15	OU isotropic		0	Inf	1.007		0	Inf
Khatu_month16	OU anisotropic		0	Inf	0.973		0	Inf
Khatu_month17	OU anisotropic		0	Inf	0.947		0	Inf
Khatu_month18	OU anisotropic		0	Inf	0.922		0	Inf
Jade								
Jade_month01	OUF anisotropic	12.198	11.531	12.875	1.002	360.811	341.082	380.810
Jade_month02	OUF anisotropic	12.669	12.063	13.283	1.015	379.690	361.515	398.082
Jade_month03	OUF anisotropic	13.566	11.917	15.267	1.016	406.866	357.388	457.884
Jade_month04	OUF anisotropic	13.973	11.793	16.242	1.015	418.694	353.367	486.660
Jade_month05	OU anisotropic		0	Inf	1.015		0	Inf
Jade_month06	OUF anisotropic	12.778	12.252	13.309	1.015	383.086	367.325	399.009

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Jade_month07	OUF anisotropic	30.946	20.714	42.133	1.015	927.116	620.562	1262.250
Jade_month08	OU anisotropic		0	Inf	1.015		0	Inf
Josh								
Josh_month1	OUF anisotropic	15.821	13.949	17.751	10.146	160.510	141.511	180.083
Ivory								
Ivory_month01	IID anisotropic		0	Inf	29.045		0	Inf
Ivory_month02	OU anisotropic		0	Inf	28.986		0	Inf
Ivory_month03	OUf anisotropic	1.638	1.276	2.021	28.562	46.780	36.446	57.721
Ivory_month04	OU anisotropic		0	Inf	28.020		0	Inf
Ivory_month05	IID anisotropic		0	Inf	27.892		0	Inf
Ivory_month06	OUf anisotropic	2.264	1.475	3.131	28.100	63.626	41.460	87.993
Ivory_month07	IID anisotropic		0	Inf	26.169		0	Inf
Ivory_month08	IID anisotropic		0	Inf	27.048		0	Inf
Ivory_month09	IID anisotropic		0	Inf	28.701		0	Inf
Ivory_month10	IID anisotropic		0	Inf	27.911		0	Inf
Ivory_month11	IID isotropic		0	Inf	28.120		0	Inf
Ivory_month12	IID anisotropic		0	Inf	26.959		0	Inf
Ivory_month13	OUf anisotropic	4.637	3.385	5.981	29.409	136.373	99.560	175.894
Ivory_month14	OUf anisotropic	5.536	4.024	7.161	29.045	160.795	116.878	207.988
Ivory_month15	OUf anisotropic	6.954	3.272	11.277	28.978	201.525	94.828	326.790
Ivory_month16	IID anisotropic		0	Inf	28.512		0	Inf
Ivory_month17	IID anisotropic		0	Inf	25.895		0	Inf
Ivory_month18	OUΩ anisotropic	3.849	2.064	5.889	27.866	107.242	57.513	164.114
Ivory_month19	IID anisotropic		0	Inf	28.368		0	Inf
Ivory_month20	IID anisotropic		0	Inf	24.856		0	Inf
Ivory_month21	IID isotropic		0	Inf	26.961		0	Inf
Ivory_month22	OUf anisotropic	2.093	1.379	2.877	25.955	54.330	35.791	74.665
Ivory_month23	IID anisotropic		0	Inf	14.994		0	Inf
Alpha								
Alpha_month01	OUF anisotropic	29.574	23.610	37.544	1.013	884.693	706.288	1072.591
Alpha_month02	OUF anisotropic		0	Inf	1.012		0	Inf
Alpha_month03	OUF anisotropic	3.751	2.928	4.769	0.995	110.220	82.239	140.121
Alpha_month04	OUF anisotropic	5.083	4.415	5.717	1.008	151.280	132.990	170.136
Alpha_month05	OUF anisotropic	6.849	5.770	8.096	1.012	204.685	169.038	241.952
Alpha_month06	OUF anisotropic	7.239	5.295	8.973	1.008	215.427	166.038	267.051
Alpha_month07	OUF anisotropic	9.420	5.807	13.230	0.999	277.955	176.251	390.386
Alpha_month08	OUF anisotropic	7.500	6.393	8.917	1.004	222.265	182.183	264.236
Alpha_month09	OUF isotropic	7.045	6.004	8.109	1.012	210.524	179.853	242.348
Alpha_month10	OU anisotropic		0	Inf	1.011		0	Inf
Jabez								
Jabez_month01	OUF anisotropic	29.574	23.610	37.544	1.013	884.693	706.288	1072.591
Jabez_month02	OU anisotropic		0	Inf	1.012		0	Inf
Jabez_month03	OUF anisotropic	3.751	2.928	4.769	0.995	110.220	82.239	140.121
Jabez_month04	OUF anisotropic	5.083	4.415	5.717	1.008	151.280	132.990	170.136
Jabez_month05	OUF anisotropic	6.849	5.770	8.096	1.012	204.685	169.038	241.952
Storm								

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storm_month01	OUF anisotropic	9.786	7.543	12.167	28.449	278.416	214.594	346.147
storm_month02	OUF isotropic	11.466	8.093	15.115	29.000	332.528	234.684	438.322
storm_month03	OUF anisotropic	8.688	6.424	11.111	29.375	255.209	188.719	326.398
storm_month04	OU isotropic		0	Inf	29.375		0	Inf
KC1								
KC1_month01	OU anisotropic		0	Inf	1.029		0	Inf
KC1_month02	OUF isotropic	14.473	9.434	20.012	1.029	439.616	286.553	607.867
KC1_month03	OU anisotropic		0	Inf	1.029		0	Inf
KC1_month04	OUF isotropic	8.816	7.461	10.224	0.995	258.957	219.175	300.320
KC2								
KC2_month01	OU anisotropic		0	Inf	1.029		0	Inf
KC2_month02	OUF isotropic	18.206	8.836	29.140	1.029	553.012	268.382	885.120
KC2_month03	OU anisotropic		0	Inf	1.029		0	Inf
KC2_month04	OUF isotropic	8.623	7.758	9.509	0.995	253.290	227.887	279.340
KC3								
KC3_month01	OU anisotropic		0	Inf	1.037		0	Inf
KC3_month02	OU isotropic		0	Inf	1.037		0	Inf
KC3_month03	IID anisotropic		0	Inf	1.037		0	Inf
KC3_month04	OUF anisotropic	12.050	10.041	14.145	1.003	356.978	297.480	419.055
KC4								
KC4_month01	OUF anisotropic	44.952	29.832	61.510	1.025	1360.491	902.898	1861.632
KC4_month02	OU anisotropic		0	Inf	1.041		0	Inf
KC4_month03	OU isotropic		0	Inf	1.039		0	Inf
KC4_month04	OUF anisotropic	11.981	9.234	14.896	1.016	359.429	277.015	446.892

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1 **Appendix 3.F.** Monthly weight consumption (kg) for each individual in the study

Identity	Kills	Increase in Fullness	Supplementary Feeding	Total month consumption
Ava				
Ava_month06	48.4	0	6.9	55.3
Ava_month07	75.3	20	20.7	116.0
Ava_month08	70.2	0	0.0	70.2
Ava_month09	43.2	0	0.0	43.2
Ava_month10	151.5	0	0.0	151.5
Ava_month11	174.9	10	0.0	184.9
Ava_month12	110.6	0	0.0	110.6
Ava_month13	14.4	0	0.0	14.4
Ava_month14	180.3	0	0.0	180.3
Khatu				
Khatu_month08	54.9	0	0.0	54.9
Khatu_month09	82.8	10	0.0	92.8
Khatu_month10	0	0	0	0.0
Khatu_month11	115.6	10	0.0	125.6
Khatu_month12	122.6	0	0.0	122.6
Khatu_month13	189.1	0	0.0	189.1
Khatu_month14	37.4	0	0.0	37.4
Khatu_month15	0	0	0	0.0
Khatu_month16	26.1	0	0.0	26.1
Khatu_month17	18.2	10	0.0	28.2
Khatu_month18	223.2	0	0.0	223.2
Jade				
Jade_month01	59.9	30	0.0	89.9
Jade_month02	50.9	10	0.0	60.9
Jade_month03	50.9	10	55.9	116.8
Jade_month04	38.4	0	0.0	38.4
Jade_month05	9.4	30	0.0	39.4
Jade_month06	0	0	0	0.0
Jade_month07	0.0	20	0.0	20.0
Ivory				
Ivory_month01	32.9	10	101.7	144.6
Ivory_month02	89.1	0	9.7	98.8
Ivory_month03	60.3	20	0.0	80.3
Ivory_month04	38.4	40	0.0	78.4
Ivory_month05	19.8	30	0.0	49.8
Ivory_month06	63.7	10	0.0	73.7
Ivory_month07	52.2	0	0.0	52.2
Ivory_month08	95.4	0	0.0	95.4
Ivory_month09	95.5	10	0.0	105.5
Ivory_month10	99.6	20	0.0	119.6
Ivory_month11	56.7	0	0.0	56.7
Ivory_month12	41.4	10	0.0	51.4
Ivory_month13	41.4	20	0.0	61.4

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Ivory_month14	154.7	20	0.0	174.7
Ivory_month15	65.3	40	0.0	105.3
Ivory_month16	40.5	30	0.0	70.5
Ivory_month17	98.2	30	0.0	128.2
Ivory_month18	40.5	0	0.0	40.5
Ivory_month19	142.3	10	0.0	152.3
Ivory_month20	0.0	10	0.0	10.0
Ivory_month21	0	0	0	0.0
Ivory_month22	190.7	10	0.0	200.7
Ivory_month23	0.0	10	0.6	10.6
Alpha				
Alpha_month01	2.3	0	170.1	172.4
Alpha_month02	3.5	0	56.7	60.2
Alpha_month03	0.0	0	28.4	28.4
Alpha_month04	0.0	10	28.4	38.4
Alpha_month05	110.6	10	0.0	120.6
Alpha_month06	107.6	0	0.0	107.6
Alpha_month07	0.0	10	0.0	10.0
Alpha_month08	0.0	10	0.0	10.0
Alpha_month09	56.7	0	0.0	56.7
Jabez				
Jabez_month01	2.3	0	170.1	172.4
Jabez_month02	3.5	0	56.7	60.2
Jabez_month03	0.0	0	28.4	28.4
Jabez_month04	0.0	10	28.4	38.4
Jabez_month05	55.3	0	0.0	55.3
Storm				
Storm_month01	16.9	0	0.0	16.9
Storm_month02	131.9	0	0.0	131.9
Storm_month03	60.3	0	0.0	60.3
KC1				
KC1_month01	41.2	10	24.3	75.5
KC1_month02	111.1	40	0.0	151.1
KC1_month03	85.1	20	0.0	105.1
KC2				
KC2_month01	41.2	10	24.3	75.5
KC2_month02	111.1	40	0.0	151.1
KC2_month03	85.1	20	0.0	105.1
KC3				
KC3_month01	41.2	10	24.3	75.5
KC3_month02	111.1	40	0.0	151.1
KC3_month03	85.1	20	0.0	105.1
KC4				
KC4_month01	41.2	10	24.3	75.5
KC4_month02	111.1	40	0.0	151.1
KC4_month03	85.1	20	0.0	105.1

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