Ecology and habitat suitability of Cape mountain zebra (*Equus zebra zebra*) in the Western Cape, South Africa

by

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Declaration

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Abstract

Endemic to South Africa, the Cape mountain zebra (*Equus zebra zebra*) historically occurred throughout the Western Cape, and parts of the Northern and Eastern Cape. However, due to human impacts fewer than 50 individuals remained by the 1950's. Conservation efforts over the past 50 years have resulted in the population increasing to over 4700 individuals and having moved on the IUCN red list, from Critically Endangered to Least Concern. As there are still many isolated meta-populations, CapeNature established a Biodiversity Management Plan for the conservation of Cape mountain zebra in the Western Cape. In 2001, 15 (six males and nine females) Cape mountain zebra was reintroduced into Bakkrans Nature Reserve, situated in the Cederberg Wilderness Area of South Africa. More than 17 years after the initial reintroduction, the species have persisted in this arid environment. No long-term monitoring has been carried out on this population of Cape mountain zebra. In this study, the demographics, diet, artificial waterhole dependency and habitat suitability of Cape mountain zebra was investigated.

Individual stripe pattern was used to determine Cape mountain zebra demographics. Driving transects and camera traps identified 21 unique individuals (100% of population) of which 19 were adults (90.4%) one was a yearling (4.8%) and one was a foal (4.8%). It was expected that the population would experience an initial lag in population growth where after it would rapidly increase; however, population growth is still very low. Adult Cape mountain zebra on the reserve currently exhibit an extremely male biased sex ratio of 1:0.27 (male:female). Population structure and organization does not display similarities to those of other well-established populations; however, a male biased population structure has been associated with other populations in the Western Cape. In addition, microhistology was used to determine the seasonal dietary preference of Cape mountain zebra. Results showed that Cape mountain zebra in Bakkrans Nature Reserve are mixed feeders as grass contributed to 41.5% of the annual diet, restios 16.4% and dicotyledons 29.3%. Leaf material was preferred annually, while stem, flower and inflorescence use increased during the wet season. Green grasses were preferred annually and were accepted >60% across all seasons.

Tallest swards were accepted during the late dry season and shortest in the late wet season.

Camera traps were used to study artificial waterhole dependency of Cape mountain zebra. Artificial watering points in the low lying areas were utilized more frequently due to more suitable habitat and higher zebra densities. Waterhole use was highest around dusk peaking at 19:00h and 20:00h. As seasons changed, Cape mountain zebra shifted their preference times to avoid intraspecific competition and accommodate for the earlier and later shifting of dusk. Finally, habitat suitability in Bakkrans Nature Reserve was analysed to determine how suitable the habitat is for a reintroduced population of Cape mountain zebra. Additionally, the suitability of three other reserves, Grootwinterhoek, Limietberg and Matjiesrivier Nature Reserves was tested for the potential reintroduction of Cape mountain zebra. Results confirmed that Bakkrans Nature Reserve has poor habitat suitability for Cape Mountain Zebra as scores were <10 and similar results were found for Matjiesrivier Nature Reserve. Furthermore, the Grootwinterhoek Nature Reserve is also of poor habitat for Cape mountain zebra. Of all the reserves, Limietberg Nature Reserve had the most suitable habitat.

Results from this study, have identified issues facing Cape mountain zebra conservation in Bakkrans Nature Reserve as well as the Western Cape and management recommendations were presented.

Opsomming

Histories, het die Kaapse berg sebra (*Equus zebra zebra*) regoor die Weskaap en dele van die noord en Ooskaap in Suid Afrika voorgekom. Alhoewel, as gevolg van impakte deur mense het hul nommers geval tot minder as 60 deur die 20ste eeu. Bewarings pogings oor die afgelope 50 jaar het teogelaat dat die populasie gegroei het tot meer as 4700 sebras en geskuif vanaf die IUCN rooi lys as Krities Bedreiged na Minste Bekommernis. Daar is steeds baie mata-populasies en as ‘n gevolg het CapeNature ‘n Biodiversitiet Bestuursplan opgestel vir die Bewaring van Kaapse bergsebras in die Weskaap. In 2001, was daar 15 (6 mannetjies, 9 wyfies) Kaapse bergsebras hervestig in Bakkrans Natuur Reservaat wat in die Sederberg Wildernes Area, Siud Afrika is. Meer as 17 jaar na die hervestiging, het die spesie sukksesvol voortduur in hierdie dorre omgewing. Voor hierdie studie, was daar geen lang termyn monitering gedoen op die Kaapse bergsebra populasie na die hervesiging. In die studie, kyk ons na die demografie, dieet, mensgemaakte watergat gebruik en habitat geskiktheid van die Kaapse bergsebra.

Individuele streep pattroon was gebruik om Kaapse bergsebra demografie te bepaal. Ry transeksies en kamera lokvalle het 21 unieke sebras identifiseer (100% van populasie) waarvan 19 volwassenes was (90.4%), 1 ‘n jaaroud was (4.8%) en 1 ;n vul was (4.8%). Dit was verwag dat die populasie ‘n stadige groei sal ondervind na die hervestiging en daarna vinneg sal groei; alhoewel, populasie groei is nogsteeds stadig. Volwasse Kaapse bergsebras op die reservaat uitstallig ‘n manlike vooroordeling van 1:0.27 (manlike:vroulik). Populasie struktuur en organisasie wys nie ooreenkomste tussen ander sebra populasies nie; alhowel, daar is ander studies wat ook ‘n manlike vooroordeel beskryf in ander Weskaapse populasies. Daarbenewens, mikrohistologiese toetse was gebruik om die seisoenlike dieet van Kaapse bergsebras te bepaal. Resultate het gewys dat Kaapse bergsebras op Bakkrans Natuur Reservaat mengsel eters is. Gras het bygedra tot 41.5% van die jaarlikse dieet, restios 16.4% en kleiner bossies 29.3%. Blaar materiaal was verkies deur al die seisoene, terwyl stingel, blom en bloeisel gebruik vermeerder het gedurende die nat seisoen. Groen grasses was verkies reg deur die jaar en >60% in elke seisoen. Langste grasses was verkies in die laat droe seisoen en kortste in die laat nat seisoen.

Kamera lokvalle was gebruik om die watergat afhanglkikheid van Kaapse bergsebras te bepaal. Watergate in die lealiggende areas was die meeste gebruik as gevolg van geskikte habitat ‘n hoer digtheid van sebras. Watergat geruik was hoogste rondom skemer, met spitstye om 19:00 en 20:00. Soos seisoene verander, het Kaapse bergsebras hulle voorkeur tye geskuif om intraspesifieke kompetisie te vermy en te akkommodeer vir die vooruit en agteruit skuif van skemer. Finaal, het ons gekyk na die habitat geskikbaarheir van Kaapse bergsebras in Bakkrans Natuur Reservaat. Daarbenewens, het ons ook die habitat geskiktheid getoets in drie ander reservate naamlik Grootwinterhoek, Limietberg and Matjiesrivier Natuur Reservaat vir die potensiele hervestiging van Kaapse bergsebras. Resultate het bevestig dat beide Bakkrans Natuur Reservaat en Matjiesrivier Natuur Reservaat swak habitat het vir Kaapse bergsebras as gevolg van die habitat geskiktheid indeks toetse wat <10 was. Van al die reservate, het Limietberg Natuur Reservaat die mees geskikte habitat vir die hervestiging van Kaapse bergsebras terwyl Grootwinterhoek Natuur Reservaat ook slegte habitat het.

Gebasseer op die vindings van hierdie studie, is kwessies in die bewaring van Kaapse bergsebras in Bakkrans Natuur Reservaat en die Weskaap geidentifiseer en bestuursplanne was aanbeveel.

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General introduction and thesis outline

1.1 Introduction

Due to notable increases in global human population numbers over the past few decades, the amount of available habitat for wildlife has decreased (Tittensor *et al*., 2014). By the year 2050 the total global population is expected to reach an all-time high of 9 billion people, whilst it is expected that most African countries will double their total population numbers by that time (Hoare, 2001). These population increases have led to the expansion of urban settlements that are compromising many wildlife species and the natural habitats they historically occurred in, through pollution, habitat loss and fragmentation (Hoare, 2001; Mateo-Thomas *et al*., 2012). In South Africa, protected areas are conserved through fencing (Lindsey *et al*., 2012); however, increased fencing is threatening the long term survival of wildlife species in conservation areas as migratory routes are disrupted, resources become limited and ecological islands are formed (Newmark, 2008; Hayward & Kerley, 2009; Cumming, 2010). Such ecological islands lead to the disruption of gene flow between populations and an increased risk of inbreeding (Caughley, 1994; Ferguson & Hank, 2010). Smaller reserves are also at risk due to the edge effects of artificial boundaries as this places increased pressure on biodiversity through biotic and physical changes (Laurance *et al*., 2007; Newmark, 2008). Thus, there is a need to identify species and areas for the conservation of endemic wildlife.

Zebras, as a species, (*Equus zebra*) are one of the most widespread herbivores across Africa, playing a key role in the maintenance and well-being of habitats (Hack *et al*., 2002). However, zebra species, such as plains zebra (*Equus quagga*), have experienced significant declines in population numbers over the past 100 years (Moehlman *et al*., 2016). Endemic to South Africa, large numbers of Cape mountain zebra (CMZ) (*Equus zebra zebra*) historically occurred throughout the Western, Northern and Eastern Cape provinces (Skead *et al*., 2007; Smith *et al*., 2007; Watson & Chadwick, 2007; Weel *et al*., 2015; Birss *et al*., 2016). Due to human impacts, CMZ numbers plummeted to less than 50 individuals by the 1950's as the species was confined to just three protected areas (Penzhorn, 1982; Kerley *et al*., 2003; Skead *et al*., 2007; Smith *et al*., 2007; Hrabar *et al*., 2015; Weel *et al.,* 2015; Kotze *et al*., 2019). These areas included the Mountain Zebra National Park (MZNP), Kammanassie Nature Reserve (KNR) as well as the Gamka Mountain Nature Reserve (GMNR) (Novellie *et al*., 2002, Watson *et al.,* 2005; Smith *et al*., 2007; Watson & Chadwick, 2007). The cause of this drastic decline was a combination of over hunting, loss of suitable habitat and competition with livestock as farmers expanded their properties (Millar, 1970; Friedman & Daly, 2004; Smith *et al*., 2007). As a result, the Mountain Zebra National Park was established in an attempt to conserve the CMZ species (Novellie *et al*., 2002; Sasidharan, 2006 Smith *et al*., 2007) and by the 1980's population numbers were high enough to allow for the re-introduction of this species in 25 newly identified conservation areas. Population numbers slowly increased as the Karoo National Park and seven other smaller nature reserves (4 within the Eastern Cape and 3 within the Western Cape) experienced positive population growth; with some reserves reaching increases of up to 25% from 1980 to 1995 (Novellie *et al*., 2002; Watson *et al*., 2005; Hrabar & Kerley, 2013; Birss *et al*., 2016). Despite the initial increase, CMZ population numbers were still extremely low and the species was placed on the IUCN red list as critically endangered (IUCN, 2000) as well as on Appendix I of the Convention of International Trade in Endangered Species (CITES) (Novellie *et al*., 2002; Birss *et al*., 2016). A conservation management plan was then compiled in an attempt to save the species from extinction (Smith *et al*., 2007). With the help of conservation initiatives and private landowners, population numbers managed to increase and an assessment by Hrabar & Kerley (2013) stated that the meta-population had successfully recovered to over 2700 individuals. This led to an IUCN red list status change to Least Concern (Hrabar *et al*., 2019) and exceeded the initial population target set out by the Equid Specialist Group Action plan in 2002 (Novellie *et al*., 2002; Birss *et al*., 2016). Currently, the meta-population is considered stable and population numbers are estimated to be around 4800 which include a total of 78 sub-populations across South Africa (Birss *et al*., 2016; Kotze *et al*., 2019). Due to stable population numbers, CMZ have been reintroduced into 9 new conservation areas in their natural distribution range, as well as 7 new areas outside of this range (Hrabar & Kerley, 2013; Birss *et al.,* 2016). These zebra now comprise roughly 70%

of the total zebra population numbers with another 1490 zebra found on private land which makes up the remaining 30% (Birss *et al*., 2016).

Although conservation actions have increased population numbers, the effects of a population genetic bottleneck threaten the survival of CMZ throughout their natural distribution ranges (Watson *et al*., 2005; Birss *et al*., 2016). Cape mountain zebra populations occur in small, genetically isolated populations throughout the Western and Eastern Cape; thus, the survival of the species is compromised through habitat fragmentation, inbreeding, and loss of genetic diversity, small sub-population sizes, and possible hybridization with other equid species (Penzhorn, 1988; Novellie *et al*. 2002; Smith *et al*., 2007; Kotze *et al*., 2019). This has led to an extensive loss in genetic diversity within the CMZ species (Novellie *et al*., 2002) and research by Moodley (2002) found that each one of the three remaining natural populations represents one third of the overall CMZ gene pool. The three distinct genetic DNA pools consist of the MZNP, KNR and GMNR populations, although both the KNR and GMNR populations are saturated, due to previous human impacts, consisting of <70 individuals (Moodley & Harley; 2005; Watson & Chadwick, 2007). It is believed that >90% of the current meta-population originated from the MZNP and that all newly introduced populations derive from here (Watson *et al*., 2005). This may become problematic as it will lead to higher levels of inbreeding and the loss of genetic diversity in future generations (Moodley & Harley, 2005). Additionally, Hrabar & Kerley (2009) found that high levels of inbreeding are linked to increased cases of sarcoid tumours in small "island" populations of mountain zebra; however, it is unclear if there is a relationship between the tumours as these cases were only reported for populations which originated from MZNP. Inbreeding depression is also more severe in environments which have sporadic rainfall patterns, high variations in temperature as well as limited food resources (Sasidahran, 2006). Thus, the Western Cape, including the Cape Floristic Region (CFR), which has limited resources for CMZ populations, could result in high levels of inbreeding depression and possibly lead to more frequent incidents of sarcoid tumours. To counter the effects of inbreeding, species from the remaining two populations, GMNR and KNR, should be reintroduced to increase genetic diversity within areas (Novielle *et al*., 2002; Watson *et al*., 2005; Smith *et al*., 2007). However, this can only be done once these populations consist of more than 90 individuals as they would be vulnerable to extinction and the disruption of social structures (Smith *et al*., 2007). The only other population which holds genetic diversity from two of the founder populations, MZNP and KNR, is De Hoop Nature Reserve (Smith *et al*., 2007). This population is therefore imperative to CMZ survival and maintainance of genetic diversity within the species (Smith *et al*., 2007). Ultimately, it will lead to healthier and more stable populations. However, recent work by Kotze *et al* (2019) found a significant loss of genetic diversity in the De Hoop Nature Reserve population over the past 15 years. Results indicate that the population is now more KNR like, with 90% of genotyped individuals forming part of this cluster (Kotze *et al*., 2019). Similar results were found across other populations which suffered a complete loss of multiple private alleles; ultimately reducing the genetic structure across the subspecies (Kotze *et al*., 2019). Future research should focus on the genetics of each population, as well as newly introduced populations, to ensure that there are no inbreeding or genetic conflicts (Watson *et al*., 2005; Smith *et al*., 2007; Birss *et al*., 2016; Kotze *et al*., 2019).

In addition to genetic deficiencies, it was found that there is a shortage of protected areas, with suitable size and habitat quality, for CMZ within the Western Cape (Hrabar & Kerley, 2009; Strauss, 2015). Palaeozoological evidence suggests that CMZ favoured open grassland and low lying habitats, before climatic changes drove them into mountainous areas (Faith, 2012; Weel *et al*., 2015). This is supported by work carried out by Novielle *et al* (1988) and Winkler & Owen-Smith (1995) in the predominantly eutrophic Mountain Zebra National Park, where it was found that CMZ preferred to utilize open plains with a high abundance of palatable grasses. Previously, extensive research was undertaken on ungulate resource use (Jarman, 1974); however, very little has been done to date on CMZ feeding habits in the CFR where grass abundance is typically low (Goldblatt & Manning, 2002; Weel *et al.,* 2015). The high required intake rate and digestive tract of equids might be a limiting factor in poor quality habitats with very low grass biomass (Jarman & Sinclair, 1979; Duncan *et al.,* 1990). This could pose problems for the future management and survival of CMZ as there are many established meta-populations in the CFR and Western Cape (Hrabar *et al*., 2015). An advantage is that zebra are able to survive in poor quality habitats better than ruminants as they are able to utilize coarse plant material due to their feeding strategies and digestive system (Jarman, 1974; Jarman & Sinclair, 1979; Penzhorn, 1988). Zebra are hind-gut fermenters which means they choose quantity over quality when foraging and digest food at a much faster rate when compared to ruminants (Jarman, 1974; Winkler & Owen-Smith, 1995). This enables them to graze on vegetation which is coarse and of a low nutritional value (Jarman & Sinclair, 1979; Penzhorn & Novellie, 1991). These adaptations have allowed zebra's to utilize a greater variety of habitats and grass species when compared to other ruminants and may indicate why they have been able to persist within the Western Cape (Jarman & Sinclair, 1979; Hack *et al.,* 2002).

Due to increased habitat fragmentation, many CMZ subpopulations have become isolated within the Western Cape (Smith *et al*., 2007; Strauss, 2015). Conservation efforts are now focused on these populations as they are saturated, genetically deficient and lack areas of suitable habitat size and quality (Hrabar & Kerley, 2009). As a result, a Biodiversity Management Plan (BMP) was developed in 2015 for the management of CMZ, specifically within the Western Cape and in South Africa in general (Birss *et al*., 2016). This BMP integrated the work and initiatives of the Mountain Zebra Working Group into a partnership with CapeNature, the World Wildlife Fund, the Wilderness Foundation and the Table Mountain Fund (Birss *et al*., 2016). Stakeholders within this group engaged to identify possible threats and challenges within CMZ populations, which could lead to high levels of inbreeding, the loss of genetic diversity, equine sarcoidosis, predation, hunting or poaching and emigration threats (Moodley, 2002; Rubenstein, 2010; Hrabar *et al*., 2015). An additional threat that was identified included the lack of management strategies for the meta-populations, not only in the Western Cape but also for other populations across South Africa (Smith *et al*., 2007; Hrabar & Kerley, 2009; Hrabar *et al*., 2015; Birss *et al*., 2016). During the BMP development process, they developed a variety of internal as well as external stakeholder consultations to reach the desired state for the conservation of CMZ populations. They stated that the desired state for a Cape mountain zebra population should be "ecologically healthy, genetically diverse as well as be scientifically sound for the conservation of the species", and managers should strive to reach this desired state for each population (Birss *et al*., 2016). A study by Hack *et al* (2002) also proposed the following conservation actions for the persistence of plains zebra (*Equus quagga*) populations: 1) that risk assessment is improved, inside and outside of protected areas; 2) that there is an increase in the understanding of zebra ecology and biology; and 3) that genetic uniformity is prevented. Such action plans can also be implemented to help strengthen CMZ management and the persistence of populations. Ultimately, the goal of this BMP was to increase management efforts towards the conservation of CMZ and to restore populations back into historic distribution ranges (Birss *et al*., 2016). The BMP stated that this should be done through planned reintroductions of CMZ into newly identified areas, which would strengthen the overall meta-population within the Western Cape and the rest of South Africa (Birss *et al*., 2016).

With the help of the BMP, three such areas were identified by CapeNature, namely, the Grootwinterhoek Nature Reserve (GNR), the Limietberg Nature Reserve (LNR) and the Matjiesrivier Nature Reserve (MNR) (Birss *et al*., 2016). These three areas all fall within the historic distribution range of CMZ (Smith *et al*., 2007); however, it is unknown when last these areas played host to the CMZ species. As a result, there is need for research to be undertaken in order to determine the suitability of these habitats for the reintroduction of CMZ. In other parts of the country, such as Mountain Zebra National Park, CMZ have shown substantial population growth and performance (Penzhorn, 1982; Penzhorn & Novellie, 1991). However, in a study conducted in Baviaanskloof Nature Reserve the authors found that the population had shown little growth and that overall performance was poor (Reaves *et al*., 2011; Weel *et al*., 2015). These results seem to coincide with other populations in the Western Cape (Watson & Chadwick, 2007; Lea *et al*., 2016). Hrabar & Kerley (2013) stated that CMZ have performed poorly in fynbos areas due to limited suitable habitats and this is supported by results of a recent study by Lea *et al* (2016), who found that low grass coverage is positively correlated to male biased populations and poor population performance. Another example is De Hoop Nature Reserve, which plays host to around 80 CMZ and many other large mammals; where they found a shortage of C4 grasses, in particular during the dry summers and that only a small part of the reserve was able to sustain large grazing herbivores (Smith *et al*., 2007). It is therefore fundamental to understand all aspects of a proposed reintroduction site before any species are moved into the new area (Wolf *et al*., 1996; Owen-Smith, 2003).

Watson & Chadwick (2007) stated that CMZ will utilize both lowlands as well as mountainous environments within their natural distribution range. However, habitat suitability depends fundamentally on the abundance of palatable food resources (Owen-Smith, 2003). For herbivores, it might appear as if resources are available everywhere, although, plant parts and species can differ substantially in nutritional value (Jarman, 1974; Owen-Smith, 2003). Large herbivores will change their behaviour in order to increase their chances of survival which ultimately creates ecological patterns throughout landscapes in which animals decide to distribute themselves (Le Roux, 2010; Owen-Smith *et al*., 2010). Targets for habitat conservation should therefore include a full range of all habitats utilized by the species (Kerley *et al*., 2003). One should also assess these habitats by looking at availability of forage, access to water, the size of an area and the fire history (Jarman, 1974; Novellie & Bezuidenhout, 1994; Watson & Chadwick, 2007). This will indicate if the area is suitable for the species and has sufficient resources to sustain the population. Additionally, it is important to understand where the mountain zebra will be relocated from and how many individuals are needed to successfully establish a new population. This is considered in order to maintain genetic diversity and to ensure the persistence of the population for future generations. Novellie *et al* (1996) stated that a minimum of four males and ten females was necessary to establish a new population which would successfully persist; however, a CMZ population should consist of more than 90 individuals before animals can successfully be removed (Smith *et al*., 2007), so as to avoid disrupting the population dynamics and to ensure positive population growth amongst the remaining individuals (Watson *et al.,* 2005; Smith *et al*., 2007). In order to keep the loss of genetic diversity to a minimum, a population also needs to maintain an effective size before individuals can be removed (Moodley, 2002; Smith *et al*., 2007). This size represents the animals which contribute significantly to the genetic diversity of the population. Loss of genetic diversity generally occurs at 1% per generation, and it was found that a minimum population size of 50 was needed in order to maintain sufficient levels of diversity and counter inbreeding depression (Smith *et al*., 2007). Thus, reintroductions can be used as an effective management tool to establish new populations and maintain genetic diversity.

In the past, many reintroduction efforts led to failed attempts; however, all current relocations are planned, implemented and regulated in line with the "Guidelines on Reintroduction and Other Conservation Translocations" as stated by the IUCN (IUCN/SSC, 2013; Kaczensky *et al*., 2016). Such guidelines have been implemented to minimise the fatalities during relocations and to ensure that all is conducted in an ethically correct manner. These guidelines require that all translocations: 1) have a comprehensive justification for the translocation; 2) have conducted a risk assessment; 3) have a design that agrees with the social, economic and political factors; 4) follow all necessary steps and project design as set out by the IUCN; 5) be thoroughly documented and made available to the public for future conservation planning. Even with these guidelines, reintroductions can still be challenging, as they are often financially expensive, logistically demanding and may lead to injury or death of the translocated species (Wolf *et al*., 1996; Harrington *et al*., 2013). Therefore, one should expect setbacks, especially if the original population was small and causes of extinction not yet identified. It is suggested that priority be given to the conservation of habitat and that reintroductions only be made as a last resort (Kaczensky *et al*., 2016). For CMZ, reintroductions have played an important part in the conservation of the species as they have significantly increased population numbers and saved the species from the brink of extinction (Novellie *et al*., 2002; Hrabar & Kerley, 2013).

Fifteen CMZ (six males, nine females) were reintroduced to Bakkrans Nature Reserve, located in the Cederberg Wilderness Area, South Africa, from MZNP in 2001. According to the most recent assessment (ie: the current study), the population now stands at 21 individuals. As this population has not shown sufficient population growth, it is important to investigate population dynamics and behaviour as inconsistencies may arise while the CMZ try to adapt and establish themselves within a new environment (King & Moehlman, 2016). This population of CMZ was selected as their current habitat falls predominantly within the same vegetation types as the three proposed reintroduction sites. This will provide an indication as to how well the reference population is performing and what possible limitations there may be to CMZ within fynbos habitats. It will also indicate if CMZ will be able to successfully establish in the other three reserves and to identify the maximum number of individuals needed to maintain a healthy population. Lastly, it will increase our knowledge on CMZ resource use which will help future managers understand CMZ behaviour and carrying capacities within the Western Cape and South Africa.

1.2 Study species

The species, *Equus zebra,* is made up of a number of different sub species and Moodley & Harley (2005), concluded that the two subspecies, namely the Cape mountain zebra (*Equus zebra zebra*) as well as the Hartmann’s mountain zebra

(*Equus zebra hartmannae*) are closely related. These two species occupied different distribution ranges in the past as CMZ occurred throughout most of the southern district of South Africa, whilst the Hartmann's mountain zebra occurred from the southern parts of Angola to central Namibia (Penzhorn, 1982; Novellie *et al*., 2002; Smith *et al*., 2007; Novellie, 2008; Weel *et al*., 2015).

Cape mountain zebra are medium sized, striped equids (Birss *et al*., 2016). They differ from their close relatives, the plains zebra, by the dark stripes on the head and body of CMZ being narrower than that of the plains zebra and they do not have the shadow effect between the stripes (Penzhorn, 1988; Penzhorn & Novellie, 1991; Birss *et al*., 2016; Bothma & du Toit, 2016). Additionally, mountain zebra have a white underbelly, a blacked tip muzzle and a distinct dewlap which is more conspicuous than those of plains zebra (Birss *et al*., 2016). Generally the different zebra sub-species can be differentiated through the stripe pattern and width (Hack *et al*., 2002); however, it has been stated that subspecific status is not supported among zebra (Lorenzen *et al*., 2008). Full grown, adult, CMZ have a shoulder height ranging from 118cm to 132cm and can weigh anywhere between 220 and 375kg (Penzhorn, 1988; Bothma & du Toit, 2016). Cape mountain zebra will feed on coarse food at heights varying between 50 to 150mm above ground level which makes them non-selective bulk feeders (Penzhorn & Novellie, 1991; Bothma & Du Toit, 2016). They focus on quantity over quality during forage selection (Jarman, 1974), although have been known to be specialist grazers, only selecting a subset of available grasses (Grobler, 1983; Schulz & Kaiser, 2013). It has been stated that mountain zebra need to drink every day; however, other studies suggest that the species can survive by only drinking every 2-3 days (Novellie & Bezuidenhout 1994; Moodley & Harley, 2005; Strauss, 2015). This is possibly due to moisture in the vegetation they forage on and environmental temperatures (Jarman, 1974).

Cape mountain zebra are not considered to be territorial and band home ranges tend to overlap extensively (Penzhorn, 1982). They roam freely, selecting feeding sites that will best suit their requirements (Penzhorn, 1982). Most of the day is spent resting and grazing (Penzhorn & Novellie, 1991). Each family band (mean range = 1-5) consists of a dominant stallion and females with their offspring (Loyd & Rasa, 1989). Family bands remain stable for many years and mares normally remain in breeding bands for life (Penzhorn & Novellie, 1991). A new breeding band will be formed once a dominant male has acquired a new female, usually one that has recently left her maternal band (Penzhorn & Novellie, 1991). The sex ratio of populations is usually 1:1 and excess males will form bachelor bands until they are strong enough to challenge the dominant male for mating rights (Penzhorn, 1982; Penzhorn & Novellie, 1991; Novellie *et al*., 2002). Such challenges are often violent and can lead to serious injury or even death (Penzhorn & Novellie, 1991). Reproduction occurs throughout the year; however, it has been found that births peak during summer months (December – February) (Bothma & Du Toit, 2016). The gestation period lasts for 12 months after which a single foal will be born (Penzhorn, 1982). Foals will leave the maternal band at a mean age of 22 months, usually in the summer, and are not forced out by the dominant male (Penzhorn & Novellie, 1991). These colts and fillies will roam freely for a while until they are taken up into new bachelor or maternal bands (Penzhorn & Novellie, 1991). The life expectancy of CMZ is approximately 25 to 30 years. The CMZ population for this study consisted of 21 individuals.

1.3 Study site

The study area consists of four different sites (Figure 1.1). Bakkrans Nature Reserve (BNR) (32. 5056^{o} S, 19. 3406^{o} E) was the reference site as this is where the Cape mountain zebra herd was located (Figure 1.2). The other three sites were the Matjiesrivier Nature Reserve (MNR) (32. 5067^{o} S, 19.3412^{o} E) the Grootwinterhoek Nature Reserve GNR) (33. 0183^{o} S, 19. 0104^{o} E) and the Limietberg Nature Reserve (LNR) (33. 2341^{o} S, 19. 1310^{o} E).

Bakkrans Nature Reserve is situated in the Cederberg Wilderness Area and is a biodiversity hotspot. The reserve is approximately 5000ha in size and falls within the transitional zone where fynbos and low succulent karoo vegetation overlap. The main vegetation type in BNR is the Swartruggens Quartzite fynbos which includes alternating mountains with broad ridges and plains (Mucina & Rutherford, 2006). It consists of predominantly sedimentary rock of the Table Mountain group, although there are also parts that consist of older Malmesbury Group shales and young Bokkeveld formations (Quick *et al*., 2011).

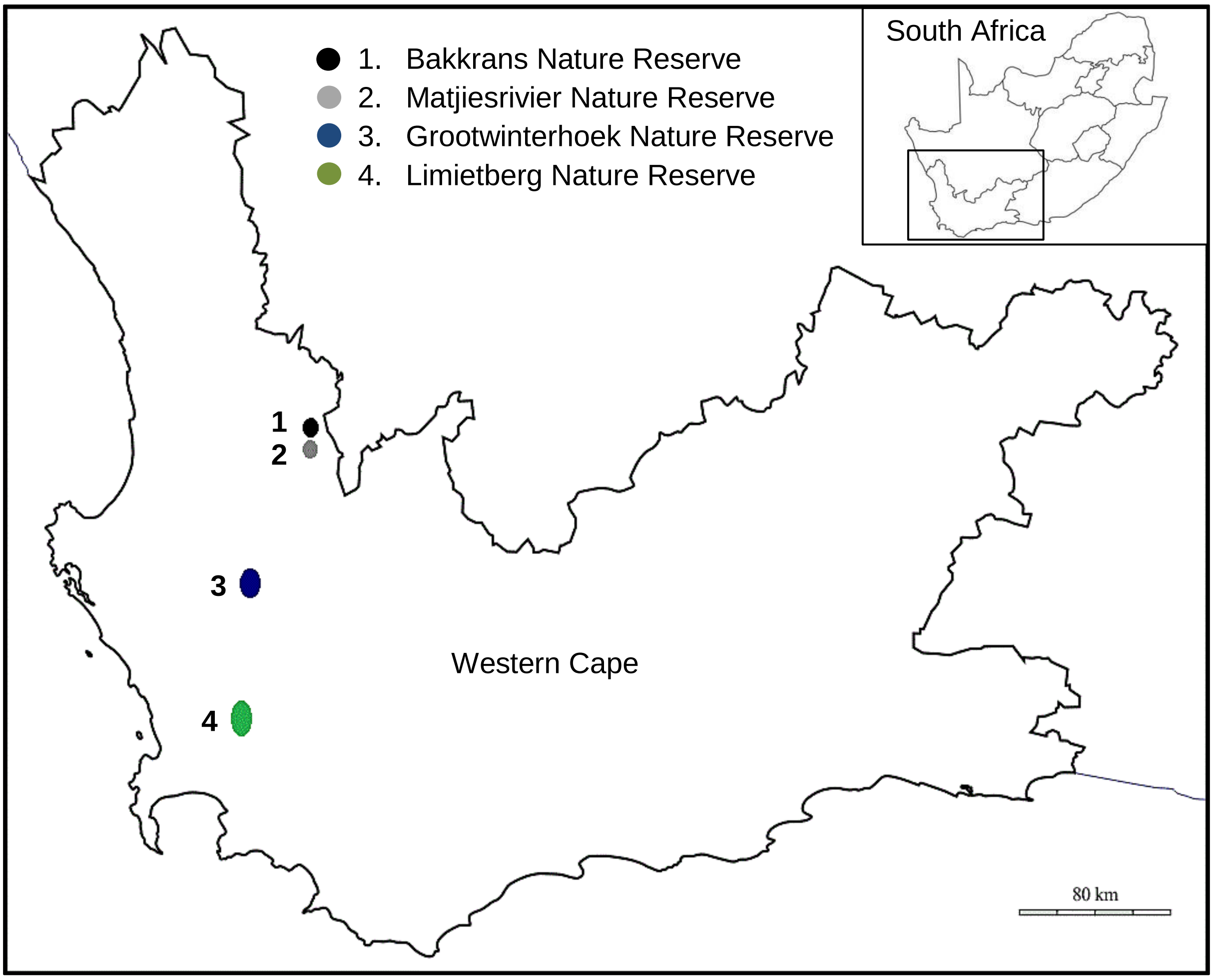

Figure 1.1: Map of the study sites in relation to the Western Cape and South Africa.

The area is dominated by Ericaceae, Proteaceae, Asteraceae and Restionaceae species and also plays host to larger mammals such as the Cape mountain leopard (*Panthera pardus pardus)* and Oryx (*Oryx gazella)* (Quick *et al*., 2011). There is also a sign of karroid elements towards the drier Cederberg areas, which is dominated by succulent dwarf shrubs. The best definition for the vegetation is an open thicket with a restioid understory. The highest part of the mountain range reaches 1500m and the reserve receives an average annual rainfall of 200-250mm of which 80% occurs in the winter (June to August) (Quick *et al*., 2011). Summers (December to February) are hot and dry with temperatures reaching over 40^{o}C at midday whilst winters are cold and wet with frequent snow and below zero temperatures.

Matjiesrivier Nature Reserve is situated in the Cederberg Wilderness Area, sharing its northern boundary with BNR. The proposed CMZ camp is approximately 2558ha in size and there is the potential to drop the fences between MNR and BNR to expand the total CMZ habitat (Appendix 1). The reserve also plays host to smaller mammals such as grysbok (*Raphicerus melanotis*) and klipspringers (*Oreotragus oreotragus*) while there are also a number of feral donkeys in the area. These will have to be removed to avoid hybridisation with the CMZ.

The main vegetation type on MNR is Swartruggens Quartzite Fynbos (Mucina & Rutherford, 2006) but on a finer scale consists of Asteraceous Fynbos and Sandy Restio Fynbos habitats. This area supports a diverse mixture of structural Fynbos types. The ridges in MNR consist of sandy and skeletal soils from the Witteberg Group and supports both restiod and ericoid shrubland with the presence of taller proteoid species. The proposed camp is situated 1200m above sea-level and experiences an average rainfall of 200-250mm of which 80% occurs in the winter. The reserve also has a natural spring which holds a large quantity of water throughout the year. Summer months are hot and dry with temperatures reaching over 40^{o}C whilst winters are cold and wet with frequent snow and below zero temperatures.

Grootwinterhoek Nature Reserve is situated adjacent to the town of Porterville, 120km north of Cape Town. The total size of the reserve is approximately 30 608ha and in 1986 a large portion (19 200ha) was declared a wilderness area. There are a variety of habitat types present on the reserve, including the following as stated by Mucina & Rutherford (2006): Winterhoek Sandstone Fynbos, Swartruggens Quartzite Fynbos, Breede Shale Renosterveld, Kouebokkeveld Shale Fynbos, Kouebokkeveld Alluvium Fynbos, Ceres Shale Renosterveld, Breede Shale Fynbos, Citrusdal Vygieveld and Matjiesfontein Shale Renosterveld. This conservancy contributes greatly to the conservation of mountainous fynbos and wildlife, and is also one of Cape Town's sources of fresh water. Mammal species that occur in the area vary from larger mammals such as the Cape leopard to small antelope species such as grysbok (*Raphicerus melanotis*) and klipspringers (*Oreotragus oreotragus*). In addition, Grootwinterhoek Nature Reserve is also a World Heritage Site. The average annual rainfall in the area is 1450mm, with the heaviest rains falling between the months of April and September. Summers (December to February) are hot and dry whilst winter (June to August) temperatures can drop to below zero degrees celcius at night and are accompanied by frequent snow.

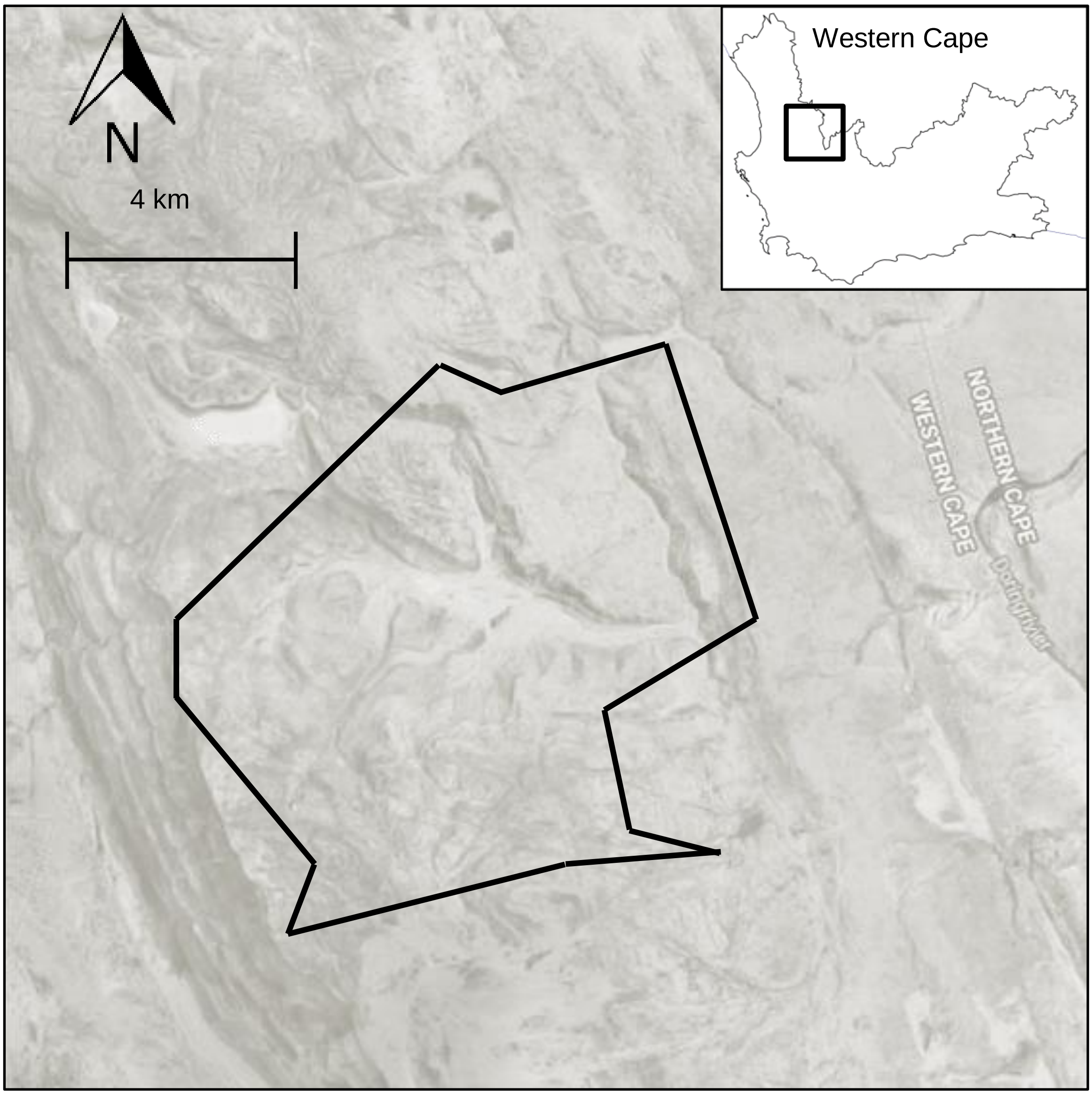

Figure 1.2: Map of BNR. Map from Google Earth (Pty) Ltd.

The area recently experienced severe fires (2017) which damaged large parts of the reserve. However, fire plays an important role in the regeneration of fynbos areas allowing seeds to germinate and grass to regenerate (Jarman, 1974; Van Wilgen *et al*., 1992).

Limietberg Nature Reserve is situated in the Du Touiskloof mountains near the towns of Paarl and Wellington and comprises an area of 117 000ha. This is an important catchment area for both the Breede and Berg rivers which flow through the reserve and supply a number of large dams with fresh water. The reserve is extremely hot and dry during the summers, but during winter, the high mountain peaks are chapped with snow and the area has an annual rainfall of 1250mm. Mammal species in the area include chacma baboons (*Papio ursinus*), klipspringers and the rarely seen caracal (*Caracal caracal*). The majority of the reserve is covered in mountainous fynbos and plays host to indigenous forest vegetation in the wetter areas. There are also alien trees that have invaded parts of the reserve such as black wattle (*Acacia mearnsii*) and pine (*Pinus*). The main habitat types that occur in Limietberg Nature Reserve as stated by Mucina & Rutherford (2006) are: Hawequas Sandstone Fynbos, Breede Alluvium Fynbos, Breede Shale Renosterveld, Kogelberg Sandstone Fynbos, Boland Granite Fynbos, Robertson Karoo, Swartland Shale Renosterveld and Swartland Alluvium Fynbos. The soils in the Limietberg Nature Reserve are lime-deficient and consist predominantly of Proteaceae and Restionaceae species (Matenaar *et al*., 2014).

1.4 Research goals and objectives

1.4.1 Goal

The main goal of this study was to provide CapeNature with guidelines on CMZ management and conservation, based on scientifically sound research; and to provide management recommendations for the future reintroduction of CMZ into nature reserves within the Western Cape.

1.4.2 Objectives and research questions

1. To determine if the reintroduced CMZ in BNR have established themselves, 17 years post reintroduction, with the same general structure as found in established populations, and if not what the drivers are for these differences. Specifically to determine:

    1.1 The direction and overall population growth.

    1.2 The adults sex ratio of CMZ in BNR.

    1.3 The average size and range of BNR Cape mountain zebra family bands.

    1.4 The age class and sexual composition of CMZ bands.

    1.5 If CMZ stallions within BNR form bachelor bands, and if so, determine the range and average size of the bands.

    1.6 Determine if CMZ bands are stable or dynamic in composition.

2. To determine how CMZ utilize graze and browse in their diet based on direct observations and microhistological analysis of dung samples. To determine how this may vary between seasons and what implications these dietary choices have with regards to availability and use.

3. To determine artificial water hole usage of CMZ within BNR and to determine factors that might influence such use patterns. Specifically to determine:
   3.1 What time of day CMZ utilize watering holes.
   3.2 Frequency of water hole use by CMZ.
   3.3 If there is a seasonal variation in the utilization of water holes.

4. To determine habitat suitability for CMZ in Bakkrans, Matjiesrivier, Grootwinterhoek and Limietberg Nature Reserves. Specifically to determine:
   4.1 If the suitability of habitat differs between seasons.
   4.2 If the habitat within Matjiesrivier, Limietberg and Grootwinterhoek Nature Reserves is suitable for the reintroduction of CMZ.
   4.3 If the habitat within BNR is suitable for the sustainability of the CMZ population.

1.5 Thesis structure

In total, this thesis consists of six chapters. Chapters Two, Three, Four and Five were written in the format of stand-alone manuscripts to help with publication in peer review journals. As a result, a degree of cross reference and repetition occurs throughout the chapters.

Chapter one provides an extensive literature review on CMZ history and conservation, the current status of CMZ, the study site, study species and research goals and objectives.

Chapter Two describes the demographics and distribution of CMZ in BNR and the factors affecting the population.

Chapter Three investigates the dietary needs of CMZ. Microhistological analysis was used to determine the seasonal variation in diet composition. The dietary preference of CMZ is discussed with regards to the study's findings.

Chapter Four focuses on artificial waterhole use of CMZ in BNR. It describes seasonal variation and the affect that habitat has on artificial waterhole usage.

In Chapter Five, the habitat suitability of CMZ in BNR is determined. The study also determined if the habitat within Matjiesrivier, Grootwinterhoek and Limietberg Nature Reserves is suitable for the reintroduction of CMZ.

Chapter six summarizes all the results of the study and provides recommendations for the future management and reintroductions of CMZ in the Western Cape province of South Africa.

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Chapter Two

Demographics and habitat preference of Cape mountain zebra (*Equus zebra zebra*) in Bakkrans Nature Reserve, South Africa

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2.1 Abstract

Cape mountain zebra (6 males, 9 females) (*Equus zebra zebra*) were reintroduced into Bakkrans Nature Reserve (BNR) in 2001, and this study aimed to investigate the

demographics and habitat preference of the resulting population. Driving transects and camera traps where used to identify 21 unique individuals (100% of population) of which 19 were adults (90.4%) one was a yearling (4.8%) and one was a foal (4.8%). Adult sex ratio was strongly male biased at 1:0.27 (male:female). A family band of two individuals and another of five individuals was present. Each band comprised of one dominant adult male with one to three adult females, zero to one yearlings and zero to one foal. The first family band consisted of one adult male and three adult females, all of unknown age, and a foal of two months. The second family band consisted of one adult male and one adult female both of unknown age. Bachelor groups consisted of one to nine individuals and were stable in membership. Bachelor bands consisted of one individual, two groups of two individuals and one group of nine individulas. Herds (multiple bands together) were never formed within BNR. The Cape mountain zebra have successfully persisted in BNR; however, their structure and organization does not exhibit similarities to those of other populations. Composition of the founder population, as well as environmental factors, have contributed to the skewed sex ratios and demographic differences when compared to other populations. Active management and continuous monitoring of this population is needed, given its apparent low recruitment and potentially low carrying capacity. Measures should also be implemented to counter the male bias sex ratio. More detailed monitoring of population growth should be implemented and population viability quantitatively assessed to better understand the dynamics of the population in BNR.

2.2 Introduction

Spatial organization of animals varies greatly among species, and studying these variations has proved challenging for sociobiologists (Linklater, 2000). Competition between animals for resources and mates is influenced by the environment, as well as the demographic structure of populations (Emrin & Oring, 1977). Linklater (2000) reported that these modifications may be affected by adult sex ratios as well as distribution; thus, there has been a common approach to investigating the association between a population’s demographic characteristics, environmental distribution, and variations in behaviour (Linklater, 2000). These associations may then be used to investigate relationships between the environment of the particular study population and the behaviour and sexual selection exhibited in a population (Jarman, 1983; Lloyd & Rasa, 1989; Lott, 1991).

With expanding human settlements and the loss of suitable habitats for wildlife, understanding the demographics of animal populations becomes more critical (King *et al*., 2016). However, long term demographic studies spanning several generations are scarce (Lloyd & Rasa, 1989). Understanding demographic structure of a specific species can provide insight into how animals react and distribute themselves throughout a landscape (Rubenstein, 2010; De Vos, 2017). However, large mammals do not distribute themselves evenly across an environment, and a number of factors influence these distributions (Jarman & Sinclair, 1979; McNaughton & Georgiadis, 1986). Such factors include the seasonal availability of resources, abiotic factors (geology, shelter, altitude, thermoregulation), proximity to drinking water, predation and fire, as well as inter and intra-specific competition (Leuthold, 1977; Sinclair, 1979; Sinclair, 1985; McNaughton & Georgiadis, 1986; Senft *et al*., 1987; Owen-Smith *et al.,* 2010). Habitat preference is the process by which animals select and utilize sites that provide them with the necessary resources for survival (Hutto, 1985; Hopcraft *et al*., 2010).

Plains zebra (*Equus quagga*) have been known to exhibit extremely flexible and highly dynamic social organization (Rubenstein & Hack, 2004). This has enabled them to overcome unpredictable social and ecological challenges such as predation risk and access to sufficient resources (Simpson *et al*., 2011). Numerous studies have focused on the demographics of plains zebra; however, very little has been documented on the demographics of Cape mountain zebra (*Equus zebra zebra*) (CMZ). Most studies have focused on the well-established populations in Mountain Zebra National Park (MZNP) and De Hoop Nature Reserve (DHNR) in South Africa. However, there are small populations of CMZ spread throughout the Western Cape, which make up between 25-30% of the total CMZ population (Lea *et al*., 2016). Thus, it is important to understand the demographics of these populations. In addition, many of these populations have been newly reintroduced into areas where the species has not been present in more than 100 years (Birss *et al*., 2016). These areas mostly consist of hardy, unpalatable fynbos vegetation with low grass cover (Birss *et al*., 2016). A recent study has shown that low grass cover is positively associated with a male biased population in zebras (Lea *et al*., 2016). This could have drastic effects on CMZ populations in the Cape Floristic Region (CFR) which historically is an area with very little grass coverage (Novellie & Winkler, 1993). Cape mountain zebra generally require a habitat which is abundant in palatable grasses (Novellie, 1994). Fynbos normally burns at intervals of 12-15 years, whilst more frequent burns are necessary to stimulate the production of grass (Van Wilgen *et al*., 1992). Thus, the lack of fire and grass could explain the low growth rate and population numbers of CMZ in the Cape Floristic Region. As a result, it is important to look at the demographic changes of the species after a reintroduction or introduction into a new area and monitor resource selection (De Vos, 2017). Continuous monitoring is needed to inform managers on the welfare of the population and to avoid the risk of extinction (King *et al*., 2016).

Cape mountain zebra populations generally consist of breeding bands (one dominant stallion and 1-5 mares with their foals) and bachelor bands (Penzhorn 1984a; Loyd & Rasa, 1989). The largest band encountered within MZNP consisted of 13 individuals: breeding bands may remain stable over many years, with females remaining in the same bands for life (Penzhorn & Novellie, 1991). Plains zebra have been more robustly studied and are similar to CMZ: their bands on average consist of a dominant male with 1-6 females (Hack *et al*., 2002; Boyd *et al*., 2016). Once a band stallion is displaced, the new stallion may take over the whole band as a unit; although, sometimes the band will split up (Penzhorn & Novellie, 1991). Displacement of a band stallion can lead to serious fighting through biting and kicking, which often results in severe wounds (Penzhorn, 1984a). Such wounds could be problematic and make CMZ susceptible to diseases, for example, sarcoid tumours, which often lead to death (Marais *et al*., 2007) (Appendix 2).

A family band is formed once a stallion acquires a female, who either recently dispersed from her maternal band, or is a member of a fragmented band that lost its stallion. Stallions may provide material rewards to females thereby increasing their reproductive success (Nunez *et al*., 2011). This is done by increased vigilance by the male, which enables females to search for resources and spend more time grazing (Nunez *et al*., 2010). Young stallions (<5 years) often lack the strength and stamina to displace dominant males for mating access (Penzhorn, 1984a). Young zebra will disperse after about 22 months and dispersal is not typically affected by the birth of siblings (Penzhorn & Novellie, 1991). Once a young female zebra leaves her natal band she could move between three to four bands before finally settling (Boyd *et al*., 2016; De Vos, 2017). Bachelor bands tend to be more unstable than family bands and generally consist of two to three individuals (De Vos, 2017), which may stay together for a few hours to a couple of years (Linklater, 2000). Cape mountain zebra are not known to be territorial, and family bands will form home ranges with extensive overlap (Penzhorn & Novellie, 1991).

Family bands and bachelor bands may unite to form herds, and the largest plains zebra herd recorded consisted of more than 400 individuals that came together from over 100 different bands (Rubenstein & Hack, 2004). Zebras may form these herds for protection from predation, to protect females from the harassment of bachelor males and to shelter bands from harsh climatic conditions (Rubenstein, 1986, Rubenstein & Hack, 2004). The formation of such large herds are unlikely for CMZ because populations tend to be much smaller, more isolated, and not as widely spread as those of plains zebra. Family as well as bachelor band size may change in relation to climatic and ecological pressure (Rubenstein, 1986); nonetheless, it has been found that unmanaged plains zebra populations often have sex ratios of 1:1 (Boyd *et al.,* 2016).

Since the initial increase of CMZ numbers in the early 2000's, various populations have established within the Western Cape of which many have remained unmanaged. Thus, in 2015, with the help of CapeNature and other beneficiaries, a Biodiversity Management Plan (BMP) for the management of CMZ within the Western Cape was established (Birss *et al*., 2016). This BMP stated that reintroductions of CMZ into areas which they historically occupied, were needed (Birss *et al*., 2016), and these pioneer populations of CMZ can provide important data on how zebra establish themselves in new environments. It is important for us to understand how CMZ adapt after reintroductions in order to improve future reintroduction success and animal welfare (Kaczensky *et al*., 2016). Hrabar & Kerley (2013) defined reintroductions as "human-assisted movement of animals among small, isolated populations managed as one metapopulation, with the aim to reinforce population size, enhance or maintain genetic variability". In addition, the IUCN has set up a "Guidelines on Reintroductions and Other Conservation Translocations", which implement, oversee and plan all reintroductions (IUCN/SSC, 2013; Kaczensky *et al*., 2016). However, these reintroductions can be very challenging and have negative effects logistically and financially, and on the animal population (Harrington *et al*. 2013). Thus, the constant monitoring of the animals is crucial as behaviour, social structures, population dynamics and distributions may all change whilst the animals are settling into their new environment (King & Moehlman, 2016, De Vos, 2017).

Bakkrans Nature Reserve (BNR) reintroduced 15 CMZ into the reserve in 2001 with the founder population consisting of six adult males and nine adult females (sex ratio of 1:1.5). It should also be noted that a neighbouring reserve reintroduced seven CMZ in 2012; however, two females broke through the fence and joined the BNR population in 2013. Management success or failure of the reintroduced CMZ has not yet been assessed. Active monitoring and management is needed to ensure the sustainability of this population, as the population may reach carrying capacity, which will be influenced by fluctuations in resources over time (Newmark; 2008; De Vos, 2017). The aim of this study was to define the demographics and organization of CMZ within BNR more than 17 years after their reintroduction. The main objective was to understand CMZ demographics (ie: age/size structure, male to female ratio, population size and growth), habitat preference and how their social organization differed from other CMZ and plains zebra populations within South Africa. The results from this chapter will contribute to management recommendations for the population in BNR as well as other populations across the Western Cape. It will form part of a bigger Biodiversity Management Plan for CMZ within the Western Cape and will enhance our understanding of CMZ reintroductions (Birss *et al*., 2016).

2.3 Methods

2.3.1 Study site

Bakkrans Nature Reserve (32. 5056^{o} S, 19. 3406^{o} E) is situated in the Cederberg Wilderness Area of South Africa and is a biodiversity hotspot. The reserve is fenced, approximately 5000ha in size, and falls within the transitional zone where fynbos and low succulent karoo vegetation overlap (See Figure 1.2 in Chapter 1). The main vegetation type in BNR is the Swartruggens Quartzite fynbos, which includes alternating mountains with broad ridges and plains (Mucina & Rutherford, 2006). Bakkrans Nature Reserve can be further divided into two vegetation types, namely: Asteraceous Fynbos, which is located on the higher lying mountain tops, and Succulent Karoo on the low lying sandy flats. The reserve consists of predominantly sedimentary rock of the Table Mountain group, although there are also parts that consist of older Malmesbury Group shales and young Bokkeveld formations (Quick *et* *al*., 2011). The area is dominated by Ericaceae, Proteaceae, Asteraceae and Restionaceae species and also supports other large mammals such as the Cape mountain leopard (*Panthera pardus pardus)* and Oryx (*Oryx gazella)* (Quick *et al*., 2011). There is also sign of karroid elements, towards the drier Cederberg areas, which is dominated by succulent dwarf shrubs. The best definition for the vegetation is an open thicket with a restioid understory. The highest part of the mountain range reaches 1500m and the area experiences an average annual rainfall of 380mm, of which 80% occurs in the winter (June to August) (Quick *et al*., 2011). Summer months (December to February) are hot and dry with temperatures reaching over 40°C whilst winters are cold and wet with frequent snow and below zero temperatures.

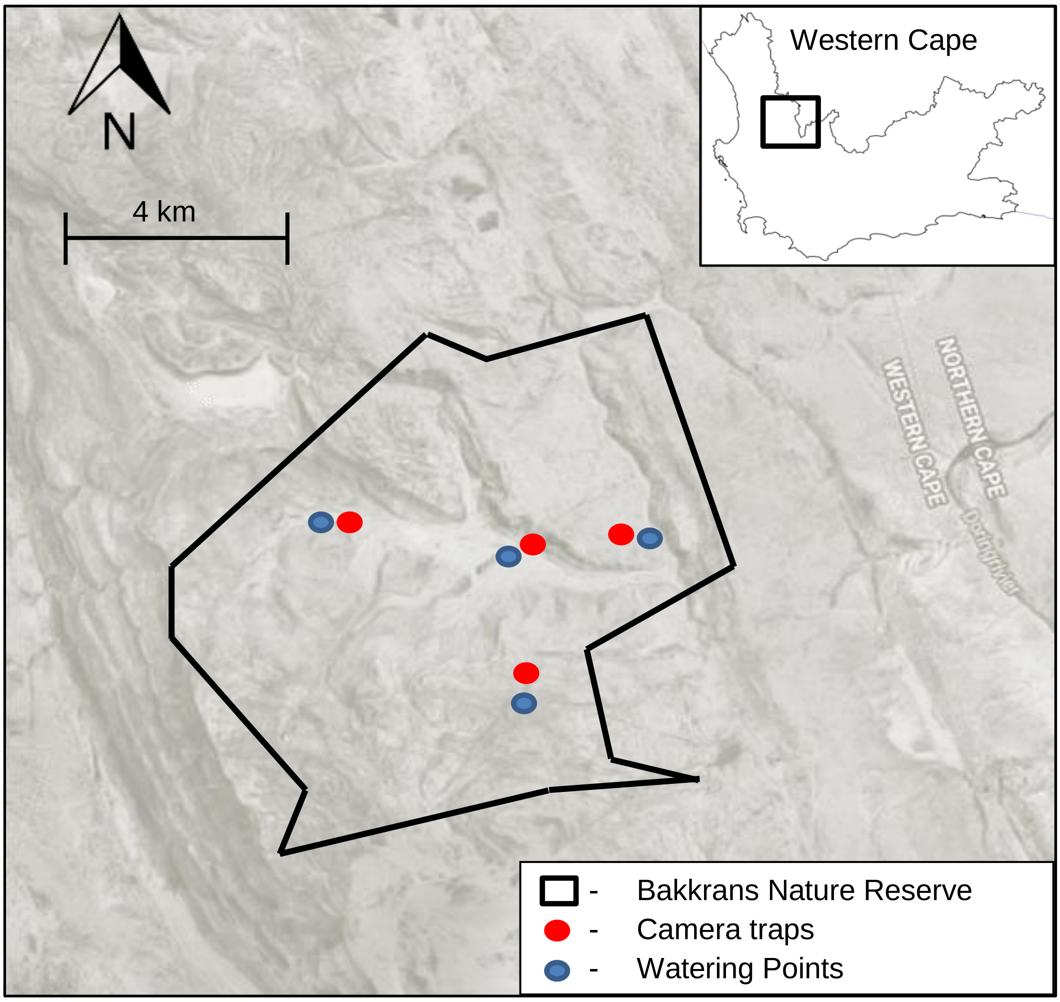

Figure 2.1: The distribution of the four Camera trap stations throughout BNR. Each camera was placed at an artificial watering point.

2.3.2 Identification and monitoring

The identification and monitoring methods used followed those of De Vos (2017), who studied the demographics of reintroduced plains zebra in Majete Wildlife Reserve, Malawi. Driving transects were conducted four days a month, between June 2018 and May 2019, at a speed of 20km/h on established roads, which allowed access to >80% of the reserve, to identify and monitor the demographics of the zebra population. Due to the predominant fynbos and karoo vegetation, detecting zebra via driving transects was effective. The short shrub-like vegetation allowed for good clearance and no vegetation was tall enough to obscure zebra sightings. Sampling was undertaken randomly during the day in order to sample different roads during different times of the day. Initial detection of zebra was done visually, up to 150m from the vehicle and when necessary binoculars were used. Additionally, camera traps were placed at each artificial watering hole to determine the demographics of each zebra band.

Once a band was located, group composition was documented (band size, age class, sex, reproductive status, and body condition) and a GPS location recorded (Smith *et al*., 2007; De Vos, 2017). Sex was determined by visual assessment of genitalia, whilst age class was determined individually by comparing size to that of an adult zebra, as used by Klingel (1969) and Grange (2006). Cape mountain zebra were classified into three different age/sex classes: foals (0-12 months), yearlings (12-24 months) and adults (≥2 years). Reproductive status was identified by the presence of a breeding stallion or pregnant females (Smith *et al*., 2007). Body condition was classified into three classes: good, poor or injured (Smith *et al*., 2007). With this information, band size (total number of individuals in a band), band composition (total males and females and number of foals, yearlings or adults) and bachelor organization (total number of males in a bachelor band) was determined.

A photograph was taken of the entire band using a 55mm Nikon D3100 camera, as well as using camera traps (Bushnell™, E3 Trophy Cam) for 24h surveying at the watering holes. During the research period each zebra was photographed on both sides to identify individuals using a difference in stripe pattern on the shoulder (De

Vos, 2017) (Appendix 3). Due to the low number of zebras in BNR, all individual zebras were easily identified. Sex ratio, number of individual bands, and band changes throughout the study was then quantified.

2.3.3 Camera trapping

Camera trapping was used for the continuous monitoring of zebra demographics between June 2018 and May 2019, and a camera trap was placed at each of the four established watering holes on the reserve. All camera traps were active for the duration of the study period. The sampling period was 187 consecutive days, which is well within the recommended time period to establish demographics for a zebra population (Karenth & Nichols, 2002). As the cameras were placed at watering holes distributed throughout the reserve, this resulted in placement within different vegetation types. On average, cameras were placed 1.1 km apart and were installed in such a way as to cover the entire watering station. Before securing each camera trap, it was set to the correct time and date, as well as to take a sequence of three photos at each event, with the interval events set at one minute. The location of each camera trap and watering hole was recorded with a GPS eTrex 30 (Garmin International, Olathe, KS, USA).

2.3.4 Statistical analysis

Statistica 13.3 (Dell software, 2018) was used to perform all statistical analyses. As the data were non-parametrically distributed, a Mann-Whitney U-test was used to test the difference in band stability of observed bachelor and family groups. This included the number of times an adult was observed to be missing from a group or joined a new group. Family (n = 2) and bachelor (n = 4) groups were monitored between June 2018 and May 2019 to determine stability. Due to seasonal variation in foal production, only adult members were considered for the group stability analysis. A simple linear regression was used to test if there was a difference between band size and the number of foals, as well as between band size and the number of foals and yearlings. ArcGIS (version 10.5) was used to map the distribution of CMZ in BNR, with data provided by CapeNature (Pty) Ltd.

2.4 Results

2.4.1 Population growth and structure

Throughout the study period (June 2018 – May 2019) a total of 125 observations were made of 21 individual CMZ which represented the entire CMZ population in BNR. This was the first time in 17 years that population numbers and demographics were determined in BNR. The 21 identified individuals were grouped into two bands (family groups), and 14 bachelor males. The first family band consisted of one adult male, three adult females, and a foal of two months. The second family band consisted of one adult male and one adult female. Bachelor bands consisted of one individual bachelor, two groups of two individuals and one group of 9 individulas. The population was comprised of 19 adults (90.4%), 1 yearling (4.8%) and 1 foal (4.8%) (Table 2.1, Figure 2.2). The sex ratio of CMZ in BNR was male biased at 1:0.27 (male:female). There was no available record for the ages of the reintroduced CMZ, and thus age of extant adults was unknown. However, the yearling was approximately 21 months old at the start of the study and dispersed to join a bachelor herd soon after observations started. The single foal was born in September 2018.

Table 2.1 Age and sex structure of the CMZ population in BNR (2018-2019).

Age class	Total	Males	Females	Sex ratio	Age class proportion of population (%)
Adults (> 24 months)	19	15	4	1:0.27	90.4
Yearlings (12-24 months)	1	1	-	-	4.8
Foals (<12 months)	1	1	-	-	4.8
Total	21	17	4	-	100.0

2.4.2 Bands and bachelor groups

Group size within BNR varied from a minimum of one to a maximum of nine individuals (mean = 3.5 ± 1.5 [SE]) (Table 2.2). These were made up of bachelor bands as well as two breeding bands with a dominant male, females (mean = 2.0 ± 1.0 [SE]) and their offspring. Only one yearling was present in a band, as was one foal. Both occurred in the same family band. Bachelor males were observed alone or in groups of one to nine individuals (mean = 3.5 ± 1.6 [SE]).

Table 2.2 Social structure and size of bands and bachelor bands of CMZ in BNR.

BANDS	Minimum	Maximum	Mean ± SE
Adult Males	1	1	1.5 ± 1.1
Adult Females	1	3	2.0 ± 1.0
Yearlings	0	1	0.5 ± 0.5
Foals	0	1	0.5 ± 0.5
Band size	2	5	3.5 ± 1.5
BACHELOR GROUPS	**Minimum**	**Maximum**	**Mean ± SE**
Adult Males	1	9	3.5 ± 1.6

There were a total of two family bands within the population and these were observed at least twice every month (n = 54 observations). These family bands retained the same number and individuals throughout the entire study period (46 observations), except on eight occasions when adults (≥2 years) were missing from their original band or were found within a new group (Figure 2.3). Bachelor bands were encountered at least once a month and moved between bands more often as compared to family bands. When bachelor males (n = 14) were encountered more than once (n = 70 observations) they were generally seen with the same band as previously encountered, except on 13 occasions where two or more adult males were seen with a different bachelor band (Figure 2.3). Bachelor bands ranged from one to nine males. Results of moves between specific individuals were not presented due to the extended study period and number of moves. It was found that band stability between family and bachelor bands were not significantly different (Mann-Whitney U-test: U=1021.0, Z=0.4, p=0.6).

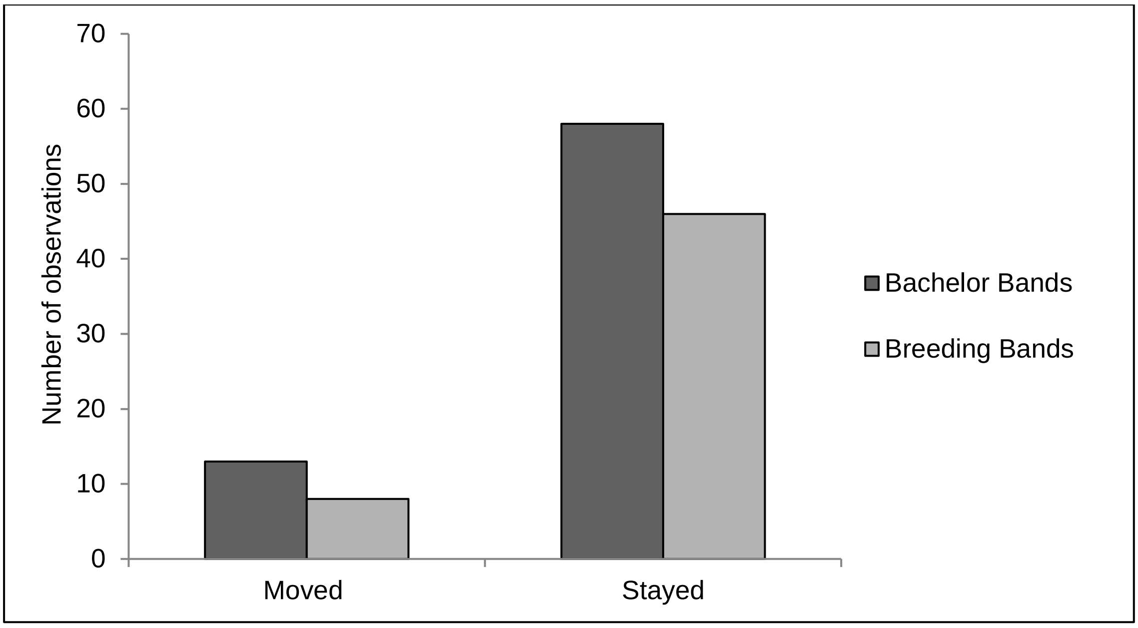

Figure 2.2: Cape mountain zebra band fidelity as shown by the number of observations in which a band or bachelor band member persisted in their original bands or changed bands.

2.4.3 Habitat preference

Although the whole of BNR is classified under the Swartruggens Quartzite Fynbos vegetation type (Mucina & Rutherford, 2006), there is a clear change in habitat type as one moves from the high lying plateau into the lower lying valley. On a finer scale the plateau habitat is classified as Asteraceous Fynbos, whilst the valley is Succulent Karoo. Cape mountain zebra distribution, as observed from driving transects and camera trapping in BNR, appeared to increase from high lying Asteraceous Fynbos areas towards low lying Succulent Karoo areas (Figure 2.4). However, there was no significant difference in habitat preference between the dry and wet season (Mann-Whitney U-test: U=385.0, Z=1.34, p=0.18). Individual CMZ occurred at a density of 0.36/km^2 and family bands at a density of 0.072/km^2. An average of 11.45 zebra were found per day, which is more than half of the total population. These included an average of 2.59 sightings per observation day.

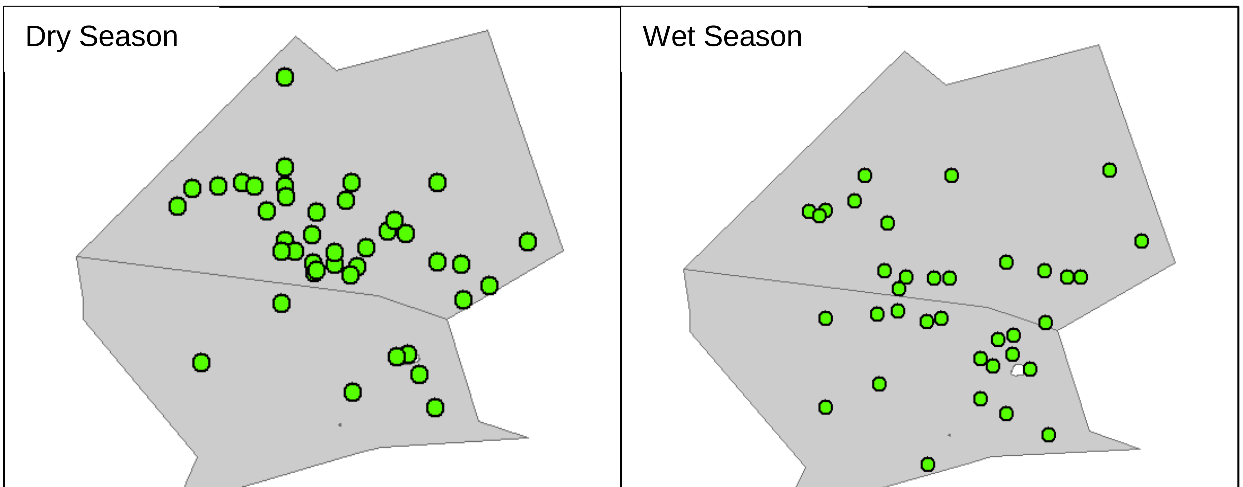

Figure 2.3: Representation of the habitat selected by CMZ between the dry and wet seasons in BNR.

2.5 Discussion

Cape mountain zebra have persisted in BNR after 15 individuals were reintroduced in 2001. After reintroduction, a zebra population may experience a lag period of slow population growth (Chivers, 1991). This is due to high levels of stress from the translocation, as well as environmental adjustments that need to be overcome. Thereafter, the population is expected to go through a period of rapid growth (Saltz & Rubenstein, 1995). In South Africa, reintroduced CMZ have experienced an annual growth rate of 0.4% within the first three to five years after reintroduction, as compared to the 9.3% increase within the following three to five years (Novellie, Millar & Lloyd, 1996). The highest population growth recorded for reintroduced plains zebra in South Africa was at an annual rate of 23% (Hack *et al*., 2002). Once at carrying capacity the annual mean growth of plains zebra ranges from 0.92 to 1.01% (Ransom *et al*., 2016). Factors such as anthropogenic, predation, and environmental pressures may influence the growth of established populations over time (Ransom *et al*., 2016). However, the only potential predator in BNR is the Cape leopard but such predation is unlikely (Hayward *et al*., 2006).

Population growth in BNR has been very slow as the population has only seen a net increase of six individuals over the past 17 years, of which two were adult females that allegedly jumped the fence from a neighbouring reserve in 2013. This slow population growth rate is likely due to the founder population which consisted of too few females (nine), as compared to males (six), when initially reintroduced. From historical data and the most recent demographic counts, only two individuals were born within the past 4-5 years, which once again emphasises the slow rate of reproduction. However, it was stated by Penzhorn (1984) that the lag period between foals is around 25 months for CMZ. The author also found that the mean age of first reproduction is 5.5 years whilst the mean oldest age of reproduction is at approximately 19 years. As no exact age record has been kept of the BNR zebra, the age of the last four remaining adult females is unknown. However, as only two male foals have been born within the last 4-5 years, it can be assumed that all females are older than five years of age. If however, they are from the founder population of 17 years ago, it could be that two or three of the females are past their reproductive age and can no longer produce offspring. Penzhorn (1984) also found that mares in Mountain Zebra National Park produced their last offspring between the ages of 17 and 21 years.

The population in BNR is currently growing at a slow rate. Slow population growth rates have also been recorded in other CMZ populations within the Cape Floristic Region. De Hoop Nature Reserve experienced a population increase of 6.6% between 1995 and 1999; however, from 1999 to 2005 this decreased to an annual growth of 4.5% (Smith *et al.,* 2007). Baviaanskloof Nature Reserve, initially reintroduced 13 individuals in 1990 and projected that at an annual growth of 4-8%, the population should consist of 90-130 individuals after 20 years (Weel *et al*., 2015). This was not the case as an aerial survey conducted 20 years after the initial reintroduction confirmed a population of a mere 26 individuals (Weel *et al*., 2015). In Kammanassie Nature Reserve, which holds one third of all CMZ genetic diversity, there were similar characteristics in the early stages after the population re-established itself. The initial population of nine individuals, showed a very slow but gradual increase in the first 20 years, as the population number increased to 19 (Watson & Chadwick, 2007). Within the following 10 years the population doubled in size. This sudden increase in population numbers was linked to an increase in annual rainfall and nine fires as compared to the two fires in the previous 20 years (Watson & Chadwick, 2007). This suggests that CMZ population growth may be positively correlated to an increase in fires, higher rainfall and better nutrition (Watson & Chadwick, 2007). Van Wilgen *et al* (1992) stated that frequent fires increase grass production, which results in simultaneous CMZ population growth. Bakkrans Nature Reserve falls within a low rainfall region and is not prone to frequent fires. Additionally, the whole Western Cape has experienced low levels of rainfall over the past 3-5 years, which could have affected the growth of the zebra population during this time. Watson *et al* (2005) found that a limiting factor in dystrophic areas is poor habitat quality with low availability of preferred food species. For example, Mountain Zebra National Park, which is abundant in palatable grasses, experienced high levels of population growth as the population increased from 55 to 230 zebra in a 20 year period (Penzhorn, 1985). These factors collectively explain poor population growth in the predominantly dystrophic Cape Floristic Area (Watson *et al*., 2005; Watson & Chadwick 2007; Weel *et al*., 2015; Lea *et al*., 2016).

The current BNR population is comprised of 90.4% adults, 4.8% yearlings and 4.8% foals. The population structure in BNR does not seem to show similarities to those of other zebra populations across the rest of Africa. Smith *et al* (2007) found that De Hoop Nature Reserve (DHNR), which has a well-established mountain zebra population, also recorded high adult to juvenile ratios from 1995-1999, when the population consisted of 81% adults, 11% yearlings and 7% foals. However, from 2000-2005 the population consisted of 75% adults, 15% yearlings and 10% foals. Similarly, plains zebra populations in Majete Wildlife Reserve comprised of 69.1% adults, 13.2% yearlings and 17.7% foals (De Vos, 2017), whilst the Hwange National Park zebra population comprised of 62.5% adults, 13.5 % yearlings and 24% foals (Georgiardis *et al*., 2003).

The sex ratio in BNR was extremely male biased (1:0.27). This is well outside that recorded in DHNR, which was reported at 1:0.89 (Smith *et al*., 2007). Additionally, plains zebra sex ratios in the Kruger National Park were recorded at 0.75:1 and in Laikipia, Kenya, at 0.73:1 (Mills & Schenk, 1992; Georgiardis *et al*., 2003). Thus, it is clear that there are limiting factors affecting CMZ population sex ratios in BNR. This finding was evident in a recent study by Lea *et al* (2016), who found that low grass coverage and high levels of unpalatable grasses, was positively associated with male biased sex ratios. These results were found across a number of reserves within the Western Cape and the authors thus classified them as refugee populations (Lea *et al*., 2016). Such populations are confined to protected areas within their historic range, which have suboptimal habitat and poor population performance (Lea *et al*., 2016). Bakkrans Nature Reserve was also included in this list, and the male bias hypothesis was further supported with the last two recorded foals (2016 & September 2018) in BNR being males. Additionally, the habitat assessment study revealed that BNR had the lowest Vegetation Index (0.03) of all four reserves included in the study and that the total grass coverage is only 13.81% (Chapter 5). The grasses found in BNR are also generally hardy and unpalatable, with low nutritional values (Van Oudtshoorn, 2014). Thus, this supports the hypothesis of Lea *et al* (2016) that there is a positive correlation of low grass coverage, high levels of unpalatable grasses and male biased populations, especially within the Western Cape and the Cape Floristic Region. However, Loyd & Rasa (1989) found that the DHNR population had a female biased birth ratio (foals that survived to maturity), although it is also situated in the Cape Floristic Region. Smith *et al* (2007) also found that a birth ratio of 5:8 was recorded in DHNR from 1999 and 2005. Despite the majority of foals being female, DHNR still has an adult male biased sex ratio (Loyd & Rasa, 1989; Smith *et al*., 2007).

Loyd & Rasa (1989) suggested that a specific sex biased offspring rate could be explained by the highly cited Trivers-Willard hypothesis. This hypothesis states that “if one sex has more variable reproductive success, generally males, then mothers in a good condition will benefit by producing more of that particular sex; whereas mothers in a poor condition would benefit by producing more of the reproductively stable sex, which is generally females” (Trivers & Willard, 1973). Trivers & Willard (1973) argued that an ungulate mother in a good condition would produce a strong son, which would be able to outcompete a daughter, as a successful son would be able to produce more grandchildren for the mother as compared to a daughter, who is limited by low reproductive rates (generally only produce one to two offspring per year) (Cameron, 2004). However, a mother in poor condition will be more likely to produce a daughter, who could outcompete a son, as most adult females would be able to produce some offspring, whereas a male in a polygynous environment would be unsuccessful and thus never mate (Cameron, 2004).

Under the Trivers-Willard hypothesis, the adult females in BNR may be in a good condition; thus producing male offspring who would have a greater chance of reproducing themselves. However, as the zebra population in BNR consists of 15 adult males and only 4 adult females, it would suggest that more male offspring would minimise the chances of reproductive success. It was never recorded that any CMZ were fatigued throughout the study period, and body condition generally remained high. A study by Loyd & Rasa (1989) in DHNR, argued that a possible reason for adult females to produce more female offspring is the status of the mare (Loyd & Rasa, 1989). They state that the foal of a dominant female will have a better chance of becoming a dominant female herself; whereas, the foal of a subordinate female may have a significantly smaller chance. It has also been found that dominant mares have a significantly higher fitness than subordinates. Thus, the female bias birth ratio regarding dominant females in DHNR should not be expected (Loyd & Rasa, 1989). This phenomenon could explain the male biased sex ratio in BNR. As there are only four remaining females of unknown ages, it is possible that there is one dominant female giving birth, while the subordinate females may be the individuals remaining from the founder population of 17 years ago. If so, these females may be past, or close to the end of their reproductive lifespan (Penzhorn, 1984).

Cameron (2004) suggested that a higher intake of glucose can lead to male bias in offspring. Other studies have also found that a higher fat intake at conception could favour male offspring (Crowford *et al*., 1987; Rosenfeld *et al*., 2003). A high-fat diet can increase the circulation of glucose which supports the hypothesis that glucose may be a contributing factor to sex determination (Cameron, 2004). Furthermore, Krackow & Hoeck (1989) found that socially stressed animals will produce male biased offspring, whilst higher levels of stress led to increased glucose circulation (Cameron, 2004). A final contributing factor could be that offspring sex may vary with time of insemination (Krackow & Hoeck, 1989; Huck *et al*., 1990). Glucose levels flux through the cycle and are important for reproduction, to such an extent that sex ratio and time of insemination could be explained by blood glucose levels (Cameron, 2004), influenced by the timing of the mating season with the dry and wet seasons in an area. Areas with different rainfall seasons experience fluctuations in the quality and quantity of food sources throughout the year (Jarman & Sinclair, 1979; Lea *et al.*, 2016). Foals in BNR were born during September, which is the end of the wet season when grasses would be senescing. Penzhorn (1984) found that the majority of offspring in MZNP were born in April, which is the end of the wet season in that area. The gestation period of CMZ is approximately 12 months (Penzhorn, 1984), which means that insemination would take place towards the end of the wet season, which is August/September in BNR. This is when grasses are senescing and have higher levels of sugars, which include glucose (Jarman & Sinclair, 1979). Throughout the current study, and specifically during the wet season, an increase in browse and woody material consumed by the CMZ in BNR was found (Chapter 3). This was due to very low grass abundance across the entire reserve. Browse, or woody material, is generally higher in sugars when compared to that of grasses, as the various species store reserves to survive through winter and fuel the bud flush in spring (Regier *et al*., 2010). Sugars can also aid plants during the cold winter months by serving as freezing protectants (Regier *et al*., 2010). As the Cederberg Wilderness Area experiences below zero temperatures during the wet season, woody plants should increase levels of sugars to survive through this period. Thus, as the CMZ diet consists of large amounts of woody material, in particular at the end of the wet season which is the insemination period, it can be assumed that their sugar or glucose levels would be higher. As a result, and based on Cameron's (2004) findings, it would suggest that the increase in glucose levels could be a contributing factor to the male biased sex ratio in BNR.

Band size (2-5, mean=3.5 ± 1.5) in BNR was within the same range as the recorded breeding herd size in DHNR (mean=3.5 ± 0.8); however, slightly lower than those of other established zebra sub-species populations. De Vos (2017) found that plains zebra in Malawi had band sizes ranging from 2-11 (mean=6.3 ± 0.21), whilst band sizes in Kruger National Park, South Africa, also fell within the same range of 2-11 (mean=4-4.5) (Smuts, 1976). However, this could simply be due to the fact that there were only two bands present in BNR, with a total of four females. There are also a number of other intrinsic and extrinsic factors which could influence band size (Rubenstein, 1986). For example, in areas with lower grass cover, thicket and predation, it would be expected that band size would be higher (Smuts, 1976). Although the likelihood of predation in BNR was very small, it was found that the larger band was seen far more frequently in the lower open areas as compared to the more dense areas on top of the plateau. The band that only consisted of one adult male and one adult female was seen on the top plateau more often. Boyd *et al* (2016) also found that a higher female bias in adult sex ratio can result in greater band sizes for any harem-forming species. As BNR is extremely male biased, one can thus assume the opposite and expect smaller band sizes, as was found in this study.

Additionally, it was found that the number of females (mean=2.0 ± 1.0), within a breeding band, fell just below the range of plains zebra populations in other studies. Hack *et al* (2002) found that the mean number of females in a breeding band in the Kruger National Park, South Africa, Hwange National Park, Zimbabwe, and Etosha National Park, Namibia, all ranged between 2.2 and 2.8 individuals. Band structure (one stallion, breeding females and their offspring) was similar in the current study when compared to that reported elsewhere for mountain and plains zebra (Hack *et al*., 2002, Boyd *et al*., 2016). Bachelor band sizes (1-9, mean 3.5 ± 1.6) in BNR were below the mean band size in DHNR (mean=5.0 ±4.0); however, they were similar to those of plains zebra populations. De Vos (2017) found that bachelor bands in Majete Wildlife Reserve, Malawi, ranged between one and eight individuals (mean of 3.0 ± 0.21). In Kruger National Park, South Africa, bachelors formed bands of one to seven individuals with a mean of two to three (Grubb, 1981). Bachelor herds as large as 50 individuals have been previously recorded; however, bands generally consist of two to three individuals (Linklater, 2000).

There was no difference in the stability of breeding bands and bachelor bands: original members remained with each other for most of the study period. Klingel (1969) reported similar results for plains zebra, as did Penzhorn (1984) for CMZ. Stable family bands may lead to increased protection for foals and a decrease in aggression, as members share resources due to stable bonds (Simpson *et al*., 2012). In contrast, plains zebra bachelor bands may experience higher levels of aggression, which could lead to less stable bonds between members (King *et al*. 2016). It was found that the BNR bachelor bands remained stable throughout the study period. The formation of bands may help bachelors with protection as well as provide the opportunity to attain females together (Boyd *et al.,* 2016). Loyd & Rasa (1989) found that CMZ have a species specific social structure which is characterised by small breeding bands that remain stable, both in their numbers and hierarchically, over extended periods of time.

In BNR, the zebra have dispersed throughout the entire reserve, although they prefer the open Succulent Karoo sandy flats as compared to the Asteraceous Fynbos areas within the mountains. There are a number of different contributing factors to these observations. The Succulent Karoo sandy flats provide access to three artificial watering holes as well as one natural spring, it is much easier to navigate through this area, there is a higher coverage of palatable plant species, it is at a lower altitude and occupies a larger area (Sherry, 1986, Forrer, 2016). As seasonal movements can be determined by grass communities which have a high proportion of nutritional species present, herbivores may choose feeding sites where they can maximize their forage and nutritional intake (Bell, 1984; Winkler, 1992). There is only one side of the reserve that connects the top plateau to the lower plains, which is separated by steep rock faces and it may be energetically expensive to travel between the two areas. Weel *et al* (2015) also stated that CMZ prefer low lying areas as these habitats are much more suitable to them. Camera trap data confirmed that the low lying areas showed more CMZ activity when compared to the top of the plateau.

2.6 Conclusion

The reintroduction efforts of CMZ in BNR have resulted in a persistent small population 17 years later. This population does not show similarities in social, age and sex structure as compared to other well established zebra populations in Africa. However, there is a link to other CMZ populations within the Western Cape, and may be the result of a low number in the founder population and unsuitable habitats. The results do suggest that CMZ possess the ability to recover when reintroduced into a safe environment with adequate resources and protection from hunting. The habitat quality of this area should however be taken into consideration, as well as the size and sex ratio of the reintroduced population. Decisions on founder population demographics must be balanced between the management goals of the reintroduction, priorities, and costs of future populations in the area.

An active management (relocation and re/introductions) and monitoring program (by vehicle or aircraft) is needed as the population is still small and demographically vulnerable. Sex ratio of births and the establishment of an age record for all the CMZ in BNR is needed. Small, fenced reserves will require diligent management and monitoring to prevent the CMZ from extirpation. This study has contributed greatly to our understanding of CMZ demographics more than 17 years after the initial reintroduction. Further research should be conducted to improve knowledge of the population, including:

1. Conducting a Probability Viability Analysis will allow management to better determine the possibility of extinction of the BNR population. This analysis works on past population data to determine the possibility of extinction of a population as well as the time frame in which it may occur (Dennis *et al*., 1991; Watson *et al.*, 2005). As the BNR zebra are low in numbers with very few females remaining, we recommend this analysis to be conducted as soon as possible. This analysis could not be done in this study as no past population data were available. Further research is needed to put a specific age on each individual CMZ.

2. Improving fire management regimes in BNR. The reserve is currently managed as a natural fire zone with the assumption that the current fire regime will promote biodiversity. The majority of BNR consists of fynbos which generally burns every 12-15 years (Watson & Chadwick, 2007). Burning at shorter intervals will favour resprouters such as grasses, and eliminate Proteaceae species (Van Wilge *et al.,* 1994). Thus, block burning should be implemented in BNR, to produce a mosaic of recently burnt veld, which is important for CMZ population growth (Watson & Chadwick, 2007). Although this option is very attractive, it could be difficult to implement as the terrain in BNR is extremely rugged.
3. Acquiring additional land should be considered to expand available habitat for CMZ. Zebra would benefit greatly if land owners came to an agreement to drop fences between reserves, turning the overall area into a conservancy. This, however, is difficult as land owners are often reluctant to share or sell land.
4. Determining factors influencing CMZ distribution in BNR may be better understood through ground-truthed vegetation maps by fine scaling habitat types within the area. Additionally, locations of all natural and which habitat type they occur in should be documented. This will help provide a clear indication of the drivers influencing zebra distribution in BNR. Maps can be created and analysed with spatial tools such as ArcGIS 10.5.
5. Comparing rainfall records to population growth rate over the past 17 years may help determine if rainfall strongly influences CMZ dynamics in BNR. Zebra population dynamics have been strongly effected by fluctuations in annual rainfall elsewhere (Georgiadis *et al*., 2003).
6. Genetic testing should be done on the CMZ to confirm which of the three genetic pools they originate from. All these CMZ were relocated from the Mountain Zebra National Park; however, the genetics has never been determined for the population. Thus, genetic deficiency and possible inbreeding may be contributing to demographical issues.
7. Reintroducing more adult females may even out the male biased sex ratio; however, if there are other underlying factors affecting demographics, we will see the same trend over the next 20 years and have similar problems in the

future. Possible solutions to this problem would be to relocate the CMZ to a more suitable environment.

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Chapter Three

Dietary preference of Cape mountain zebra (*Equus zebra zebra*) in Bakkrans Nature Reserve, South Africa

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3.1 Abstract

Seasonal movements and habitat use by herbivores is primarily determined by seasonal variation of forage. Historically, Cape mountain zebra (*Equus zebra zebra*) occurred throughout the Western Cape Province in South Africa, favouring grasslands. Resource use of Cape mountain zebra was studied in Bakkrans Nature Reserve, which falls in a transitional zone between Fynbos and Succulent Karoo habitats. Cape mountain zebra seasonal diet was assessed, as well as factors influencing plant and species selection. Grasses contributed 41.5% to the annual diet of the species: *Ehrharta calycina* contributed the most (21.6%), followed by *Merxmuellera stricta*

(5.3%) and *Stipagrostis obtusa* (5.3%). *Ehrharta calycina* contributed the most across all four seasons, while *S. obtusa* became more important in the late dry season. Browse contributed substantially (52.5%) to the annual diet: *Helichrysum dasyanthum* contributed the most (10.7%), followed by *Helichrysum moeserianum* (7.1%) and *Ischyrolepsis capensis* (5.9%). *Helichrysum dasyanthum* contributed the most across all four seasons. Leaf material was preferred annually, while stem, flower and inflorescence use increased during the wet season ($\chi^2_{(df=3)}$ = 23.55; p< 0.001). Green grasses were preferred annually, with zebra selecting green grasses >60% across all seasons. There was no increase in browse utilization during the wet season (Kruskal-Wallis: H=3.71, p=0.29). Zebra selected the tallest sward height during the late dry season and the shortest in the late wet season ($\chi^2_{(df=3)}$ = 343.32; p<0.001). Zebra exhibited high dietary plasticity, presumably due to the lack of adequate resources. Active management of this population is needed in the form of increased fire regimes to spur the growth of fresh grass and the acquisition of additional land to allow Cape mountain zebra access to low lying areas with more suitable habitat.

3.2 Introduction

Zebra species are generally classified as pure grazers (Dekker, 1997; Strauss, 2015; De Vos, 2017). They occur in open grasslands, savanna and woodlands, and often use migratory paths to follow high grass abundances across seasons (Young *et al*., 2005; Schoenecker *et al.,* 2016). Seasonal rotation of grazing pressures during these migrations may enable environments to support a higher density of grazers as compared to a system where animals are confined to only part of their annual range (Sinclair & Fryxell, 1985; Novellie, 1987). Plains zebra (*Equus quagga*) tend to follow the flush of newly sprouted grasses after the rain (Bell, 1971), but at a finer scale their dietary intake may be influenced by minimizing the cost of predation whilst maximizing their food quality intake (De Vos, 2017). This is done through higher bite rates which would result in sufficient food intake, without an increase in foraging time and as a result, they are able to spend more time on vigilance (Seeber *et al*., 2019). Zebra will distribute themselves in habitats with high grass coverage where they can increase the intake of high quality food instead of areas abundant in low quality food resources (Schoenecker *et al*., 2016). As many reserves in South Arica are fenced, the natural migration of zebra may be hindered. Such hindrances can have serious implications for conservation areas, which are usually too small to allow seasonal movement of grazers and often lead to forced relocations or culling (Novellie, 1987; Ekernas & Berger, 2016). That said, not all zebra populations will necessarily migrate and may remain in one area if conditions are suitable and resources abundant (Schoenecker *et al*., 2016).

Cape mountain zebra (*Equus zebra zebra*) (CMZ) are hind gut fermenters, which enables them to consume high quantities of low quality forage, as compared to ruminant animals which will predominantly target high quality food resources (Hoffman, 1972; Clauss *et al*., 2003; Schoenecker *et al*., 2016). They can also extract nutrients from all plant sources through the process of coprogaphy (Schoenecker *et al*., 2016). Being fairly non-selective, feeding on lower quality grasses high in fibre and low in protein, equids retain a high rate of food intake and fast rate of food passage (Clauss *et al*., 2003; Schoeneker *et al*., 2016). Owen-Smith (2002) found that the minimum required protein intake of herbivores is between 6-7%: protein levels are generally much lower in grasses and sedges as compared to forbs and shrubs. As seasons change, so does the nutritional value of plant species (Codron *et al*., 2007). Newly emerged palatable grasses boast higher protein levels, however, as the growing season progresses the grasses become reinforced with fibre and lose nutritional value (Jarman & Sinclair, 1979; Georgiadis *et al*. 1990). As a result, large herbivores will alter their behaviour in order to cope with these environmental changes (Fritz *et al*., 1996). Thus, in the dry season, selecting for forbs and shrubs may be more efficient to meet nutritional requirements. Plains zebra (*Equus quagga*) diet consists primarily of grasses, whilst they occasionally browse to elevate protein intake (Berry & Louw, 1992). During the dry season, plains zebra will select longer grasses than during the wet season, and distribute themselves in habitats with lower levels of fibre (McNaughton, 1985; Kleynhans *et al*., 2011). During the winter, they will eat a broader range of species as compared to in summer (Owen-Smith *et al*., 2013). Cape mountain zebra are classified as tall-grass feeders (Novellie, 1990) and may only include browse in their diets once the quality and quantity of grasses decline in the winter (Penzhorn, 1982). Previous studies in the Mountain Zebra National Park found that CMZ select grasses with a high leaf:stalk ratio and at heights between 40-150mm (Penzhorn & Novellie, 1991;Novellie & Winkler, 1993).

In dystrophic ecosystems, such as the Cape Floristic Region, forage is of a low quality (Strauss, 2015) and grasses are not abundant, in particular in the western regions

(Cowling & Holmes, 1992). Consequently, large herbivores occur in low numbers within these areas (Du Toit & Owen-Smith, 1989; Coetzee, 2002; Grange & Duncan, 2006). Historically, CMZ inhabited large areas of the Western Cape as well as the Cape Floristic Region, and they had to overcome major dietary challenges to satisfy their nutritional needs in such a nutrient poor environment (Skead *et al*., 2007). Understanding ungulate resource use is critical for the successful management of species such as CMZ (Gaillard *et al*., 2008). Paleozoological evidence suggests that CMZ were typically associated with open grasslands and not the rocky slopes of the Western Cape mountain ranges (Faith, 2012). This is further supported by studies undertaken in the predominantly eutrophic Mountain Zebra National Park (Winkler & Owen-Smith, 1995; Weel *et al*., 2015). Holecheck *et al* (1982) found that an important factor in ungulate nutritional ecology is the assessment of habitat quality as well as faecal nutritional status through Nitrogen (N) and Phosphorous (P) levels. However, very little work has been done on CMZ resource use within the Cape Floristic Region, which is dominated by low grass abundances (Weel *et al*., 2015). The majority of studies have focused on habitat preference, whilst only three known studies looked at dietary composition and preference respectively (Smith *et al*., 2011; Weel *et al*., 2015; Strauss, 2015).

Dietary studies tend to focus on the composition of plant growth forms (gramminoids, shrubs, dwarf shrubs, forbs and succulents), plant parts (leaves, stems, roots), and the taxonomy of any unique species that form part of the particular study species' diet (Grunow, 1980; Strauss, 2015). Such analyses often focus on preferred and principal species within the diet. Preferred species refer to those species which occur in the diet more frequently, whilst principal species are those which occur in the greatest quantity (Johnson, 1980; Owen-Smith & Cooper, 1987; Everett *et al*., 1992). This provides valuable information on the behavioural ecology of the species, including the decisions an animal makes in the form of changes in behaviour that allows it to increase its chances of survival (Owen-Smith *et al*. 2010). Ultimately, this leads to understanding ecological patterns, such as how animals decide to distribute themselves throughout a landscape (Le Roux, 2010).

Diet of CMZ in Bakkrans Nature Reserve (BNR) was studied from June 2018 – May 2019. Microhistology of faeces can be used to identify plant cells, hairs and crystals within a plants epidermal layer, and over the years has shown to be a highly effective and accurate method to determine a species diet (Hansen *et al*., 1977; Hanley & Hanley, 1987; Winkler, 2004). The aim of this study was to determine the seasonal dietary composition of CMZ in BNR, through microhistology of faecal matter. It was hypothesized that CMZ in BNR would utilize more browse than CMZ living in pure grassland areas such as the Mountain Zebra National Park. The results from this study will help inform CMZ management in BNR and the study will contribute to the management of CMZ within the Western Cape Province as part of a larger study being conducted by CapeNature (Birss *et al*., 2016).

3.3 Methods

3.3.1 Study site

Bakkrans Nature Reserve (32. 5056^{o} S, 19. 3406^{o} E) is situated in the Cederberg Wilderness Area of South Africa, and is a biodiversity hotspot. The reserve is approximately 5000ha in size and falls within the transitional zone where fynbos and low succulent karoo vegetation overlap. The main vegetation type in BNR is the Swartruggens Quartzite fynbos which includes alternating mountains with broad ridges and plains (Mucina & Rutherford, 2006). BNR can be further divided into two vegetation types; namely Asteraceous Fynbos, which is located on the higher lying mountain tops, and Succulent Karoo on the low lying sandy flats. It consists of predominantly sedimentary rock of the Table Mountain Group, although there are also parts that consist of older Malmesbury Group shales and young Bokkeveld formations (Quick *et al*., 2011). The area is dominated by Ericaceae, Proteaceae, Asteraceae and Restionaceae species and also plays host to larger mammals such as the Cape mountain leopard (*Panthera pardus pardus)* and Oryx (*Oryx gazella)* (Quick *et al*., 2011). There is also a sign of karroid elements towards the drier Cederberg areas, which is dominated by succulent dwarf shrubs. The best definition for the vegetation is an open thicket with a restioid understory. The highest part of the mountain range reaches 1500m and the area experiences an average annual rainfall of 200-250mm, 80% of which occurs in the winter (June to August) (Quick *et al*., 2011). Summer months (December to February) are hot and dry with temperatures exceeding 40^{o}C, whilst winters are cold and wet with frequent snow and below zero temperatures.

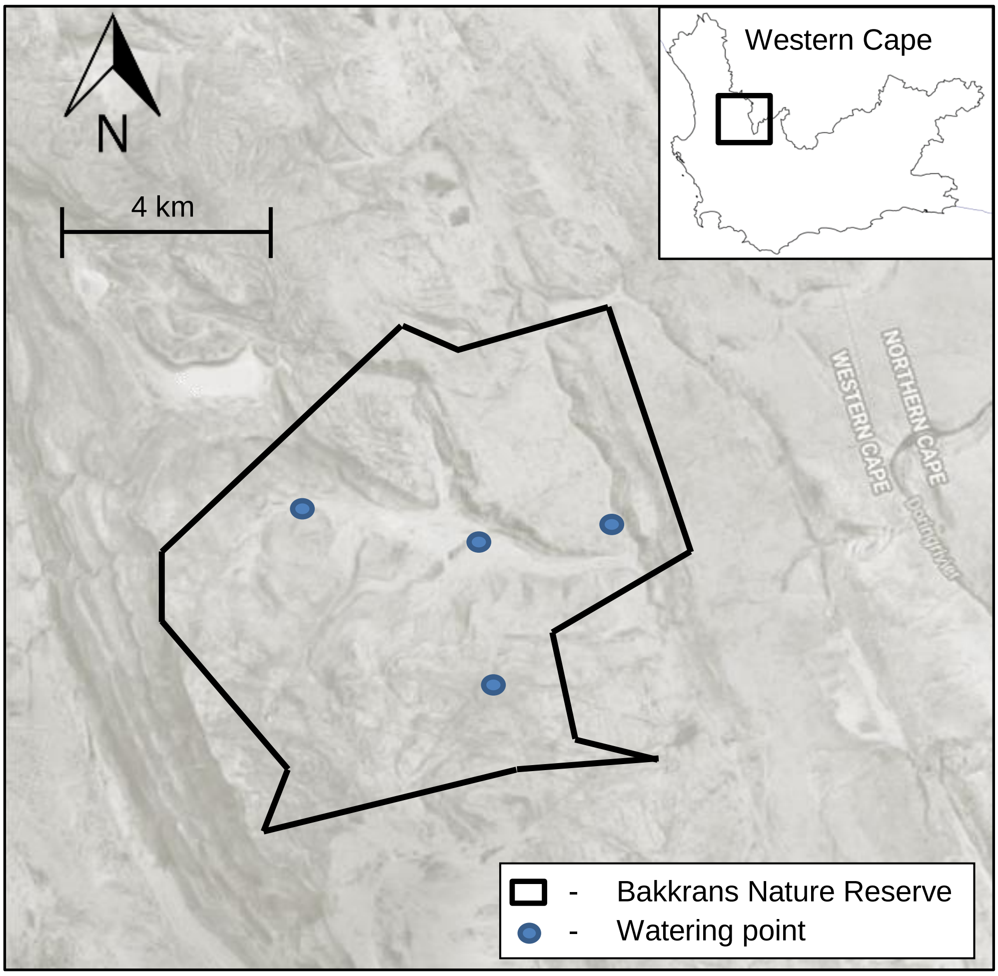

Figure 3.1: Map of BNR and present artificial watering points.

3.3.2 Faecal sampling

Fresh faecal samples (recently deposited, and preferably still wet) and vegetation samples were collected between June 2018 and May 2019. To ensure that no samples were contaminated by soil, insects and fungi, only fresh samples were used (<5hours) (Grant & Casey, 1996). Once a faecal sample was located, at least one full pellet was collected by hand, placed into a paper bag and marked with a location and date. To ensure robust sampling, a minimum of 50 dung samples were collected per season. Samples were collected across four seasons, namely: Early dry (September – November), Late dry (December – February), Early wet (March – May) and Late wet (June – August). A 200g mixed sample of dried and uncontaminated dung was analysed from each collection per season using microhistological analysis (Morrison, 2008). Dung piles were stored in a freezer and later dried in an oven at 60°C for 24h. Each separate dung pile was assumed to be from a separate individual for a given time and location. Vegetation samples (>10 leaves, stems and seeds) were collected from individual plants that zebra were observed feeding on, for microhistological comparison. These observations were done through direct observations of an identified zebra band and feeding site (Le Roux, 2010). Plant samples were placed into paper bags and then preserved in a plant press (Harborne, 1988).

3.3.3 Microhistology

The microhistological analysis followed the same methods of Morrison (2008), who used microhistology to determine the diets of horses in Kentucky, USA. Both plant and faecal samples that were collected in the field were dried and ground through a 1mm-screen using a Wiley mill (Thomas Mills, Model 4). Thereafter, plant pigments were removed by soaking 1g of dried sample in 20ml of household liquid bleach (6% NaClO) in a 100ml specimen cup for six minutes. Cups were shaken occasionally to blend contents and gas build-up was allowed to vent after each blending. The samples were then rinsed with distilled water for up to 30 seconds over an 80-mesh screen and set aside to dry. For each individual plant sample, a sub-sample (0.05g) was spread out over a 24 x 30mm cover glass and mounted onto a microscopic slide (25.4 x 76.2mm) by making use of a permanent mounting medium (Sulfix 6, Entellan) (Morrison, 2008). Five different slides were made for each plant sample and ten slides were made for each season of dung samples, to ensure accuracy. Slides were then left to dry for 24h. A standard Zeiss 16 binocular microscope (magnification camera) was used to view slides at 125 power magnification and visual identifications were made of plant epidermal and cellular characteristics. Photographs were taken of each individual plant species' epidermal and cellulose layers for later comparison to those found in the zebra dung samples.

Evaluation of each individual plant sample slide was done through the observational procedure as described by Sparks (1968). The lower left hand corner was used to start observations, moving from bottom to top and left to right in a sweeping motion. This ensures the observation of the entire slide. If three or more particles were present in the viewing area, they were examined to determine if they consisted of epidermal material, prickle hairs, both, or unidentifiable material. Further analysis was conducted only if an area consisted of at least three particles that could be identified as epidermis or prickle hairs.

For each season, ten permanent slides were made from the 50 prepared dung samples. Each slide was ensured to be of a high quality, with all clearly visible, evenly distributed, and free of air bubbles before evaluation. Species composition was determined by searching for plant fragments within the faeces and taking note of the frequency counts of each species that occurred. This was done by evaluating twenty random locations on each of the slides (200 locations in total per season). Locations were defined if the viewing area, under standard magnification, had at least three individual fragments which could be identified. Thereafter, the frequency of individual species was counted (number of identifiable parts out of the total 200 locations).

3.3.4 Utilization of plant parts, sward length and greenness

Throughout all seasons, the utilization of plant parts, acceptance of sward length and greenness of forage, selected by CMZ, was recorded. These methods were done in accordance to Le Roux (2010), who studied the dietary preference of Sable antelope (*Hippotragus niger*) in the Kruger National Park, South Africa. Direct observations were used to identify positive feeding sites. Once the CMZ had moved off, a quadrant was laid out within the positive feeding site (Figure 3.2). Within this quadrant, all heights of freshly bitten grass were measured, the plant parts utilized recorded and plant greenness accepted was recorded. Un-grazed leaves of the same tuft were used to measure sward length, or a comparison was made to similar species within the same block. Within these quadrants, plant parts that were utilized on the freshly bitten/eaten plants were recorded (Appendix 4). These were classified as flowers and inflorescence, leaves, and stems. Greenness of grasses was classified by three classes, namely: green, semi-green, and brown. All of these were recorded a total of 15 times per quadrant. Once 15 recordings were made the quadrant was moved to the next positive feeding site. A total of 12 quadrants were sampled per season, equating to a total of 180 measurements per season. Quadrants were selected randomly on an observed CMZ band.

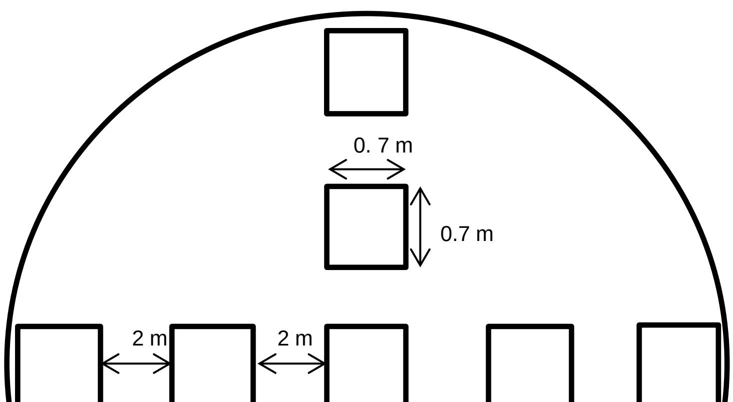

Figure 3.2: The quadrant layout which was used to measure the utilization of plant parts, stem heights and greenness. All of these were recorded within each block.

3.3.5 Statistical analysis

Relative abundance of each species was calculated as a percentage of the total abundance. All plant species which were present in a zebra's total diet were considered. All statistical analysis was conducted in Statistica version 13.3 (Dell Software, 2018). A chi-squared goodness of fit test was used to determine the utilization of each species across seasons, and Wilcoxon tests were conducted to determine differences in the top 5 preferred species between all individual seasons.

A chi-square goodness of fit test was used to determine the difference in plants utilized, and to determine the greenness of plant parts used between seasons. Wilcoxon tests were used to determine the difference in plant parts used, greenness between individual seasons, and to determine the differences in sward height accepted between all individual seasons. The difference in browse used between seasons was tested using a Kruskal-Wallis test, and the difference in sward height utilized between seasons was tested using a chi-square goodness of fit test.

3.4 Results

3.4.1 Dietary contribution

Microhistological analysis revealed that CMZ diet in BNR consisted of 25 different plant species. Of these, seven grass species contributed to 41.5% of the annual diet, seven restio species contributed 16.4%, one sedge species contributed 3.8%, seven dicotyledons species contributed 29.3% and three geophyte species contributed 3.1%, while the remaining 5.9% was unidentified (Table 3.1). Grasses contributed primarily to the diet in all four seasons but decreased to the lowest level in the moderate early wet season when browse species increased by >4%. Only three grass species, *Ehrharta calycina, Merxmuellera stricta* and *Stipagrostis obtusa* contributed to >5% of the annual diet, of which *E. calycina* was consumed the most. Of the other grasses, only two contributed between 2-5% of the diet, namely: *S. ciliata* and *E. villosa*. Other grasses were seldom utilized throughout all seasons. Annually, *E. calycina* contributed to >20% to the diet and was preferred most in the warm, early dry season (27.8%). The other two principal species, *M. stricta* and *S. obtusa,* each contributed 5.8% to the annual diet with both preferred most in the warm, late dry season (6.6% and 7.7%).

Of the browse species, *Helichrysum dasyanthum* contributed the most (10.7%) to CMZ annual diet and was favoured in the cold, late wet season (11.6%). Only two other browse species contributed to >5% of the annual CMZ diet, namely: *Helichrysum moeserianum* (7.1%) and *Ischyrolepis capensis* (5.9%). No consumption pattern was detected for any other browse species due to their relatively low annual contribution to diet. The bulk of the CMZ diet consisted of 5-6 species each season, which contributed >55% to the overall diet. A significant difference was found in the utilization of the top five species across all four seasons (Friedman ANOVA: $x^2_{(df=3)} = 68.92$; $p<0.001$). On a finer scale, utilization of the top five species between two individual seasons was tested. A significant difference was found when two individual seasons were compared to each other, but there was no preference detected for the top five species between any two seasons.

Table 3.1: The annual and seasonal percentage contribution of Grasses, Restios, Sedges, Dicotyledons, Geophytes and unidentified species recorded in the diet of CMZ in BNR.

	Annual ± SD	Early Dry ± SD	Late Dry ± SD	Early Wet ± SD	Late Wet ± SD
Grasses					
Ehrharta calycina	21.6 ± 4.61	27.8 ± 3.62	20.2 ± 2.81	16.8 ± 2.52	21.5 ± 3.81
Merxmuellera stricta	5.3 ± 1.53	6.3 ± 1.44	6.7 ± 1.92	4.4 ± 0.96	3.6 ± 0.77
Stipagrostis obtusa	5.3 ± 1.74	3.6 ± 0.87	7.7 ± 1.44	4.4 ± 0.78	5.3 ± 0.66
Stipagrostis ciliata	3.8 ± 1.01	2.6 ± 0.45	3.7 ± 0.83	4.0 ± 0.72	4.9 ± 1.12
Ehrharta villosa	2.5 ± 0.41	2.2 ± 0.31	2.4 ± 0.66	2.4 ± 0.34	3.0 ± 0.47
Aristida canesence	1.8 ± 1.54	3.2 ± 1.29	1.3 ± 0.78	2.8 ± 1.47	0
Aristida diffusa	1.2 ± 1.12	0.9 ± 0.32	2.6 ± 0.91	0	1.1 ± 0.71
Total	**41.5**	**46.6**	**44.6**	**34.8**	**39.4**
Restios					
Ischyrolepis capensis	5.9 ± 1.92	8.4 ± 1.42	4.6 ± 0.62	6.1 ± 1.23	4.4 ± 0.83
Elegia mucronata	3.4 ± 0.93	2.5 ± 0.46	3.9 ± 1.34	4.4 ± 0.59	2.9 ± 0.36
Ficinia dunensis	3.3 ± 1.01	3.4 ± 0.55	2.1 ± 0.85	4.4 ± 0.57	3.4 ± 0.54
Thamnochortus insignis	1.8 ± 1.05	0.9 ± 0.43	2.7 ± 1.07	2.5 ± 0.64	1.2 ± 0.38
Willdenowia incurvata	0.9 ± 0.64	0.9 ± 0.28	0	1.0 ± 0.42	1.5 ± 0.42
Elegia filacea	0.6 ± 0.78	0	1.4 ± 0.62	0	1.0 ± 0.51
Hypodiscus aristatus	0.5 ± 0.61	0.9 ± 0.31	0	0	1.1 ± 0.14
Total	**16.4**	**17.0**	**14.7**	**18.4**	**15.5**
Sedges					
Ficinia indica	3.8 ± 1.72	2.0 ± 0.83	4.6 ± 1.82	5.8 ± 1.44	2.7 ± 0.92
Total	**3.8**	**2.0**	**4.6**	**5.8**	**2.7**
Dicotyledons					
Helichrysum dasyanthum	10.7 ± 0.71	10.0 ± 0.74	10.6 ± 0.83	10.5 ± 0.62	11.6 ± 0.84
Helichrysum moeserianum	7.1 ± 1.12	5.9 ± 2.93	6.9 ± 0.75	8.0 ± 0.85	7.8 ± 0.93
Tetragonia fruticosa	3.9 ± 0.49	4.2 ± 0.27	4.3 ± 0.57	3.4 ± 0.46	3.6 ± 0.48
Nylandtia spinosa	2.6 ± 0.82	2.1 ± 0.45	2.1 ± 0.41	3.7 ± 0.54	2.7 ± 0.42
Lycium cinereum	1.8 ± 1.44	1.6 ± 0.89	0	2.1 ± 0.97	3.4 ± 0.71
Hermannia cuneifolia	1.7 ± 0.56	1.5 ± 0.41	1.5 ± 0.45	2.4 ± 0.41	1.3 ± 0.25
Heliophila cornopifolia	1.5 ± 0.71	1.4 ± 0.52	1.7 ± 0.73	0.8 ± 0.33	2.1 ± 0.93
Total	**29.3**	**26.7**	**27.1**	**30.9**	**32.5**
Geophytes					
Lampranthus watermeyeri	1.7 ± 0.65	0.9 ± 0.12	1.6 ± 6.52	2.3 ± 0.42	1.8 ± 0.32
Cheiridopsis namaquensis	0.9 ± 0.37	0.5 ± 0.25	1.0 ± 0.44	1.3 ± 0.44	0.9 ± 0.23
Lampranthus aduncus	0.6 ± 0.44	0	0.7 ± 0.21	0.3 ± 0.41	0.9 ± 0.25
Total	**3.1**	**1.4**	**3.3**	**4.0**	**3.6**
Unidentified	6.0 ± 0.32	6.3 ± 0.35	5.7 ± 0.31	5.9 ± 0.32	6.3 ± 0.37
Total	**100**	**100**	**100**	**100**	**100**

3.4.2 Plant parts utilized

Utilization of plant parts fluctuated throughout the study period as availability of plant species changed with the seasons (Figure 3.3). Leaves were preferred over other plant parts annually, with the highest utilization occurring in the cool, early wet season (71%) and the lowest in the cold, late wet season (49%). Stem use was highest in the cold, late wet season (42%) while it was lowest in the warm, late dry season (7%). Inflorescence and flower use was highest in the warm, late dry season (28%) and lowest in the cold, late wet season (9%).

It was found that CMZ utilized plant parts differently across all four seasons (Friedman ANOVA: $x^2_{(df=3)} = 23.55$; $p< 0.001$). There was no difference in plant parts utilized between the early dry and late dry (Wilcoxon: p=1.00), early dry and late wet Wilcoxon: p=0.82), or late dry and late wet (Wilcoxon: p=0.88) season. However, there was a difference in plant parts utilised between the early dry and early wet (Wilcoxon: p<0.05), late dry and early wet (Wilcoxon: p<0.05), and early wet and late wet (Wilcoxon: p<0.05) season.

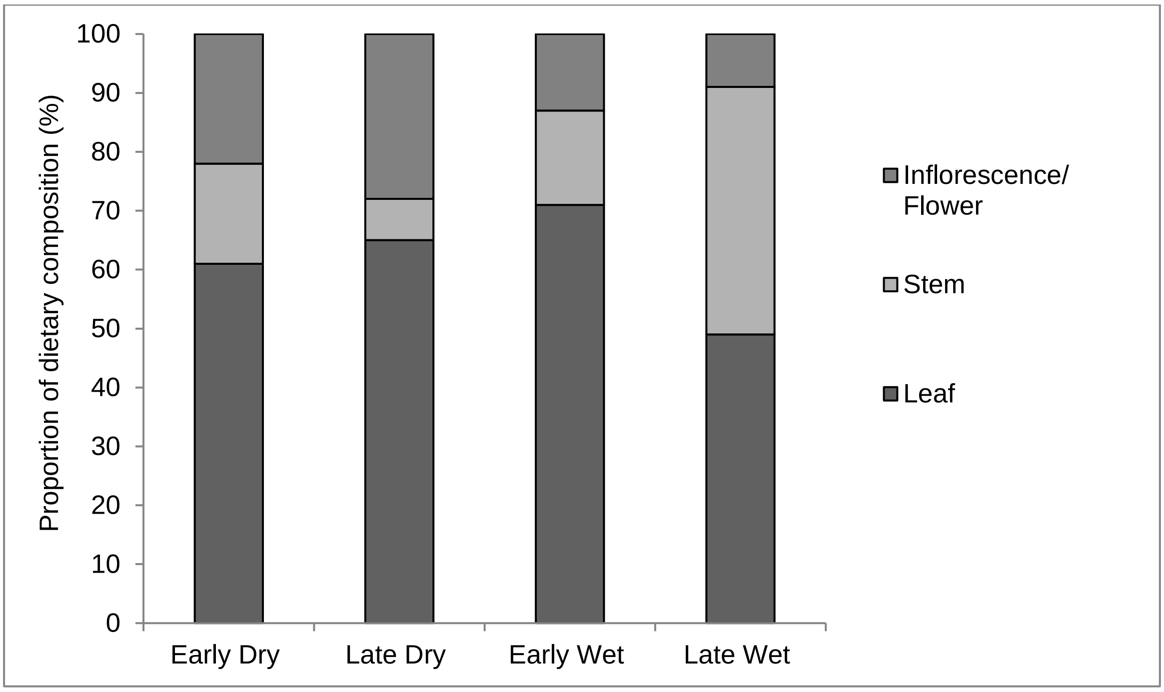

Figure 3.3: Representation of the plant parts utilized by CMZ in BNR throughout all four seasons.

3.4.3 Greenness of plants utilized

Greenness of selected plants varied across the four seasons (Figure 3.4). As expected, green parts were favoured throughout all four seasons with highest use in the moderate, early dry season (79.3%) and lowest use during the cool, early wet season (61%). Partially senesced plants (i.e. semi-green) were utilized most in the cool, early wet season (25.6%) and least in the moderate, early dry season (13.7%). Brown plant part utilization increased during the cool, early wet season, contributing 13.4% to the diet, while utilization was at the lowest during the moderate, early dry season (4.5%).

Cape mountain zebra selected for the greenness of plants differently across all four seasons (Friedman ANOVA: $x^2_{(df=3)} = 50.62$; $p<0.001$). There was a significant difference in greenness selection between the early dry and late dry (Wilcoxon: $p<0.05$), early dry and early wet (Wilcoxon: $p<0.05$), early dry and late wet (Wilcoxon: $p<0.05$), late dry and early wet (Wilcoxon: $p<0.05$) as well as the early wet and late wet (Wilcoxon: $p<0.05$) seasons. No difference in utilization between the late dry and late wet (Wilcoxon: $p= 0.59$) season was detected.

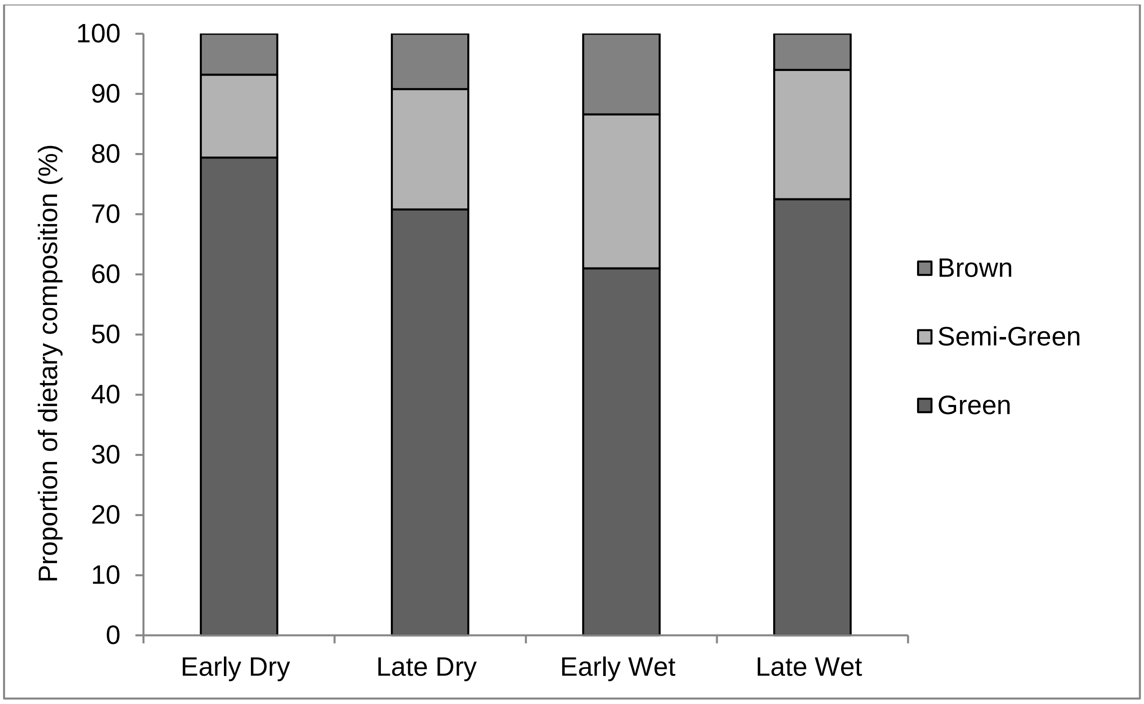

Figure 3.4: Representation of the greenness of plants utilized by CMZ throughout all four seasons in BNR.

3.4.4 Browse utilization

The difference between the amount of graze and browse utilized by CMZ fluctuated across the four seasons (Figure 3.5). The total amount of browse consumed was highest in the cool, early wet season (63.5%), whilst it was lowest during the moderate, early dry season (51.8%).

No significant difference was found between percentage graze and browse utilized across all four seasons (Kruskal-Wallis: H=3.71, p=0.29). As the early wet season had the largest portion of browse consumed, this was compared to the other seasons. A significant difference in browse utilization was found between the early wet season and both the early dry (Wilcoxon: p<0.05) and late dry (Wilcoxon: p<0.05) seasons. However, no significant difference was detected between the early wet and late wet season (Wilcoxon: p=0.07).

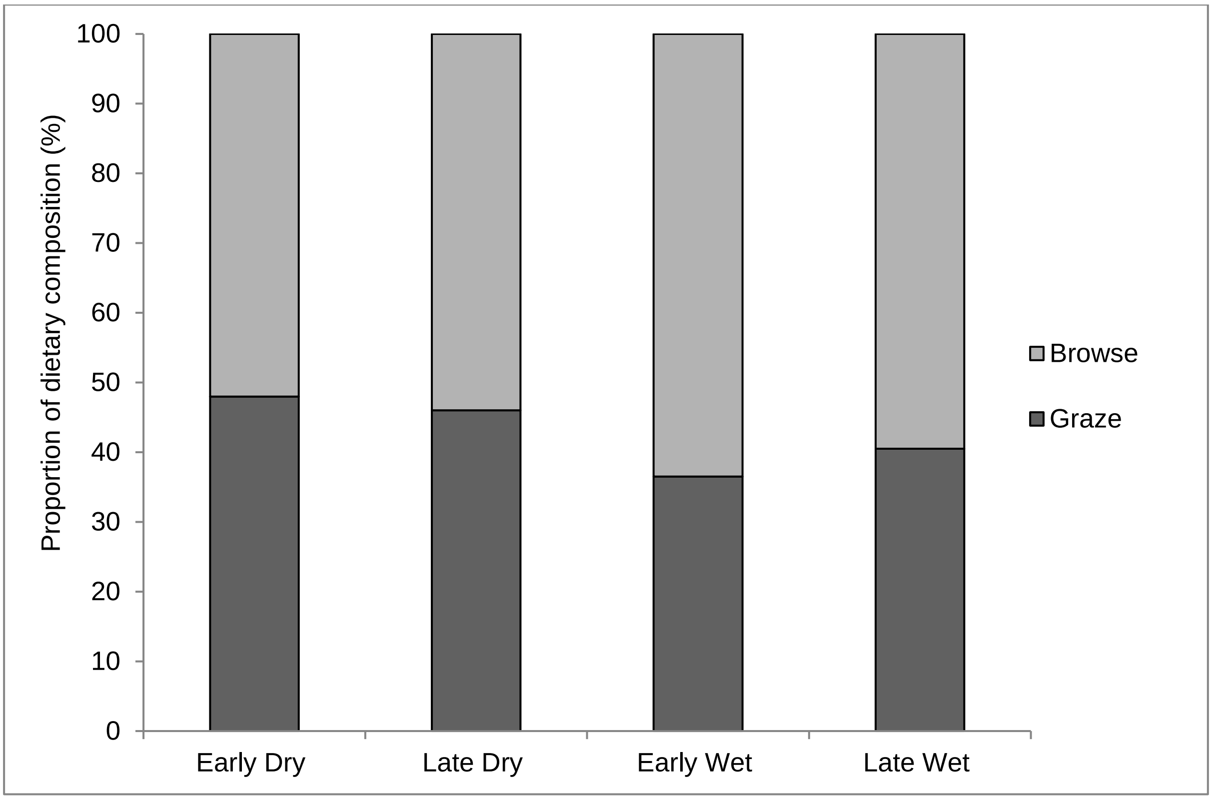

Figure 3.5: Representation of the proportion of graze and browse consumed by CMZ throughout all four seasons in BNR.

3.4.5 Grass height acceptance

It was found that CMZ selected for different grass heights across all four seasons (Figure 3.6). Cape mountain zebra preferred to graze on longer swards during the warm, late dry season (mean=340mm) and the shortest swards were consumed during the cold, late wet season (mean=156mm).

A significant difference was found in sward length utilization between the four seasons (Friedman ANOVA: $x^2_{(df=3)}$ = 343.32; *p*<0.001). A difference in sward length utilization was detected between the early dry (220mm) and late dry (340mm) (T-test: t = -19.1; *df* = 179; *p*<0.001), early dry (220mm) and late wet (156mm) (T-test: t = 19.2; *df* = 179; *p*<0.001, late dry (340mm) and early wet (226mm) (T-test: t = 14.5; *df* = 179; *p*<0.001), late dry (340mm) and late wet (156mm) (T-test: t = 28.7; *df* = 179; *p*<0.001) as well as early wet (226mm) and late wet (156mm) (T-test: t = 15.6; *df* = 179; *p*<0.001). There was no significant difference in sward length utilization between early dry (220mm) and early wet (226) (T-test: t = -1.35; *df* = 179; *p*=0.19).

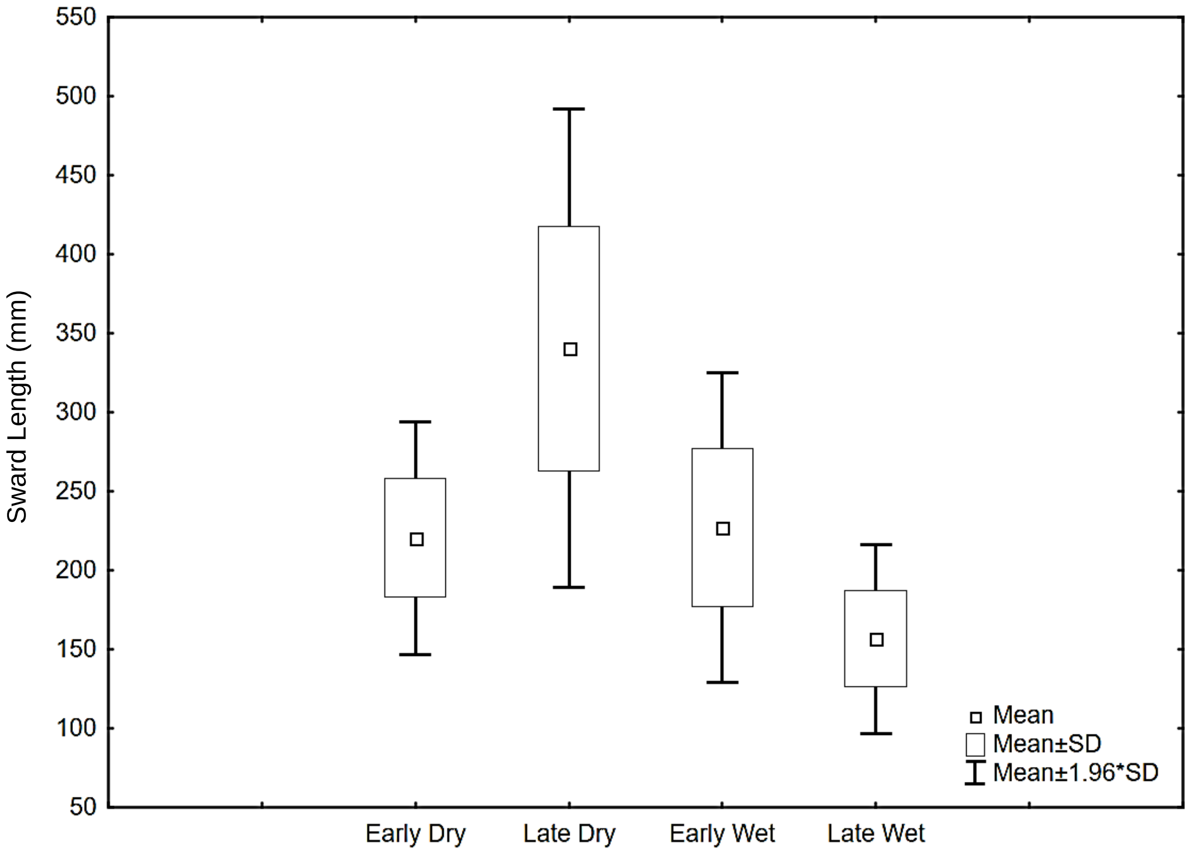

Figure 3.6: Representation of the sward lengths utilized by CMZ throughout all four seasons in BNR.

3.5 Discussion

Cape mountain zebra diet generally consists of a wide variety of grass species (>24) and several will contribute to >5% of the annual and seasonal diet (Smith *et al.,* 2011; Weel *et al*., 2015). It was found that CMZ diet in BNR only consisted of seven grass species, of which only three contributed to >5% of the annual diet. Those species were *Ehrharta calycina, Merxmuellera stricta* and *Stipagrostis obtusa*, whilst *E. calycina* was the only species preferred across all four seasons. Cape mountain zebra can be highly selective grazers, and in the Mountain Zebra National Park only utilized seven of 17 available species (Penzhorn, 1982). Browse species also contributed significantly to annual CMZ diet (>50%) in BNR. Three important browse species that contributed to >5% of the annual diet were, *Helichrysum dasyanthum* (10.7%)*, Helichrysum moeserianum* (7.1%), which are dicotyledons, as well as the restio *Ischyrolepsis capensis* (5.9%).

The annual contribution of grass species to CMZ diet in BNR was 41.5%, which is substantially lower than reported in other studies. Within Baviaanskloof Nature Reserve, grasses contributed to 95.3% of the annual CMZ diet (Weel *et al*., 2015), and a total of 17 grass species contributed to 72.6% of the total annual diet of CMZ in Bontebok National Park (Strauss, 2015). Within the Mountain Zebra National Park, grasses contributed 98% to the annual diet and 92-99% to the seasonal diet of CMZ (Winkler, 1992). In De Hoop Nature Reserve, grasses made up 88% of the CMZ diet with restio species also contributing to a portion of the annual diet (Smith *et al.,* 2011).

The dietary contribution of grasses in BNR was 46.6% in the early dry season, 44.6% in the late dry season, 34.8% in the early wet season and 39.4% in the late wet season. The seasonal dietary proportion of grasses in BNR differed fundamentally from those in other studies. In Bontebok National Park, the dietary contribution of grasses was 43.3% in the early dry season, 67.9% in the late dry season, 83.8% in the early wet season and 81.2% in the late wet season (Strauss, 2015). In Baviaanskloof Nature Reserve, grasses contributed to >90% of the total diet in all four seasons (Weel *et al*., 2015). The increase of grazing during the dry season, may be linked to a flush of fresh grass growth, which has higher nutritional value, lower tannin content and greater palatability than most browse species (Jarman & Sinclair, 1979; Cooper & Owen-Smith, 1985; Sukumar & Ramesh, 1992).

The grass species contribution to the diet in BNR showed little similarity to other studies. In Bontebok National Park, CMZ preferred species such as *Themeda triandra* (20.9%)*, Cymbopogon marginatus* (14.5%) and *Eragrostis curvula* (13.3%); whereas, in Baviaanskloof Nature Reserve, *Tristachya leucothrix* (39.4%) and *T. triandra* (27.6%) were preferred (Strauss, 2015; Weel *et al*., 2015). These are all highly palatable grasses which play an important role in the diets of ungulates all across Africa (Jarman & Sinclaire, 1979; Van Oudtshoorn, 2014). None of these grasses were present in the study area, which is also largely due to the fact that BNR only had three dominant grass species across the reserve. In addition, the grass species present in BNR are generally hardy, unpalatable grasses (Van Oudtshoorn, 2014). In BNR, *E. calycina* contributed to the largest portion of the annual diet (21.6%) as well as seasonally, being highest in the early dry season (27.8%) and lowest in the early wet season (16.8%). The only other study where *E. calycina* was present was in Bontebok National Park; however, the species only contributed 1.7% to the annual CMZ diet (Strauss, 2015). The two other preferred species in the current study were *M. strica* and *S. obtusa*, each contributing 5.3% to the annual diet. Although *S. obtusa* is a highly palatable grass, it only occurred within selected patched in BNR; whereas, *M. stricta* is plentiful in BNR but is considered to be very unpalatable (Van Oudtshoorn, 2014). Watson *et al* (2005) also found that *M. stricta* was generally avoided in the Mountain Zebra National Park; however, many other palatable grasses were available in the park.

There was also no comparison in the browse species selected in the diet between BNR and other studies, except for one restio species, *Ischyrolepsis capensis,* which was favoured annually (7.9%) in Bontebok National Park (Strauss, 2015). This was also the most favoured restio species in BNR, contributing 5.9% to the annual diet, being highest in the early dry season (8.4%). The two most favoured browse species in BNR were *Helichrysum dasyanthum* and *Helichrysum moeserianum*, which combined made up >17% of the annual diet. The most preferred browse species was *H. dasyanthum,* contributing >10% to the diet across all seasons and favoured most in the late wet season (11.6%). *H. moeserianum* was also preferred in the wet season, contributing 8.0% to the seasonal diet. During the late wet season there was a sudden flush of wildflower species. These species are strongly selected by CMZ, which explains the increase in use of *H. dasyanthum* and *H. moeserianum* during the late wet season. A preference for flowering species has not yet been observed in any other studies; however, the acceptance of restios is well recorded. In Baviaanskloof Nature Reserve, restios made up 3.4% of the annual diet (Weel *et al*., 2015), whilst Strauss (2015) found that restios contributed 10.7% annually to CMZ diet in Bontebok National Park. In BNR, restios made up 16.4% of the annual diet, which is substantially more than in other studies. On occasion, CMZ were found to browse on geophytes. Strauss (2015) found that geophytes made up 7.9% of CMZ diet in Bontebok National Park. As geophytes are able to store water for extended periods, they may increase CMZ water intake, especially in the dry season.

It was found that CMZ in BNR selected for leaf material when compared to other plant parts. Leaf material made up the bulk of the diet throughout all four seasons; however, there was an increase in stem material use in the late wet season, as the amount of browse increased in CMZ diet, and grass leaf material declined. Penzhorn & Novellie (1991) found that CMZ target species with high leaf:stalk ratio, with little or no moribund material. Nevertheless, they will utilize both stem and leaf components of selected grasses as course grazers (Penzhorn, 1982). An increase of flower and inflorescence use was found during the dry season. Likewise, Strauss (2015) found that CMZ in Bontebok National Park preferred to utilize stems with inflorescences during the dry season. This is also the time that grasses flower and new inflorescences start to emerge (Clayton *et al*., 2006; Van Oudtshoorn, 2014).

Plant greenness utilized in BNR was highest in the early dry season (79.3%) and lowest in the early wet season (61%). As the early wet season follows the hot dry summer, grasses become senescent during this time, which explains the increase of brown plant material in the diet. The results are supported by Van Soest (1987), who found that herbivores will favour young green leaves, as mature leaves are associated with carbohydrate build up. In the Mountain Zebra National Park, Penzhorn & Novellie (1991) found that CMZ diet selection is directed predominantly at greener grasses. Strauss (2015) also found that CMZ in Bontebok National Park generally utilized (>60%) greener grass throughout all four seasons, with the highest being in the early dry season (75%) and lowest in the early wet season (63%).

It was found that CMZ in BNR preferred grasses slightly taller than grasses selected by zebra in many other studies, with the exception of one. Cape mountain zebra generally fed on grasses between 50-150mm in height in Mountain Zebra National Park (Penzhorn & Novellie, 1991). In Bontebok National park, CMZ preferred to feed on grasses between 100-140mm in height (Strauss, 2015). Bell (1970) found that CMZ and plains zebra favoured similar heights in grasses; however, in Etosha National Park, Namibia, and in the At-hi-Kaputei Plains, Kenya, plains zebra preferred grasses >500mm in height (Havarua *et al*., 2014; Oawaga, 1975). In comparison, the CMZ in BNR targeted grasses ranging between 150-340mm which is slightly above the selection range of most other CMZ populations. The seasonal height of grasses fed on in Bontebok National Park averaged 120mm in early dry, 150mm in late dry, 125mm in early wet, and 100mm in late wet seasons (Strauss, 2015). In BNR, the seasonal grass heights utilized were 220mm during early dry, 340mm in late dry, 226mm in early wet and 156mm in the late wet season. The increase during the late dry season could be due to the change of habitat preference of the CMZ. During this season, the CMZ spent more time on top of the plateau where taller grasses, such as *M. stricta* were present. Additionally, the lack of grazers in the area for most of the year results in taller grasses. Grobler (1981) found that grass height influences food selection for CMZ. Consequently, young short growth contains less structural tissue, and is therefore favoured by herbivores (Van Soest, 1987).

Due to the lack of grasses, and general unpalatability thereof, it was found that the bulk of CMZ diet in BNR consisted of browse. Annually, browse made up >55% of the diet, with dicotyledons (29.3%) contributing the most, followed by restios (16.4%). Although the percentage of browse consumed is much higher than previously recorded, such increases in browse consumption is not unusual for zebra species. Former studies found that Grevy's zebra (*Equus gervyi*) can increase browse consumption to 30% in the dry season, especially in drought stressed environments (Churcher, 1992; Kleine, 2010; Williams, 2002) and a study by Schulz & Kaiser (2013) found that the diet of wild asses (*Equus africanus* and *Equus khur*) was made up predominantly of browse species. Strauss (2015) also observed a high portion of browse in CMZ diet, especially during the dry season (20-30%) in Bontebok National Park. In comparison, the current study found an increase in browse utilization (>5%) during the wet season; however, this falls over winter when grasses are senescing. Unlike areas of other CMZ studies, BNR receives winter rains whilst the dry hot summers do not favour the growth of grass. Thus, it can be assumed that one of the biggest drivers of changes in diet may be fluctuations in seasonal availability of forage (Schoenecker *et al*., 2016). Unlike ruminant mammals, zebra species are able to eat large quantities of low quality forage due to their specialized digestive system (Schoenecker *et al*., 2016). McNaughton (1985) also stated that plains zebra have evolved to predominantly graze on grasses of lower quality in order to minimize competition with other, more selective herbivores in the area. Generally, CMZ will prefer grasses with protein levels higher than 4% (Penzhorn, 1982) and will increase their intake of browse when the quantity and quality of available grasses declines (Penzhorn & Novellie, 1991). As grass quality and quantity in BNR is annually very low, browse utilization by CMZ is higher than grass utilization throughout all four seasons. Plains zebra have been found to increase browse intake in order to maintain sufficient protein levels, especially during a drought (Berry & Louw, 1982). However, although browse contains higher levels of protein, it cannot be classified as a high quality food source (Codron *et al*., 2007). The higher levels of tannin and allelochemicals typically found in browse could be problematic for grazers (Owen-Smith, 1997). If such a dietary shift happens, it could increase the probability of large-scale die-offs of the species due to severe nutritional stress (Landman & Kerley, 2001). Thus, the high levels of browse intake in BNR may be detrimental to CMZ in the long term.

It appears that the dietary results are greatly affected by the lack of grass abundance in BNR, which only covers 13.8% of the reserve (Chapter 5). In comparison, it was found that shrubs covered 20.6% of the landscape, geophytes covered 13.6%, and restios covered 6.9% (Chapter 5). Of the grass species present, the majority are very hard and unpalatable with low nutritional value (Van Oudtshoorn, 2014). In Mountain Zebra National Park, CMZ generally avoided areas with 0-16% grass coverage and preferred areas with grass coverages >50% (Novellie & Strydom, 1987). The only part of BNR with grass coverage >16% is the Top Plateau which consists largely of *M. stricta*. In the Mountain Zebra National Park, rocky slopes had high grass coverage (31%); however, the CMZ tended to avoid these areas as it was dominated by *M. stricta* which is unpalatable (Novellie & Strydom, 1987). Smith *et al* (2011) also found that CMZ will concentrate their foraging in a limited number of habitats. Watson *et al* (2005) found that limited suitable grassy habitats will drive poor population performance in CMZ. However, in Baviaanskloof Nature Reserve, poor population performance was exhibited by CMZ despite its favourable environment with high grass coverage (Weel *et al*., 2015). It is possible such performance is more strongly linked to competition with other grazers (Weel *et al*., 2015). The only other large herbivore in BNR is the Oryx, which is well adapted to semi-arid areas and could possibly compete for the same resources as CMZ. Thus, results suggest that the biggest driver of dietary selection in BNR is the limitation of adequate resources.

3.6 Conclusion

Unlike other studies, grasses did not contribute most to CMZ diet in BNR; however, the CMZ did utilize larger quantities of browse than zebra populations in previous studies. The lack of palatable grasses in BNR appears to have driven CMZ to dietary plasticity, in that the species exploits browse species. The high portion of browse in their diet may portend poor population performance. As a result, careful management of CMZ and their required forage species in BNR will be essential for long term persistence of the population in the reserve.

The results of this study have provided an in depth understanding of the dietary needs of CMZ in the Cape Floristic Region; however, future research could strengthen knowledge on this subject by addressing the following:

1. Conducting nutrient analysis on Nitrogen and Phosphorous levels within CMZ dung to determine if they are meeting their nutritional needs. In comparison, the same analysis should be done on the plant species to determine nutritional value of the species which are present in the CMZ diet. This is important because protein is essential for mass gain, whilst phosphorous deficiency may lead to low reproductive rates among ungulates (Grant *et al*., 2000). If there are deficiencies, a better management strategy needs to be developed or managers would have to consider the use of supplementary feed to sustain body condition. However, supplementary feed should be used as a last resort.
2. The implementation of a better fire regime in BNR and use of this as a tool to shape suitable habitats. Controlled burns at appropriate intervals will promote the growth of grass species and decrease the amount of woody plants in the area (Kraaij *et al*., 2013). This will play an important role in the Cape Floristic Region as palatable grasses become moribund with low nutritional value and in the absence of fire (Bond *et al*., 2003).

3. Including additional dietary analysis such as direct observations and stable isotope analysis, in future research. This may reduce errors that may arise from a single analytical method, such as microhistology. It would also provide a better indication of the total amount of C3 and C4 vegetation selected by CMZ (De Vos, 2017).
4. The acquisition of additional land would allow CMZ to access a greater abundance and diversity of resources. Weel *et al* (2015) found that lowland habitat is more suitable for CMZ and that additional land should allow zebra to access such areas. Thus, efforts should be made to increase land for CMZ, with possible relocations to these areas or removal of fences to allow them access to more suitable resources.
5. Research should focus on the total amount of time spent foraging per day. This will give an indication if CMZ in BNR need to spend more time foraging to reach the same nutritional satisfaction as CMZ in other areas where palatable grasses are plentiful.

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Chapter Four

Artificial waterhole dependency of Cape mountain zebra (*Equus zebra zebra*) in Bakkrans Nature Reserve, South Africa

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4.1 Abstract

Habitat fragmentation, expanding human developments and changes in climate are increasingly limiting access to water for many African wildlife species. Artificial watering points can be used as a management tool to supply Cape mountain zebra (*Equus zebra zebra*) with suitable water sources within semi-arid environments but require careful planning as there can be negative repercussions. This study aimed to better understand seasonal artificial water point use by Cape mountain zebra in Bakkrans Nature Reserve, South Africa. Three out of four artificial watering points were monitored from 1 June 2018 to 31 May 2019 with the use of camera traps, and all positive zebra sightings were recorded. It was found that Cape mountain zebra utilized artificial watering points primarily around dusk, peaking at 19:00h and 20:00h. Artificial watering points in the low lying areas were utilized more frequently which correlated with more suitable zebra habitat and higher animal densities ($\chi^2_{(df=2)}$ = 7285.22, p<0.001). Cape mountain zebra sightings at artificial watering points (n=1062) increased during the dry season (n=626), with the early dry season being the highest (n=351) ($\chi^2_{(df=3)}$ = 9461.90, p<0.001). These findings provide insight into factors that correlate with changes in artificial waterhole use by Cape mountain zebra in closed populations. Further research is needed on water quality, effects of habitat degradation around artificial watering points, and interactions with other herbivores and predators in the area. This will assist managers in developing a water privacy policy for arid and semi-arid protected areas.

4.2 Introduction

Access to water is one of the most important factors affecting the survival and reproductive success of Cape mountain zebra (Skinner & Chimimba, 2005; Smith *et al*., 2007). Historically, many zebra species made use of migrations to follow the seasonal changes in resource availability (Ekernas & Berger, 2016); however, with increased changes in climate and habitat fragmentation by human expansion, access to resources, such as water, is becoming more limited to wildlife (Hulme *et al*., 2001; Moehlman *et al.,* 2016). As a result, the migration of zebra, specifically, has been restricted to large ecosystems such as the Serengeti (Ekernas & Berger, 2016; Ogutu *et al*., 2016). Outside of these areas, fragmented habitats have led to a decline in plains zebra (*Equus quagga*) population numbers (Moehlman *et al.,* 2016), whilst Cape mountain zebra (*Equus zebra zebra*) (CMZ) faced similar threats in the past. During the 1900's, with the expansion of agricultural activities, local farmers nearly extirpated CMZ because they competed for the same resources as domestic livestock (Smith *et al*., 2007).

During the dry warm season, equids are very dependent on water; thus, it plays a significant role in their distribution, movement patterns and habitat use (Schoenecker *et al*., 2016). Large herbivores experience fluctuations in annual and seasonal resource availability, especially in arid and semi-arid environments (Valeix, 2010). Species require adequate amounts of water throughout the year to complement forage selection and any changes in diet (Valeix, 2010). During the wet season, equids are able to make use of pools of water in fields, and in sub-zero environments they are even able to eat snow for hydration (Kaczensky *et al.,* 2010). This allows them to forage further away from more permanent watering points such as rivers, dams and borehole guzzlers (Feh *et al.,* 2002; Schoenecker *et al.,* 2016). However, Redfern *et al* (2003) found that plains zebra mostly utilize areas >5km away from a water source, although they can range 10-30km away to meet their foraging requirements. As a result, zebra rely on behavioural strategies to avoid both dehydration and starvation (Smith & Grant, 2009). They do this by, for example, distributing themselves in nutrient rich habitats, staying close to water, or migrating to areas with higher levels of forage (Moehlman *et al*., 2016). Jarman (1973) also found that grazers are generally more water dependant than browsers, as the moisture content of grasses will drop to <10% by the late dry season. Differences in water dependency among ungulate species may arise as a variety of behavioural and physiological mechanisms are used to maintain adequate body temperature and water levels (Cain *et al*., 2011). Due to a higher digestive throughput, hind gut fermenters will experience higher levels of water loss through faeces; thus, equid species are highly water dependant and need to access water on a daily basis (Cain *et al*., 2011). A lack of any of these resources will have negative effects on the distribution and ecology of zebra as both forage and water is fundamental to their survival (Antrobus, 2014).

Climatic changes are predicted to decrease the annual rainfall throughout most of Africa and could further limit access to surface water and forage in the future (Hulme *et al*., 2001). Zebra will have to utilize larger areas to satisfy their water and forage requirements to adjust to decreasing resource availability (Smith & Grant, 2009). Thus, the carrying capacity of both protected and non-protected areas may change (Bartlem-Brooks *et al*., 2013). Subsequently, zebra recruitment rates may also be altered. Research conducted on Grevys zebra (*Equus grevyi*) found that foals will face increased mortality and recruitment will decline if zebra have to travel too far a distance in search of resources (Williams, 1998). As a result, zebra numbers could drastically decrease if droughts persist throughout Africa (Skinner & Chimimba, 2005). High rainfall variations in arid and semi-arid areas may result in severe droughts and increased herbivore mortality (Walker, 1987; Owen-Smith *et al*., 1990). These elevated levels of stress could already be affecting plains zebra populations, given their recently up listed conservation status, from Least Concerned to Near Threatened (King & Moehlman, 2016). Cape mountain zebra are currently classified as Least Concern on the IUCN red List and the majority of the populations are found in fenced private nature and game reserves, (Birss *et al*., 2016; Hrabar *et al*., 2019). This may limit their access to resources as CMZ likely exhibited migratory behaviour in the past, moving across the Western and Eastern Cape following resources (Watson *et al*., 2005; Smith *et al*., 2007; Weel *et al*., 2015).

With drastic expansions of human settlements and major climatic changes, empirical knowledge of behavioural and demographic characteristics and conservation efforts will play an important role in combating detrimental effects of climate change, resource competition and habitat fragmentation (King *et al*., 2016). If done with proper planning, one of the most effective management tools to combat these effects is the use of artificial watering points (AWPs) (Traill, 2003). Artificial watering points are most commonly used in arid and semi-arid environments to help maintain wildlife densities where natural water sources are unpredictable (Chamaille-Jammez *et al*., 2007). In addition, AWPs are able to extend herbivore forging range and help with the management of water dependant species (Redfern *et al*., 2005; Loarie *et al*., 2009). Valeix (2010) found that when water sources become depleted, herbivores are forced to concentrate in the immediate vicinity of the last remaining areas with drinking water, resulting in higher levels of aggression between species. Thus, AWPs may help to relieve aggression between herbivores around watering points, especially in the dry season (Valeix, 2010).

If not correctly managed, AWPs can have severe consequences for certain species. A study by Harington *et al* (1999) in the Kruger National Park found that during times of severe drought, AWP's caused an unwanted influx of common grazers into areas which they would not normally occupy. This had an effect on the more rare species that occupy these areas because the large, common, grazers would out-compete them for resources (Harrington *et al.,* 1999; Owen-Smith & Mills, 2006). Common grazers also attracted more predators, exposing the more uncommon species to greater risk (Cain *et al*., 2011). Artificial watering points also have an effect on the surrounding vegetation: they have been blamed for increased herbivory around these points and the consequent negative effects on vegetation (Smit *et al*., 2007). This may also lead to increased erosion around watering points or even local desertification (Eckhard *et al*., 2000; Gereta *et al*., 2004). In areas that lack complete protection, permanent water sources can attract pastoralists and their livestock, thus increasing competition for limiting resources. However, the piosphere effect argues that vegetation gradients will form around permanent watering points and maintain heterogeneity (Chamialle-Jammes *et al*., 2009; Landman *et al*., 2012) Therefore, managers need to be informed on how different AWPs are being utilized across the reserve, so that predictions can be made on the impact and distribution of animals on the surrounding vegetation (Smit *et al*., 2007).

In 2001, 15 CMZ were reintroduced to Bakkrans Nature Reserve and have distributed throughout the reserve. The only other large mammals on the reserve are Oryx (*Oryx gazelle*) and their population is estimated to be at around 20 individuals. Due to limited water sources, solar powered AWPs were established across the reserve in 1999. This aided with the establishment of the newly introduced CMZ population and also sustains the other animals that are found in the reserve, especially during the dry season. The aim of this study was to determine artificial waterhole use by CMZ in BNR and to determine if there were any seasonal variations in such usage. The study hypothesised that: (1) CMZ would utilize AWPs diurnally; (2) AWPs would not be used equally; and (3) AWPs would be visited more frequently during the dry season as compared to the wet season (Cain *et al*., 2011; Sirot *et al*., 2016). The results from this study will inform the management team of BNR towards the positioning and closures of AWPs. Very little is known about how CMZ use water points within closed reserves. The study will also contribute to the management plan for CMZ within the Western Cape, South Africa, which forms part of a larger study conducted by CapeNature (Birss *et al*., 2016).

4.3 Methods

4.3.1 Study site

Bakkrans Nature Reserve (32. 5056º S, 19. 3406º E) is situated in the Cederberg Wilderness Area of South Africa and is a biodiversity hotspot (Figure 4.1). The reserve is approximately 5000ha in size and falls within the transitional zone where fynbos and low succulent karoo vegetation overlap (See Figure 1.2 in Chapter 1). The main vegetation type in BNR is the Swartruggens Quartzite fynbos, which includes alternating mountains with broad ridges and plains (Mucina & Rutherford, 2006). Bakkrans Nature Reserve can be further divided into two vegetation types, namely: Asteraceous Fynbos, which is located on the higher lying mountain tops, and Succulent Karoo on the low lying sandy flats. The reserve consists of predominantly sedimentary rock of the Table Mountain group, although there are also parts that consist of older Malmesbury Group shales and young Bokkeveld formations (Quick *et al*., 2011). The area is dominated by Ericaceae, Proteaceae, Asteraceae and Restionaceae species and also supports other large mammals such as the Cape mountain leopard (*Panthera pardus pardus)* and Oryx (*Oryx gazella)* (Quick *et al*., 2011). There is also sign of karroid elements, towards the drier Cederberg areas, which is dominated by succulent dwarf shrubs. The best definition for the vegetation is an open thicket with a restioid understory. The highest part of the mountain range reaches 1500m and the area experiences an average annual rainfall of 200-250mm, of which 80% occurs in the winter (June to August) (Quick *et al*., 2011). Summer months (December to February) are hot and dry with temperatures reaching over 40ºC whilst winters are cold and wet with frequent snow and below zero temperatures.

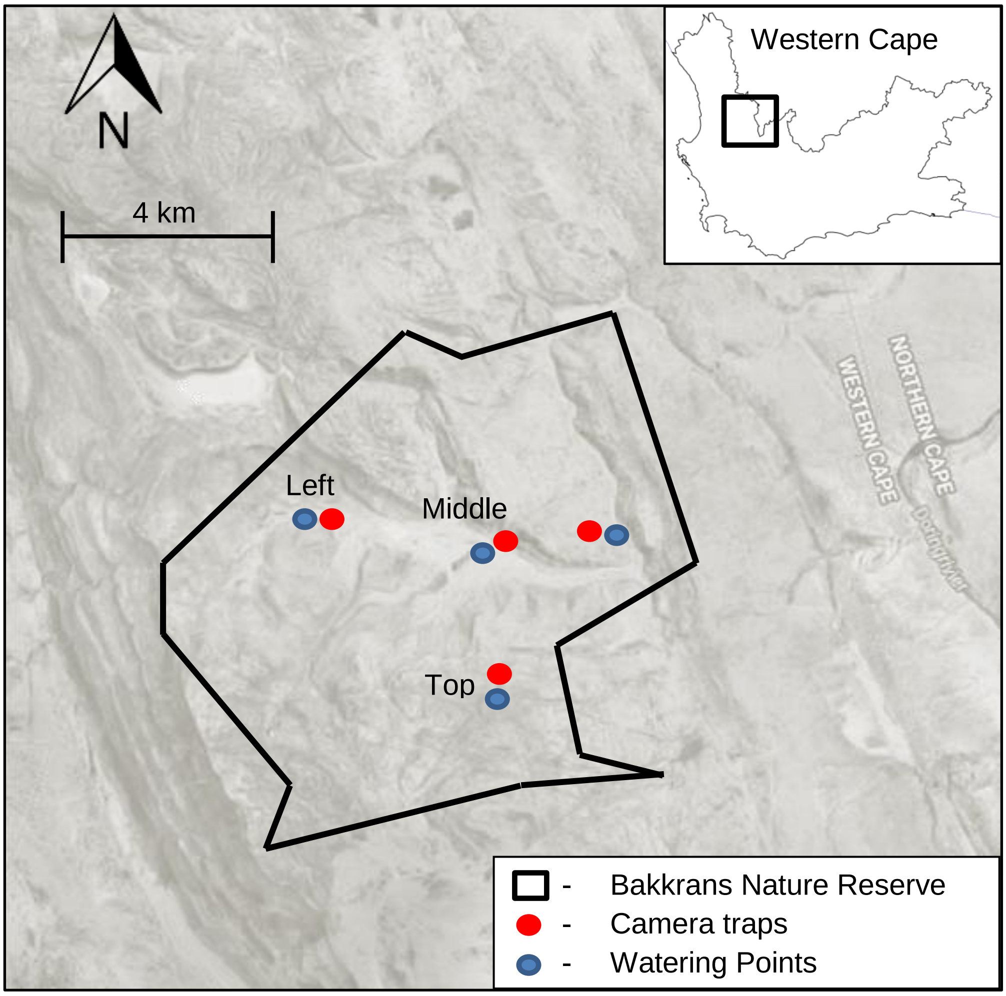

Figure 4.1: The distribution of the four artificial waterholes in BNR. A camera trap was placed at the Top, Middle and Left points. The remaining AWP was often dry, although a camera trap was positioned nearby for demographic data.

4.3.2 Artificial waterhole usage

Artificial waterhole usage in BNR was monitored between June 2018 and May 2019, by installing camera traps (Bushnell^{TM}, E3 Trophy Cam) at three (Top, Middle, Left) different AWPs located in the reserve (Figure 4.1). Camera traps were preferred over observational studies because they allow for the long term (diurnal, nocturnal and unobtrusive) observation of the study species within their natural habitat (Stein *et al*., 2008). Two (Left and Middle) of the cameras were located in the low lying Succulent Karoo flats, whilst the remaining camera (Top) was placed at the only AWP in the upper Asteraceous Fynbos habitat located on the plateau. The three cameras were placed at the most active AWPs that were all frequently used. The remaining AWP was not selected for this part of the study because it was often dry. Cape mountain zebra were observed to visit this watering hole; however, as it was often dry, it could not be included in the study as a positive sighting of waterhole utilization. There is also one natural spring on BNR which has at least 2 small pools (3m diameter) and provides water all year round. However, these pools are located deep within a valley dominated by restios, which is not a favoured habitat for CMZ, so were not monitored.

Camera traps were mounted on wooden poles, at a height of 75cm, which were planted in the ground at least 6m from the AWP. This allowed for a wide angle view of the watering hole to ensure that the maximum photographic data of any CMZ activity at the AWPs were collected. A GPS location was recorded for each individual camera station. The camera traps were set to high sensitivity and programmed to take a quick sequence of three photos each time, with a delay of 60 seconds between each sequence. At night, the cameras used an infra-red flash to capture images, which enabled 24h waterhole observations. Infra-red flash was preferred over white flash to avoid startling zebra and possibly influencing watering hole use. All cameras were monitored once per month: AWPs were easily accessible from established roads which enabled battery life and memory space to be closely monitored. Each 16GB memory card was replaced each month, and if battery life was below 50% the batteries were replaced. Where necessary, vegetation in a cameras field of view was minimally cleared to prevent the movement of grasses and bushes from triggering the cameras.

Photographs were downloaded and saved on a monthly basis. Any questionable sightings were discarded and only positive zebra sightings were used for the analysis. Bands and individuals were identified to avoid double counting. Cape mountain zebra data at the three AWPs were attributed to location, exact time and the seasonal period: Early dry (September to November, mean rainfall: 12.6mm per month), late dry (December to February, mean rainfall: 8.3mm per month), early wet (March to May, mean rainfall: 14.2mm per month), and late wet (June to August, mean rainfall: 37.8mm per month).

4.3.3 Statistical analysis

Statistica 13.3 (Dell software, 2018) was used to conduct all statistical analyses. To analyse if the frequency of visits by CMZ to artificial watering holes were different by watering hole, a Chi-squared Goodness of fit test was used. Each time a camera took a photograph of a zebra or portion of a zebra or group of zebras visiting the AWP, it was classified as an independent visit. A Chi-square goodness of fit test was used to determine if there was a daily waterhole use pattern. A correspondence analysis was used to test if different seasons corresponded with different times of day that zebra preferred to utilize AWPs within BNR. Thereafter, a Chi-square Goodness of fit test was used to determine if there was any difference within the pattern or correspondence analysis.

4.4 Results

A total of 1062 zebra sightings (a photograph that contained a portion of a Cape mountain zebra or zebras) were recorded using Bushnell™ camera traps between June 2018 and May 2019 at three different artificial watering holes within Bakkrans Nature Reserve (Figure 4.2). However, these three watering holes were not visited equally ($x^2_{(df=2)}$ = 7285.22, p<0.001). A difference in the number of visitations to watering holes by season was detected ($x^2_{(df=3)}$ = 9461.90, p<0.001). Of the 1062 zebra sightings, 351 were in the early dry season, 276 in the late dry season, 309 in the early wet season, and 126 in the late wet season (Figure 4.3).

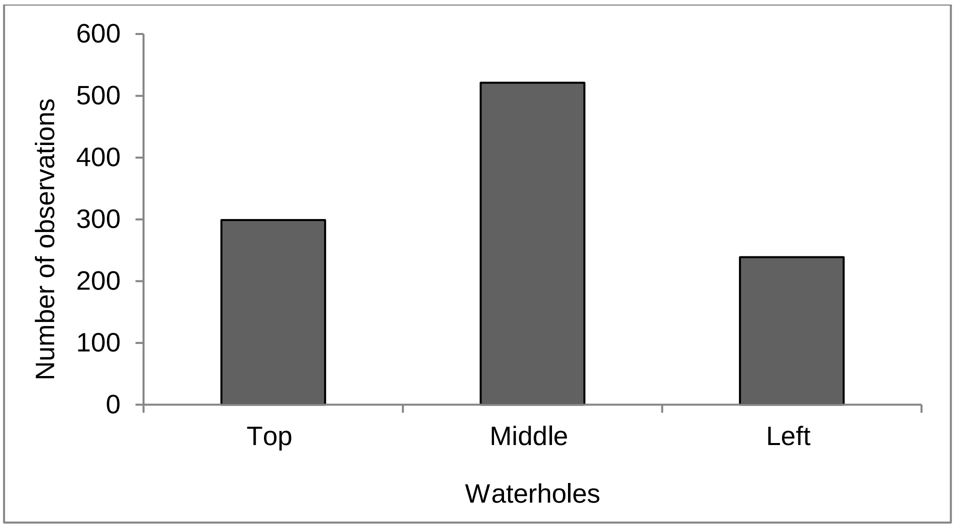

Figure 4.2: The comparative representation of the number of CMZ sightings among the three different artificial waterholes in BNR ($x^2_{(df=2)}$ = 7285.22, p<0.001).

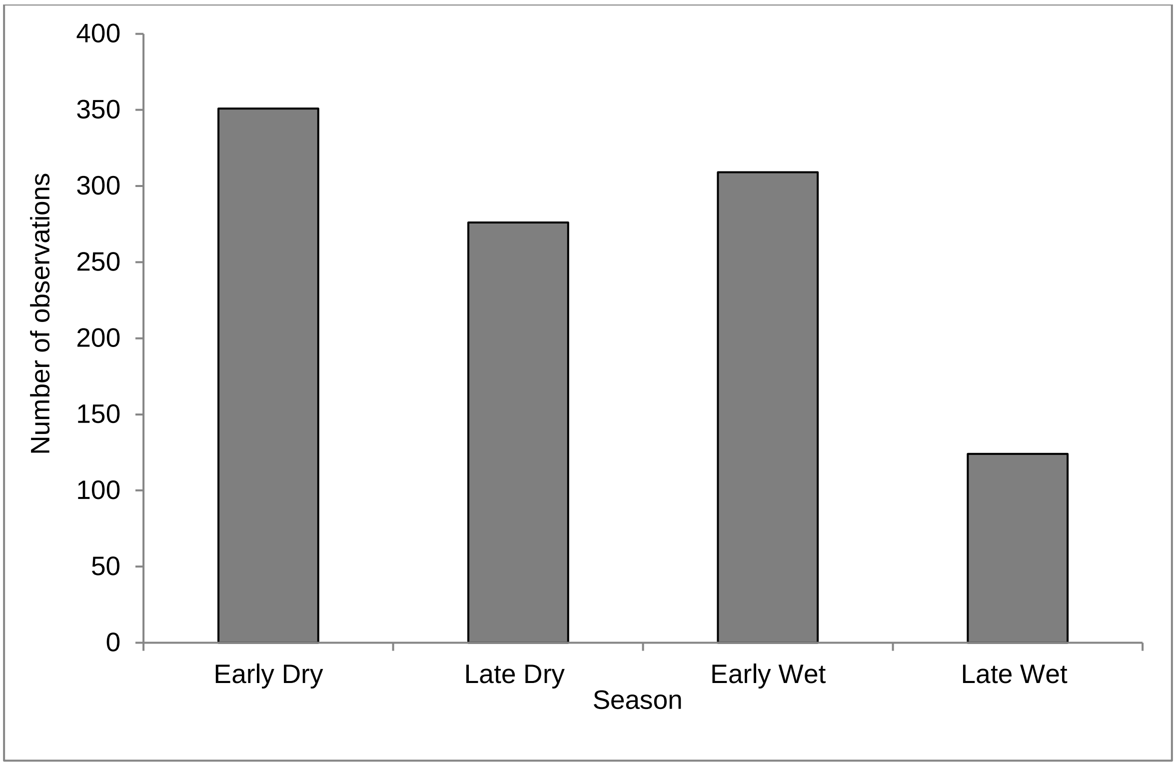

Figure 4.3: The comparative representation of the number of zebra sightings across the different seasons in BNR ($x^2_{(df=3)}$ = 9461.90, p<0.001).

Cape mountain zebra were recorded using artificial waterholes during each hourly interval across a 24-hour period (Figure 4.4). A significant difference was found between the number of visits by CMZ to artificial waterholes and time of day ($x^2_{(df=23)}$ = 1431.41, p<0.001). The majority of CMZ sightings were recorded at dusk and dawn, peaking at 19:00h (74 sightings) and 20:00h (80 sightings). A difference was detected between the time of day that CMZ preferred to visit artificial waterholes and the different seasons ($x^2_{(df=72)}$ = 238.94, p<0.001). The strongest correspondence in each season was 17:00h during the early dry, 21:00h during late dry, 18:00h during the early wet and late wet season.

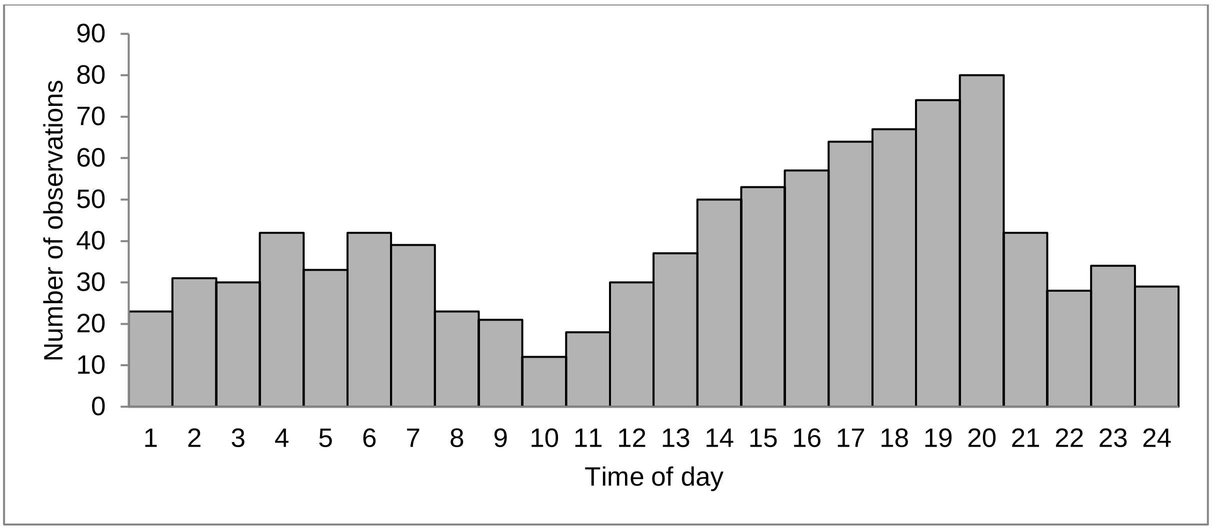

Figure 4.4: The total number of visits by CMZ bands or individuals to artificial waterholes during each hour across 24 hours in BNR ($x^2_{(df=23)}$ = 1431.41, p<0.001).

Cape mountain zebra were recorded utilizing artificial waterholes in two different habitat types ($x^2_{(df=1)}$ = 89.28, *p*<0.001), (Figure 4.5), with the Succulent Karoo being highest at 521 observations and Asteraceous Fynbos lowest with 299 observations.

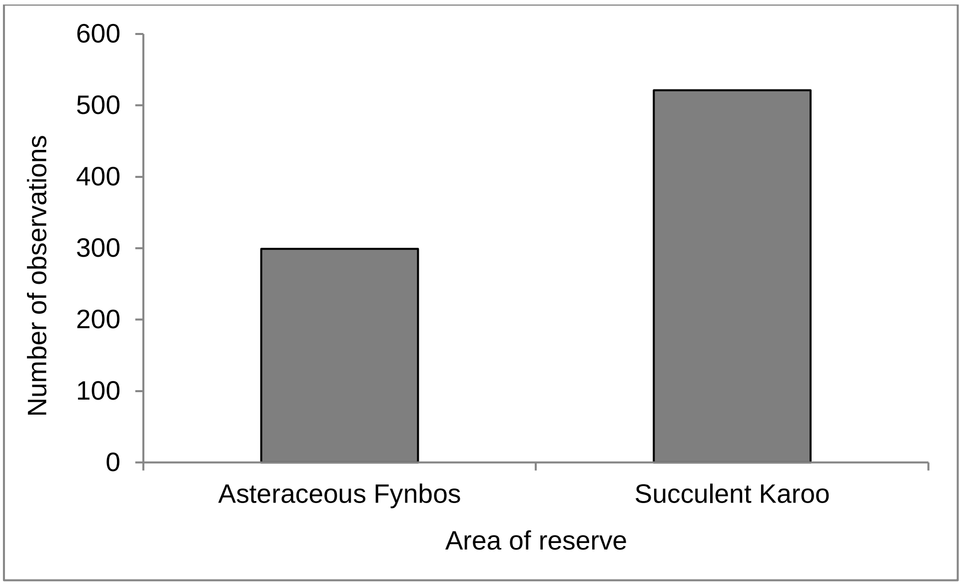

Figure 4.5: The total number of CMZ observations between the two different vegetation types ($x^2_{(df=1)}$ = 89.28, p<0.001).

4.5 Discussion

Small fenced reserves hinder the migration of large herbivores to better resources; thus, the provision of water to animals in these areas is crucial, especially during the dry season. All three of the monitored AWPs in BNR were utilized by CMZ, but not equally. The centrally located water hole (Middle) was used more frequently than the other two. This may be due to the higher density of CMZ in this area, the central location of the watering point, and ease of access. This AWP is situated in the Succulent Karoo habitat which was found to be utilized more than the Asteraceous Fynbos AWP. This is supported by the results in Chapter 2 and 3, as CMZ preferred to forage in the low lying Succulent Karoo habitat. Conditions favour CMZ within this habitat as they have access to three AWPs, one natural spring, and an abundance of resources. Weel *et al* (2015) also stated that low lying areas are more suitable for CMZ.

The only previously recorded findings on CMZ water usage were by Penzhorn & Novellie (1991) and Cleaver (2004), who found that CMZ were water dependant and had to drink daily, with the peak time being from late afternoon to dusk. Usage of AWPs in BNR peaked at 19:00h and 20:00h, which concurs with the Penzhorn & Novellie (1991) findings; however, there were no similarities to previous studies on plains zebra. Plains zebra in Tsavo National Park, Kenya, Hwange National Park, Zimbabwe, Kruger National Park, South Africa, and Majete Wildlife Reserve, Malawi, all used APWs diurnally, with peaks around 09:00h, 13:00h and 14:00h (Ayeni, 1975; Cain *et al*., 2011; De Vos, 2017; Rubenstein, 2010; Valeix *et al*., 2007), and Hayward & Hayward (2012) found that plains zebra never utilized watering points at night. Cape mountain zebra utilized AWPs at different times of the day in different seasons in BNR. During the early dry season, CMZ preferred to utilize AWPs at 17:00h whilst in the late dry season the preferred time was 21:00h. However, in both the early and late wet season they preferred to utilize AWPs at 18:00h. These time differences between seasons may be driven by the change in time of dusk. In the dry season (summer) dusk is at a later time, whereas in the wet season (winter) dusk is much earlier. Penzhorn & Novellie (1991) found that CMZ prefer to drink water from late afternoon till dusk. In comparison, De Vos (2017) found that added heat pressure and competition with other species drove plains zebra to utilize AWPs at 20:00h in the dry season. Thus, the seasonal changes of AWP utilization may be the result of the increase in inter and intra-specific competition for water, as natural sources become limited in the dry season (Valeix *et al*., 2007; Sirot *et al*., 2016).

Camera trap data showed an increase in AWP utilization by all species in BNR during the dry season. It was found that species such as Oryx and Chacma Baboons (*Papio ursinus*) spent extended periods of time at the AWPs during this time. Although the study did not explicitly test interspecific competition, these observations should still be taken into consideration, especially as baboons were never seen utilizing AWPs at night. Ayani (1975) also found that Oryx would use watering points predominantly during daylight hours. Thus, competition with Oryx and baboons may drive CMZ in BNR to use AWPs at night. Thermoregulation may also drive the CMZ to utilize AWPs at a later time as it becomes increasingly energetically costly to travel to AWPs during the day, due to the lack of trees, and thus shade in BNR which exposes CMZ to summer temperatures of 40^{o}C at midday. These factors may suggest why the CMZ in BNR are utilizing AWPs at cooler times of the day. Valeix *et al* (2008) also found that thermoregulation played an important role in time spent accessing water by plains zebra within Hwange National Park, Zimbabwe. The diurnal preference may also be due to the presence or abundance of large predators in other study areas (Hayward *et al*., 2006; Hayward & Hayward, 2012; Sirot *et al*., 2016; De Vos, 2017). Zebra will utilize watering points diurnally to avoid predators which are more active nocturnally (Hayward *et al*., 2006; De Vos, 2017). Predator densities in BNR are very low, with the only large predator being the Cape leopard. Predation on CMZ by Cape leopard has been reported as very unlikely (Hayward *et al*., 2006). Thus, the lack of likely predators in BNR may eliminate the element of fear among CMZ and enable them to utilize AWPs at night.

There was a very notable increase in zebra sightings at AWPs from the late wet season to the dry season; however, the early wet season still showed frequent CMZ waterhole visits. The increase in dry season visits corresponds with other studies. De Vos (2017) also found that plains zebra increased AWP visits in the dry season, and Valeix *et al* (2008) found similar results for plains zebra in Hwange National Park, Zimbabwe. The increase of AWP visits during the dry season may be a consequence of surface water becoming increasingly limited (Jarman, 1973), as BNR received the lowest monthly rainfall during this season. It may also be linked to behavioural and morphological mechanisms used to maintain body temperature and water balance (Cain *et al*., 2006). The increased water usage by CMZ in the hot dry season may aid in keeping body temperature low. Higher water requirements are also necessary to more efficiently digest grass, as compared to browse (Western, 1975; Valeix *et al*., 2007). Jarman (1973) found that grass moisture levels decrease below 10% towards the end of the dry season. This is supported by Western (1975), who found that grazers in Amboseli National Park, Kenya, were much more water dependant than browsers. An increase in grass consumption was found during the dry season by CMZ (Chapter 3), which may drive CMZ to utilize AWPs more frequently in the dry season. An increase in AWP visits during the early wet season was also detected. As BNR is situated in a semi-arid environment, it receives the majority of its rain during the late wet season, with the first heavy rains generally recorded at the end of the early wet season (mean = 14.2mm per month) and start of the late wet season (mean = 37.8mm per month). However, the Western Cape has been in a severe drought for the past few years, receiving later and less frequent rains during the usual wet season. The first rains in the study area were only recorded in June 2019, which was during the late wet season. Subsequently, the effects of the dry season would be carried over into the early wet season. Temperatures during the early wet season were still extremely high (up to 35^{o}C at midday) and may have contributed to the increase in AWP visits. The CMZ also increased their total intake of brown forage during this time (Chapter 3), which would be water deficient. As a result, CMZ may increase their water intake to aid in digestion and supplement the low water content in their forage (Walker, 1975; Epaphras *et al*., 2008). Thus, results from this study suggest that AWPs in BNR act as a valuable water source to CMZ during the dry season.

The notable increase in visits of CMZ to AWPs during the dry season may lead to habitat over-utilization and degradation within the areas surrounding AWPs (Cain *et al*., 2011; Madzikanda & Fritz, 2016). Vegetation degradation around these AWPs has the potential to homogenize the habitat, which may leave the system vulnerable to starvation-induced mortalities, especially during extended drought period (Smit & Grant, 2009). Thus, it is suggested that water holes be relocated by at least 5km annually to combat the effects of erosion and overgrazing (Ayeni, 1977, Du Toit, 2003). However, piosphere development theory suggests that vegetation cover will be maintained, up to 5km, around permanent watering points despite increased herbivore activity (Chamaille-Jammes *et al*., 2009). Jafari *et al* (2008) also found that grazing may even increase heterogeneity within piospheres, although it is dependent on initial vegetation and the grazing patterns of specific herbivores (Adler *et al*., 2001).

Chamaille-Jammes *et al* (2009) suggested that increased woody cover and loss of heterogeneity will be more likely at large landscape scales and that smaller scale environments will maintain heterogeneity within piospheres. Thus, piospheres in BNR may maintain heterogeneity and high vegetation coverage as it is a small scale reserve with few large herbivores.

4.6 Conclusion

Due to limited water sources in BNR, the provision of water from AWPs is critical to the survival of CMZ, especially during the dry season. The increase of CMZ sightings at AWPs during the dry season demonstrates the importance of these waterholes for the future persistence of CMZ within arid and semi-arid regions. Changes in climate also predict a decrease of rainfall across Africa, consequently limiting the access species have to natural surface water (Hulme *et al*., 2001). When correctly managed, AWPs have the ability to supply a number of species with sufficient resources and reduce mortalities. However; AWPs should be closely monitored because over utilization of these points may lead to habitat degradation and increased aggression between species (Chamaille-Jammes *et al*., 2016; Sirot *et al*., 2016).

The first hypothesis, that CMZ will utilize AWPs predominantly during the day, was rejected. Support was found in the data for the second hypothesis, that CMZ would not use AWPs equally, and for the third hypothesis, that AWPs would be utilized more frequently in the dry season. These results have provided a deeper understanding of the water utilization of CMZ within a semi-arid environment; however, future studies can improve knowledge on this subject by focusing on the following:

1. Quality of water sources should be assessed to determine if water quality is affecting waterhole usage by CMZ. There are a number of factors that could be affecting water quality at the AWPs; namely, the AWPs receive water from different sources, and depth of the borehole could affect water quality, as could the distance that water travels through plastic pipelines. This can be tested by measuring the water pH levels, salinity, oxygen concentration, mineral composition and surface water temperature (Wolanski & Gareta, 2001; Epaphras *et al*., 2008). Water should also be tested for algae content and the possibility of diseases that might be transmitted through other species or through the water source (Ayeni, 1975; Epaphras *et al*., 2008).

2. Species interactions around watering holes should be assessed as the dry season may increase competition and aggression around AWPs (Cain *et al*., 2011). This could be done by conducting 12h waterhole observations and quantifying the interactions between specific species and CMZ, as well as the timing and length of interactions (Ayeni, 1975). This may provide some insight as to whether specific species are driving CMZ to utilize AWPs at certain times of the day/night. Camera trap data should also include predator AWP activity and compared to that of CMZ. This will provide an indication of how predator densities may affect CMZ water point utilization.
3. Habitat degradation surrounding the AWPs should be assessed by looking at the rate and intensity of plant species disappearance within the area (Ayeni, 1975). This can be done through point transects in the surrounding area and comparing this to point transects at least 1-2km from the watering points. It will give an indication of the total amount of soil coverage by plants as well as total number of species present. The areas surrounding AWPs are prone to disturbance, which will leave room for invasive species to colonize and dominate the area, and lead to less suitable habitats for herbivores. Thus, close monitoring of these areas is crucial.
4. Assessment of dung-water content should be carried out. Grazers lose water content (60-70%) through dung and may have to utilize water points more frequently than other herbivores (Cain *et al*., 2011). As the CMZ in BNR have a high browse diet, they may lose less water through dung and would not be as water dependant as CMZ elsewhere. The total amount of visits by individual CMZ could be assessed and compared to dung water content. The water content of selected plant species should also be assessed to determine how much moisture CMZ can obtain from certain plant species. This study found that CMZ foraged on geophytes (Chapter 3) and because these plants hold high concentrations of water, they may act as a valuable source of water uptake for CMZ.
5. Total distance travelled between water utilization should be assessed by fitting a satellite collar to one of the CMZ in each band. This can help quantify distance travelled and how much energy CMZ use before returning to an AWP.

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Chapter Five

Habitat suitability for Cape mountain zebra (*Equus zebra zebra*) in four private nature reserves within the Western Cape, South Africa

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5.1 Abstract

Habitat suitability is measured through four primary habitat essentials: food, water, shelter and protection. Habitat suitability of Bakkrans Nature Reserve, South Africa, was assessed to determine how suitable the reserve is for a reintroduced and now partially established population of Cape mountain zebra (*Equus zebra zebra*) (CMZ). Comparatively, the suitability of three other reserves for the potential reintroduction of CMZ was also assessed, namely: Grootwinterhoek, Limietberg and Matjiesrivier Nature Reserves. These reserve sites were identified as they all fall primarily within similar habitat types. It was found that Bakkrans Nature Reserve has poor habitat suitability, with Habitat Suitability Index scores of <10. Similar results were found for Matjiesrivier Nature Reserve and Grootwinterhoek Nature Reserve. This is as a result of low grass abundance and general lack of palatable grasses. Of all the reserves, Limietberg Nature Reserve had the most suitable habitat (*VI=1.00)*, with a high quantity of palatable and semi-palatable grasses favourable for CMZ. Results therefore suggest that only Limietberg Nature Reserve will be suitable for CMZ reintroductions. Furthermore, the existing population in Bakkrans Nature Reserve may need to be translocated to a more suitable area due to poor population performance. Active management of this population is needed, given the below optimum habitat and low carrying capacity. Management measures for Bakkrans Nature Reserve should also include better fire regimes to spur the regrowth of grasses, however ultimately translocation to Limietberg Nature Reserve may be a solution.

5.2 Introduction

Habitat selection can be defined as the behavioural decisions an animal makes which results in how the species are distributed throughout different scales in the environment (Bailey *et al*., 1996). Due to the heterogeneous nature of natural landscapes, habitat types will be used disproportionately (Jarman, 1974; Sinclair, 1979; Morris, 2003). Animals modify their movement patterns and habitat use to minimise the chances of encountering or being captured by predators, whilst at the same time satisfying their nutritional needs (Fortin *et al*., 2005; Fischhoff *et al*., 2007). Plains zebra (*Equus quagga*) have been found to modify their movement patterns in order to avoid one of their main predators, lions (*Panthera leo)* (Fischhoff *et al*., 2007). However, they cannot always rely on detecting lions in an area; thus, they alter their movement patterns by utilizing areas during different times of the day, thereby minimising the chances of encountering a predator (Fischhoff *et al*., 2007). They can also alter their feeding pattern and spend a larger amount of their time in a vigilance state (Seeber *et al*., 2019). Ultimately, these decisions will give them the best chance of survival within their territory.

Species distribution ranges have been the most reliable indicator for determining the macro-ecology of various species (Brown, 1995; Gaston & Blackburn, 2000) and forms the foundation for conservation planning and management (Myers *et al*., 2000; Rondinini *et al*., 2006). However, despite the increase in quality and quantity of data on a large number of terrestrial mammals, these data are not homogeneous across taxa or over very large scales (Gaston, 2003). Small scale maps of species distribution are sufficient for management of macro-ecology but often lack information at the scale most useful for real conservation action (Boitani *et al*., 2004). This lack of consistency can be an obstacle, especially for studies assessing the conservation status of species and communities, as the success of conservation actions will depend on the accuracy of determining a species geographic range and the precision of management recommendations (Boitani *et al*., 2004). Landscape connectivity is one of the most important aspects for animal dispersal as well as gene flow throughout populations (Coulan *et al*., 2004; Vigniere, 2005; Stevens *et al*., 2006). In a continuous landscape, animal dispersal allows animals back and forth movements in order to utilize a variety of different resources (Baguette & Van Dyck, 2007). Fragmentation hinders the movement of gene flow, as individuals at shorter distances are genetically more related compared to individuals at longer geographic distances (Wright, 1943). Within fragmented landscapes, animal dispersal shifts to faster, more direct searches for resource patches or suitable habitats (Baguette & Van Dyck, 2007). Dispersal routes within these areas are likely to include habitats that animals find hospitable because dispersal risks and costs are increased in hostile environments (Wang *et al*., 2008). Dispersal distances are greatly increased through fragmented landscapes. As a result, habitat fragmentation and land use, affects landscape connectivity and hinders gene flow between populations; thus, leading to less suitable habitats (Berry *et al*., 2005).

Habitat suitability has been defined as the probability of a species to use a specific habitat (Wang *et al*., 2008). Habitat suitability models of species distribution can be used to evaluate and predict suitable habitats or resource patches within a landscape (Pearce & Boyce, 2006). Such suitability maps can provide an indication of the probability of a specific habitat to be used by a species based on a range of species-environmental relationships (Boyce *et al*., 2002; Guisan & Thuiller, 2005). A suitability map will give us valuable information on the distribution of resources available for a given species within a specific landscape (Wang *et al*., 2008). Conservationists have become increasingly dependent on models of natural systems and populations which aid them in decision making over management strategies (Pascual, & Hilborn, 1995). Over the past two decades there has been a drastic rise in the use of spatial habitat models and more recent studies have linked Geographic Information Systems (GIS) to multivariate models in an attempt to understand species habitat association, and habitat suitability for a specific species (Hirzel *et al*., 2001). Many of these studies have focused on already established populations; however, there may be greater need to determine habitat suitability for populations potentially being translocated into new areas (Wolf *et al*., 1996).

Historically, Cape mountain zebra (*Equus zebra zebra*) (CMZ) occurred throughout the Western Cape province and western parts of the Eastern Cape province of South Africa (Skead *et al*., 2007; Weel *et al*., 2015). However, they currently occur in small genetically isolated populations, and the shortage of protected areas of suitable size and habitat quality now threatens the survival of this species (Smith *et al*., 2007; Hrabar & Kerley, 2009). As a result, a Biodiversity Management Plan (BMP) was developed by CapeNature for the management of CMZ within the Western Cape (Birss *et al*., 2016). This BMP states that CMZ should be reintroduced into areas which they historically occupied (Birss *et al*., 2016). These will be the pioneer populations of CMZ and will provide data on how these zebra establish themselves in new habitats. Hrabar & Kerley (2013) defined reintroductions as "human-assisted movement of animals among small, isolated populations managed as one metapopulation, with the aim to reinforce population size or enhance or maintain genetic variability". In addition, the IUCN has set up a "Guidelines on Reintroductions and Other Conservation Translocations", which implements, oversees and plans all reintroductions (IUCN/SSC, 2013; Kaczensky *et al*., 2016). However, these reintroductions could be very challenging and have negative effects logistically and financially, and on the animal population itself (Harrington *et al*., 2013). These populations are not always self-sustainable as suitable habitat can be limited within the release area (Wolf *et al*., 1996; Komers & Curman, 2000). Thus, it is recommended that future translocation protocols be based on thorough habitat assessments (Wolf *et al*., 1996): habitat quality being described as "good" or "poor" is inadequate, and often not worth the cost and risk involved (Owen-Smith, 2003).

Commers & Kurman (2000) stated that the purpose of habitat assessments should be to maximise the initial population growth, whilst at the same time shortening the period at which the population is at risk. Habitat suitability depends fundamentally on the abundance of palatable food resources (Owen-Smith, 2003). For herbivores, it might appear as if resources are available everywhere; however, plant parts and species can differ substantially in their nutritional values (Jarman, 1974; Owen-Smith, 2003). It is important for animals to make decisions on what to eat and what not to eat, as these decisions have consequences for them successfully meeting their physiological demands (Owen-Smith & Novellie, 1982). This is especially important for females who are lactating or in the final stages of gestation (Oftedal, 1984). In semi-arid areas, rainfall plays an important role in determining habitat quality and suitability for large grazing ungulates (Walker, 1993). Vegetation growth is mostly seasonal and nutritional values and physical characteristics can vary widely with time (Jarman, 1974; Sinclair, 1979). As a result, animals need to adapt accordingly to the circumstances if they are to meet their nutritional needs throughout all seasons (Jarman & Sinclair, 1979; Owen-Smith, 2003). Habitat suitability is also measured by substantial protection from predators, and shelter from harsh environmental conditions (Owen-Smith, 2003; Wang *et al*., 2008). The three habitat essentials – food, shelter and security, cannot be viewed separately and all must be taken into consideration when assessing habitat suitability (Owen-Smith, 2003). Risk of predation may inhibit animals from using certain areas which are abundant in food resources, whilst a lack of food resources in secure areas might force animals to forage in places with higher predation risk (Sinclair, 1985; Hayward *et al*., 2006). One of the most important components of foraging behaviour is learning which food types to eat or avoid, and at the same time having the knowledge of where to find these food types (Jarman & Sinclair, 1979; Owen-Smith, 2003). A good understanding of a species foraging behaviour, and its limits, plays an important role in assessing when and where a population will thrive or perish (Owen-Smith, 2003; Smith *et al*., 2011; Weel *et al*., 2015). Conservation agencies are faced with the challenge of how they should respond to small and declining populations of charismatic species within conservation areas (Owen-Smith, 2003). Most often they turn to translocations of these species in or out of the areas of concern (Wolf *et al*., 1996; Commers & Kurman, 2000). Some of these translocations have been extremely successful, such as the White rhinoceros (*Ceratotherium simum*) in Africa (Gordon, 1991). However, there have also been numerous failures that are not adequately explained (Novellie & Knight, 1994). It is fundamental to understand all aspects of a proposed reintroduction site before any species are moved into the area (Wolf *et al*., 1996; Owen-Smith, 2003).

This study focussed on the habitat suitability of an area that already hosts a CMZ population, post reintroduction, and three areas which have been identified as possible CMZ reintroduction sites. The sites were selected as they consist of similar habitat types and fall within the historic range of CMZ. Habitat suitability for CMZ in these areas and the possible factors affecting suitability were determined. The primary objectives were to understand the habitat suitability of each reserve through availability of food resources, by determining the biomass of forage species and calculating a Vegetation Index (VI) for each reserve. The results from this chapter will contribute to management recommendations for the population of CMZ in Bakkrans Nature Reserve and additionally, results will contribute to the Biodiversity Management Plan for CMZ within the Western Cape as a whole (Birss *et al*., 2016) enhancing our understanding of CMZ reintroductions.

5.3 Methods

5.3.1 Study area

The study area consisted of four different sites (Figure 5.1 & 5.2). Bakkrans Nature Reserve (BNR) (32. 5056^{o} S, 19. 3406^{o} E) was used as the reference site because it already hosts a CMZ population. The other three sites were the Grootwinterhoek Nature Reserve (GNR) (33. 0183^{o} S, 19. 0104^{o} E), Limietberg Nature Reserve Complex (LNR) (33. 2341^{o} S, 19. 1310^{o} E) and Matjiesrivier Nature Reserve (MNR) (32. 5067^{o} S, 19.3412^{o} E). CapeNature management required a Habitat Suitability Index (HSI) for each reserve and assuming the values are high enough, decisions will later be made with regards to fencing. That said MNR management have already established a section to be fenced for the possible reintroduction of CMZ (Appendix 1).

Bakkrans Nature Reserve is situated in the Cederberg Wilderness Area of South Africa and is a biodiversity hotspot. The reserve is approximately 5000ha in size and falls within the transitional zone where fynbos and low succulent karoo vegetation overlap. The main vegetation type in BNR is the Swartruggens Quartzite fynbos, which includes alternating mountains with broad ridges and plains (Mucina & Rutherford, 2006). Bakkrans Nature Reserve can be further divided into two vegetation types, namely: Asteraceous Fynbos, which is located on the higher lying mountain tops, and Succulent Karoo on the low lying sandy flats. The reserve consists of predominantly sedimentary rock of the Table Mountain group, although there are also parts that consist of older Malmesbury Group shales and young Bokkeveld formations (Quick *et al*., 2011). The area is dominated by Ericaceae, Proteaceae, Asteraceae and Restionaceae species and also supports other large mammals such as the Cape mountain leopard (*Panthera pardus pardus)* and Oryx (*Oryx gazella)* (Quick *et al*., 2011). There is also sign of karroid elements, towards the drier Cederberg areas, which is dominated by succulent dwarf shrubs.

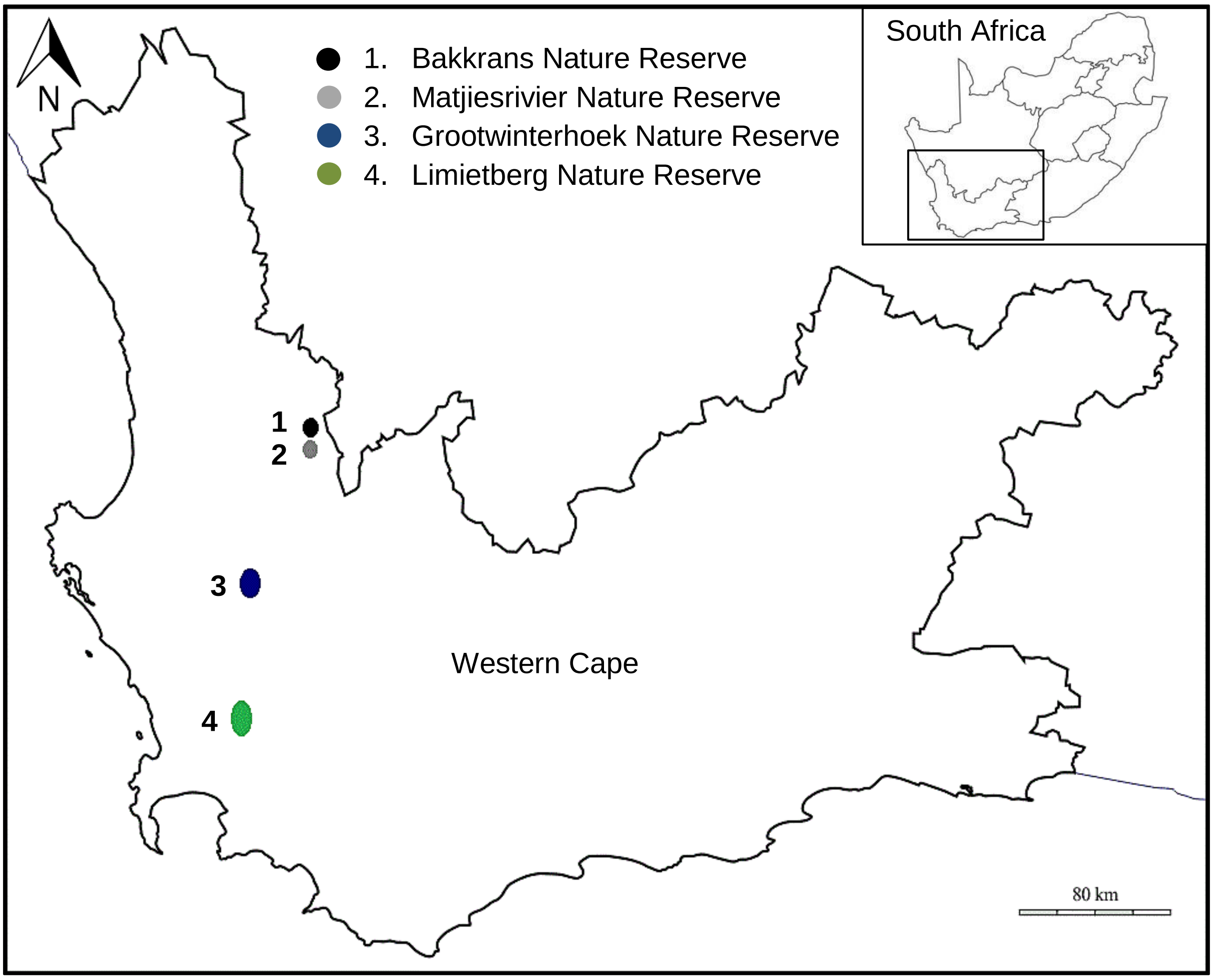

Figure 5.1: Map of the study sites in relation to the Western Cape province of South Africa.

The best definition for the vegetation is an open thicket with a restioid understory. The highest part of the mountain range reaches 1500m and the area experiences an average annual rainfall of 200-250mm, of which 80% occurs in the winter (June to August) (Quick *et al*., 2011). Summer months (December to February) are hot and dry with temperatures reaching over 40°C whilst winters are cold and wet with frequent snow and below zero temperatures.

Matjiesrivier Nature Reserve is situated in the Cederberg Wilderness Area, sharing its northern boundary with BNR. The proposed CMZ camp is approximately 2558ha in size and there is the potential to drop the fences between MNR and BNR to expand the total CMZ habitat (Appendix 1). The reserve also plays host to smaller mammals such as grysbok (*Raphicerus melanotis*) and klipspringers (*Oreotragus oreotragus*) while there are a number of feral donkeys in the area. These would have to be removed to avoid hybridisation with the CMZ. The main vegetation type in MNR is Swartruggens Quartzite Fynbos (Mucina & Rutherford, 2006) but on a finer scale consists of Asteraceous Fynbos and Sandy Restio Fynbos habitats. This area supports a diverse mixture of structural Fynbos types. The ridges in MNR consist of sandy and skeletal soils from the Witteberg Group and supports both restiod and ericoid shrubland with the presence of taller proteoid species. The proposed camp is situated 1200m above sea-level and receives an average rainfall of 200-250mm, of which 80% occurs in the winter. The reserve also has a natural spring which holds a large quantity of water throughout the year. Summer months are hot and dry with temperatures reaching over 40^{o}C whilst winters are cold and wet with frequent snow and below zero temperatures.

Grootwinterhoek Nature Reserve is situated adjacent the town of Porterville, 120km north of Cape Town. The total size of the reserve is approximately 30 608ha and in 1986 a large portion (19 200ha) was declared a wilderness area. There are a variety of habitat types present in the reserve, including the following as stated by Mucina & Rutherford (2006): Winterhoek Sandstone Fynbos, Swartruggens Quartzite Fynbos, Breede Shale Renosterveld, Kouebokkeveld Shale Fynbos, Kouebokkeveld Alluvium Fynbos, Ceres Shale Renosterveld, Breede Shale Fynbos, Citrusdal Vygieveld and Matjiesfontein Shale Renosterveld. This conservancy contributes greatly to the conservation of mountainous fynbos and wildlife, and is also one of Cape Town sources of fresh water. Mammal species that occur in the area varies from larger mammals such as the Cape leopard to small antelope species such as grysbok (*Raphicerus melanotis*) and klipspringers (*Oreotragus oreotragus*). In addition, GNR is also a World Heritage Site. The average annual rainfall within the area is 1450mm, with the heaviest rains falling between the months of April and September. Summers (December to February) are hot and dry whilst winter (June to August) temperatures can drop to below zero degrees celcius at night and are accompanied by frequent snow. The area recently suffered from severe fires (2017) which damaged large parts of the reserve. However, fire plays an important role in the regeneration of fynbos areas which allows seeds to germinate and grass to regenerate (Jarman, 1974; Van Wilgen *et al*., 1992).

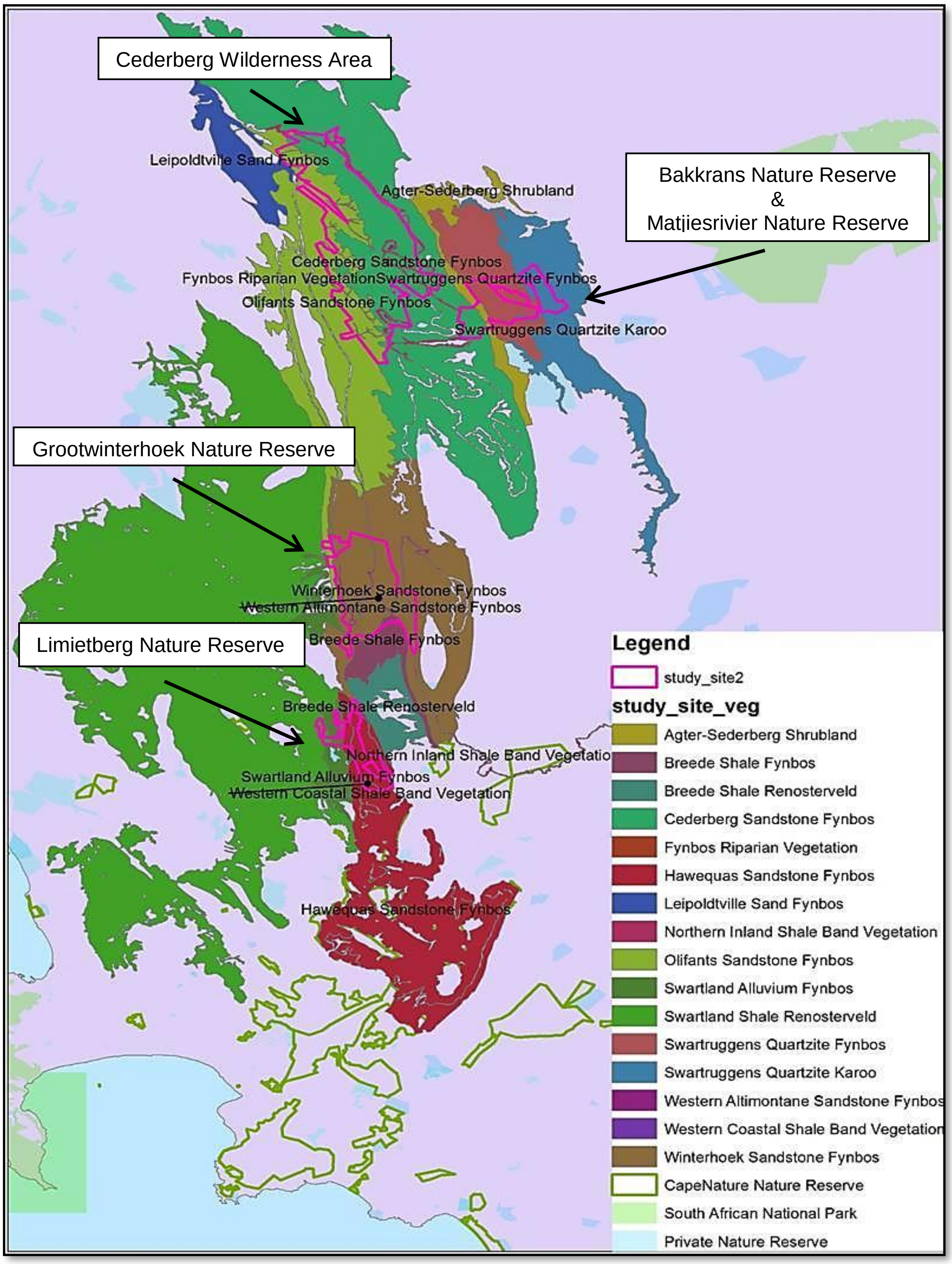

Figure 5.2: Map of the study sites and vegetation types. Provided by CapeNature Pty (Ltd).

Limietberg Nature Reserve is situated in the Du Toitskloof Mountains near the towns of Paarl and Wellington and comprises a size of 117 000ha. This is an important catchment area for both the Breede and Berg rivers which flow through the reserve and supply a number of large dams with fresh water. The reserve gets extremely hot and dry during the summers, but during winter, the high mountain peaks are chapped with snow and the area has an annual rainfall of 1250mm. Mammal species in the area include chacma baboons (*Papio ursinus*), klipspringers and the rarely seen caracal (*Caracal caracal*). The majority of the reserve is covered in mountainous fynbos and plays host to indigenous forest vegetation in the wetter areas. There are also alien trees that have invaded parts of the reserve such as black wattle (*Acacia mearnsii*) and pine (*Pinus*). The main habitat types that occur in Limietberg Nature Reserve as stated by Mucina & Rutherford (2006) are as follows: Hawequas Sandstone Fynbos, Breede Alluvium Fynbos, Breede Shale Renosterveld, Kogelberg Sandstone Fynbos, Boland Granite Fynbos, Robertson Karoo, Swartland Shale Renosterveld and Swartland Alluvium Fynbos. The soils in the LNR are lime-deficient and consist predominantly of Proteaceae and Restionaceae species (Matenaar *et al*., 2014).

5.3.2 Habitat suitability and Vegetation Index

A habitat suitability study, following the methods of Watson *et al* (2005) and Strauss (2015), was conducted in MNR to determine if the habitat is viable for the reintroduction of CMZ (Appendix 5). The same methods were repeated in BNR in order to compare the sites. Due to inaccessibility, the habitat suitability assessments of GNR and LNR were completed using only remote sensing data. This was also conducted for BNR and MNR in order to compare all reserves to each other. A point survey for grass cover was randomly conducted (Novellie & Strydom, 1987), throughout both MNR and BNR on a monthly basis. Strauss (2015) and Weel *et al* (2015) stated that 1-2 plots within each vegetation type should be sufficient to determine vegetation cover in the reserves. GPS locations of each plot were recorded to repeat the process in the different seasons. The habitat suitability of these areas was then assessed using the Habitat Suitability Index as described by Novellie and Winkler (1993). This method incorporated the total number of the food plant species, as well as the acceptability of each specific food plant species. A 200 point survey (10 rows of 20 points spaced 1m apart) was conducted in each randomly selected plot to determine the graminoid species cover (Novellie & Strydom, 1987). A strike was recorded if the point fell within an imaginary line around the base of the plant (Roux, 1963). Additionally, the total number of dung piles were counted in a 1ha area surrounding each 200 point survey plot to determine frequency of area use by CMZ.

For the remote sensing analysis a perceived grass *Vegetation Index* (VI) as described by Lea *et al* (2016) was developed. The latter authors also conducted a study on habitat suitability for CMZ, throughout multiple reserves, in the Western Cape. The VI incorporates fine scale differences in vegetation types by assessing the amount of palatable grass coverage within each reserve. However, this assessment does not quantify the biomass of all palatable grasses, but rather acts as a systematic assessment of grass species dominance and richness which can be estimated across populations. All vegetation maps and other resources that were used for assessments are freely available online (SANBI, 2006). The National Vegetation Map of South Africa (Mucina & Rutherford, 2006), was used and overlaid with the boundary of each reserve. Thereafter, the area of all vegetation types occurring on the reserves was estimated by using ArcGIS Desktop version 10. Each of these vegetation types has a list of 'Important Taxa' which are the species that occur frequently, are in high abundance, or are the dominating taxa within the landscape (Mucina & Rutherford, 2006). Grass abundance was calculated by identifying the total number of graminoid species on the list (excluding Restionaceae, Cyperaceae and Juncaceae) and then weighted by a factor of two. Grass species were then ranked according to their palatability (1 = low, 2 = medium, 3 = high) with the use of previously published resources and online databases (Van Oudtshoorn, 2014). Graminoid species with no palatability information available were excluded from the list. A vegetation index was then compiled for each individual vegetation type (VI_v) occurring within a reserve and was calculated as:

$$VI_v = \Sigma PT + \Sigma 2PD$$

Where T is the total number of non-dominant grass species in the listed vegetation type, D is the total number of dominant grass species and P is the palatability of each individual grass species with the vegetation type.

Finally, a standardized vegetation index (VI) was calculated for all of the reserves as:

$$VI = \frac{\Sigma(CVI_V)}{VI_{max}}$$

Where C is the total percentage that each vegetation type covers within the reserve and VI_{MAX} is the highest VI score attained by any of the reserves in the study.

All species recorded in BNR were compared to those species found in MNR, GNR and LNR. Similarity of species amongst the different reserves was determined, as well as any other species that might be a viable dietary species for CMZ, and any species that was recorded as a CMZ diet component in previous studies.

5.3.3 Statistical analysis

The Habitat Suitability Index for BNR and MNR was calculated as follows:

$$HSI = \sum a_i c_i,$$

Where, a_i is the acceptability index of species *i,* and c_i represents the total percentage cover of species *i*. Acceptability of each species was determined from the dietary preference study presented in Chapter 3. Species of low grazing value were given an acceptability index of 0.1, and species of intermediate grazing value were given an acceptability index of 0.5. Additionally, the total number of dung piles within a 1ha range was counted at the sites in BNR to indicate CMZ use. Habitat Suitability Index values were compared using a Mann-Whitney U test.

A Kruskal-Wallis test was used to determine the difference in plant coverage between BNR and MNR. T-tests were used to determine the difference in percentage *E. calycina* between habitats in the reserves and then between BNR and MNR. T-tests were also used to determine the difference in HSI scores between habitat types in the reserves and then between BNR and MNR. T-tests were used to determine the difference in grass heights between seasons in the reserves and between BNR and MNR.

5.4 Results

5.4.1 Percentage plant coverage

It was found that MNR had higher grass coverage (19%) when compared to BNR (14%), while more restios were present on MNR (18%) as compared to the 7% on

BNR (Figure 5.3). There was a significant difference in the percentage plant coverage between BNR and MNR (Kruskal-Wallis: H=92.54, p<0.001).

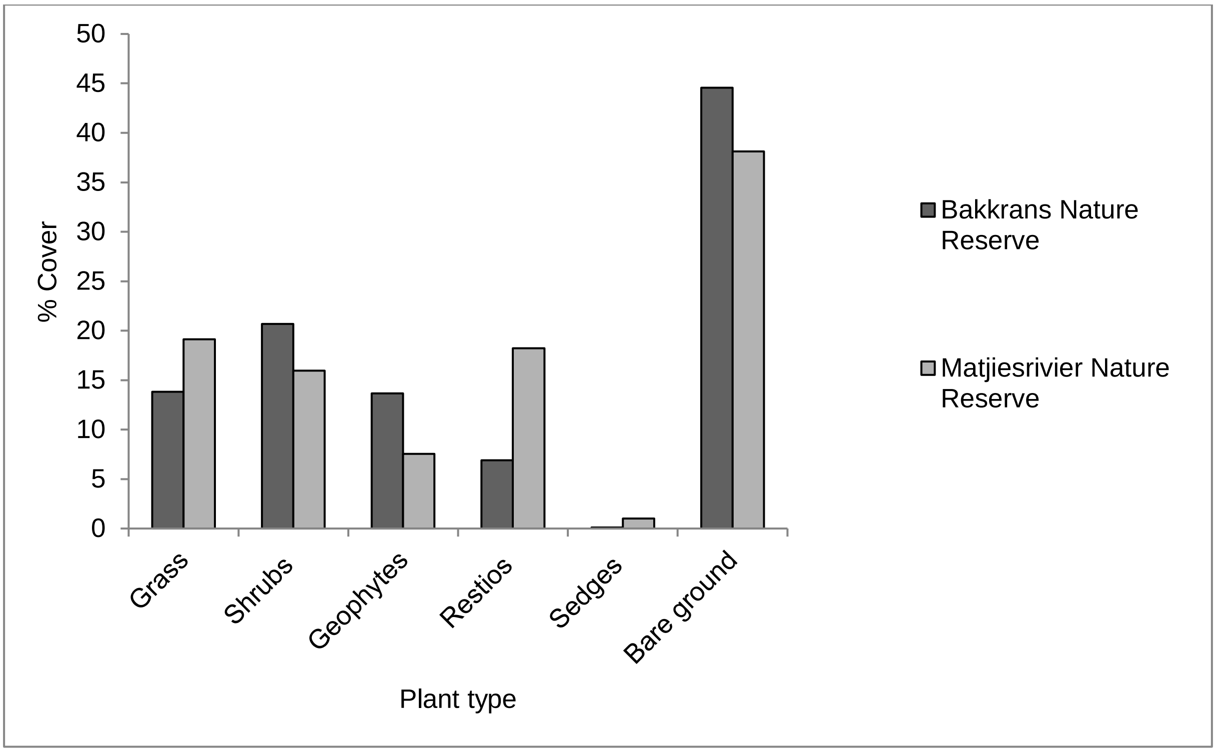

Figure 5.3: The percentage coverage of each plant type in BNR and MNR.

There was a difference in available grass species between BNR and MNR (Table 5.1). A highly favoured species, *E. calycina* (see Chapter 3), was more abundant in MNR (8.8%) as compared to BNR (5.9%). There was also a difference in the availability of *H. dasyanthum* (which was highly favoured by CMZ), with higher availability at BNR (4.1%) as compared to MNR (1.3%). *M. stricta* availability differed slightly between BNR (2.9%) and MNR (1.8%); however, this is considered to be an unpalatable grass (van Oudtshoorn, 2014). Another unpalatable grass, *A. diffusa*, was more abundant in MNR (3.2%) as compared to BNR (0.8%). The availability of *S. namaquensis,* a palatable grass, was much higher in MNR (3.2%) as compared to BNR (0.4%).

Table 5.1: The availability of grass species and the most favoured browse species *Helicrysum dasyanthum* in BNR and MNR.

Species	% BNR	% MNR
Aristida canescence	0.4	-
Aristida diffusa	0.8	3.2
Avena fatua	-	0.3
Bromus pectinatus	-	0.2
Cladoraphis spinosa	0.5	-
Ehrharta calycina	5.9	8.8
Ehrharta villosa	0.5	-
Helicrysum dasyanthum	4.1	1.3
Hyparrhenia hirta	-	0.7
Merxmuellera stricta	2.9	1.8
Pennisetum mucrourum	-	0.5
Stipagrostis ciliata	0.7	-
Stipagrostis namaquensis	0.4	3.2
Stipagrostis obtusa	1.7	0.4

5.4.2 Habitat Suitability Index (HSI)

A total of 27 habitat suitability transects were completed in BNR, and 20 were completed in MNR. The HSI calculated in each habitat type in BNR, was not positively correlated with the number of dung piles (Table 5.2); however, there was a positive correlation between HSI scores and percent grass coverage. The highest HSI (5.65) was recorded in the Asteraceous Fynbos habitat, although the highest number of dung piles (56) was found in the Succulent Karoo habitat. All of the sites in BNR had an HSI <10, which is considered poor CMZ habitat quality (Novellie, 1994). Results found that the Asteraceous Fynbos habitat had higher grass coverage and higher total vegetation coverage as compared to the Succulent Karoo habitat. There was a significant difference in the amount of *E. calycina* available within the Asteraceous Fynbos Habitat as compared to the Succulent Karoo (T-test: t=2.19, *df*=25, *p*=0.037). There was no difference in the quantity of *E. calycina* available between BNR and MNR (T-test: t= -1.27, *df*=45, *p*= 0.21) (Table 5.1 and 5.2).

Table 5.2: The HSI scores for BNR in each habitat type with the number of dung piles that were present, grass coverage, and total vegetation coverage.

Habitat	**Site**	***H.S.I***	**Dung piles #**	**% Grass Cover**	**% *E. calycina***	**Total % Veg cover**
Asteraceous Fynbos	1	0.10	45	3.0	0.0	52.0
	2	0.00	37	0.0	0.0	50.5
	3	4.69	42	48.0	15.5	66.5
	4	0.00	24	0.0	0.0	46.0
	5	1.10	35	9.5	4.0	63.0
	6	1.89	29	12.0	8.0	57.5
	7	2.77	11	30.0	7.5	62.5
	8	2.74	16	32.0	8.0	61.0
	9	5.59	27	30.0	25.5	50.5
	10	0.84	12	4.0	4.0	47.0
	11	2.21	5	10.5	10.5	65.0
	12	3.84	7	25.5	15.5	74.5
	13	4.86	5	25.0	22.5	68.5
Succulent Karoo	1	0.74	25	10.5	3.5	51.5
	2	1.68	56	30.0	3.5	53.0
	3	0.32	36	6.5	1.5	55.5
	4	0.00	41	0.0	0.0	58.5
	5	1.29	39	8.0	5.5	59.0
	6	1.47	9	7.0	7.0	48.0
	7	0.00	15	2.0	0.0	45.0
	8	0.00	7	0.0	0.0	46.5
	9	2.05	41	44.5	2.5	58.5
	10	0.75	26	5.0	3.5	39.0
	11	0.62	17	18.0	0.0	50.0
	12	0.53	12	2.5	2.5	62.5
	13	0.00	33	0.0	0.0	45.5
	14	4.10	51	19.5	19.5	57.0

The HSI scores for MNR were generally higher than those for BNR, and MNR also had a higher % grass coverage (Table 5.3). There was a positive correlation between HSI scores and percent grass coverage in MNR. The two highest HSI scores (14.5

and 6.49) were recorded in the Sandy Restio Fynbos habitat in MNR; however, there was no significant difference in the HSI scores between Asteraceous Fynbos and Sandy Restio Fynbos habitats (T-test: t= -1.50, *df*= 17, *p*= 0.15). Using the Novellie (1994) scale of CMZ habitat quality, only one site in MNR fell within the range of moderate CMZ habitat quality (HSI = 11-20). As mentioned the rest of the sites had an HSI <10 and were considered poor CMZ habitat (Novellie, 1994). Results found that the Asteraceous Fynbos habitat had a higher quantity of *E. calycina* as compared to the Sandy Restio Fynbos habitat.

Table 5.3: The HSI scores for MNR in each habitat type including the percentage grass coverage and total vegetation coverage.

Habitat type	Site	H.S.I	% Grass cover	% *E. calycina*	Total % Veg cover
Asteraceous Fynbos	1	1.42	11.5	3.5	52.0
	2	0.11	1.0	0.5	56.0
	3	4.04	13.0	8.5	58.5
	4	0.79	4.5	0.0	51.0
	5	0.74	3.5	3.0	56.5
	6	0.84	4.0	4.0	58.0
	7	4.40	26.0	19.5	62.5
	8	1.92	13.5	8.0	60.5
	9	5.81	30.5	27.5	74.5
	10	3.78	18.0	18.0	77.0
	11	3.89	26.0	16.0	75.5
	12	1.25	22.0	5.0	68.0
	13	2.92	18.0	12.5	59.5
	14	1.34	9.0	5.5	58.0
	15	6.14	31.5	28.5	66.0
Restio Sandy Fynbos	1	0.95	4.5	4.5	59.5
	2	14.5	24.5	10.0	44.5
	3	6.49	21.5	4.0	58.5
	4	0.49	18.0	0.0	61.0
	5	2.14	13.5	6.5	55.5

5.4.3 Grass abundance

The height distribution of grass tufts in BNR changed across seasons, with higher abundance of taller grasses (>150mm) in the winter (June to August); however, these changes were relatively small (Table 5.4).

Table 5.4: The canopy spread cover of all grass species, in three height classes in BNR across two seasons.

Height Class	Number of tufts measured	Percent of tufts	Canopy spread cover Mean	Canopy spread cover Standard Error
Summer				
< 50mm	0	0.0	0.0	0.00
50-150mm	82	18.3	115.6	2.82
>150mm	365	81.7	458.5	11.94
Total	447	100.0		
Winter				
< 50mm	4	1.1	38.5	3.13
50-150mm	47	12.4	105.5	4.86
>150mm	327	86.5	350.5	7.12
Total	378	100.0		

In MNR height distribution of grass tufts also changed across seasons, with higher abundance of taller grasses (>150mm) in the summer (December to February) (Table 5.5).

Table 5.5: The canopy spread cover of all grass species, in three height classes in MNR across two seasons.

			Canopy spread cover	
Height Class	Number of tufts measured	Percent of tufts	Mean	Standard Error
Summer				
< 50mm	0	0.0	0.0	0.00
50-150mm	9	2.1	137.8	5.73
>150mm	421	97.9	476.7	9.75
Total	430	100.0		
Winter				
< 50mm	0	0.0	0.0	0.00
50-150mm	38	11.4	120.8	4.23
>150mm	296	88.6	403.3	8.61
Total	334	100.0		

A difference in the mean grass height was detected between summer (dry season) and winter (wet season) in BNR, as grass tufts were much taller in the summer (T-test: $t = 5.44$, $df = 823$, $p < 0.001$). Similar results were found for MNR as grass tufts were significantly taller in the summer as compared to the winter (T-test: $t = 7.21$, $df = 762$, $p < 0.001$) (Figure 5.4).

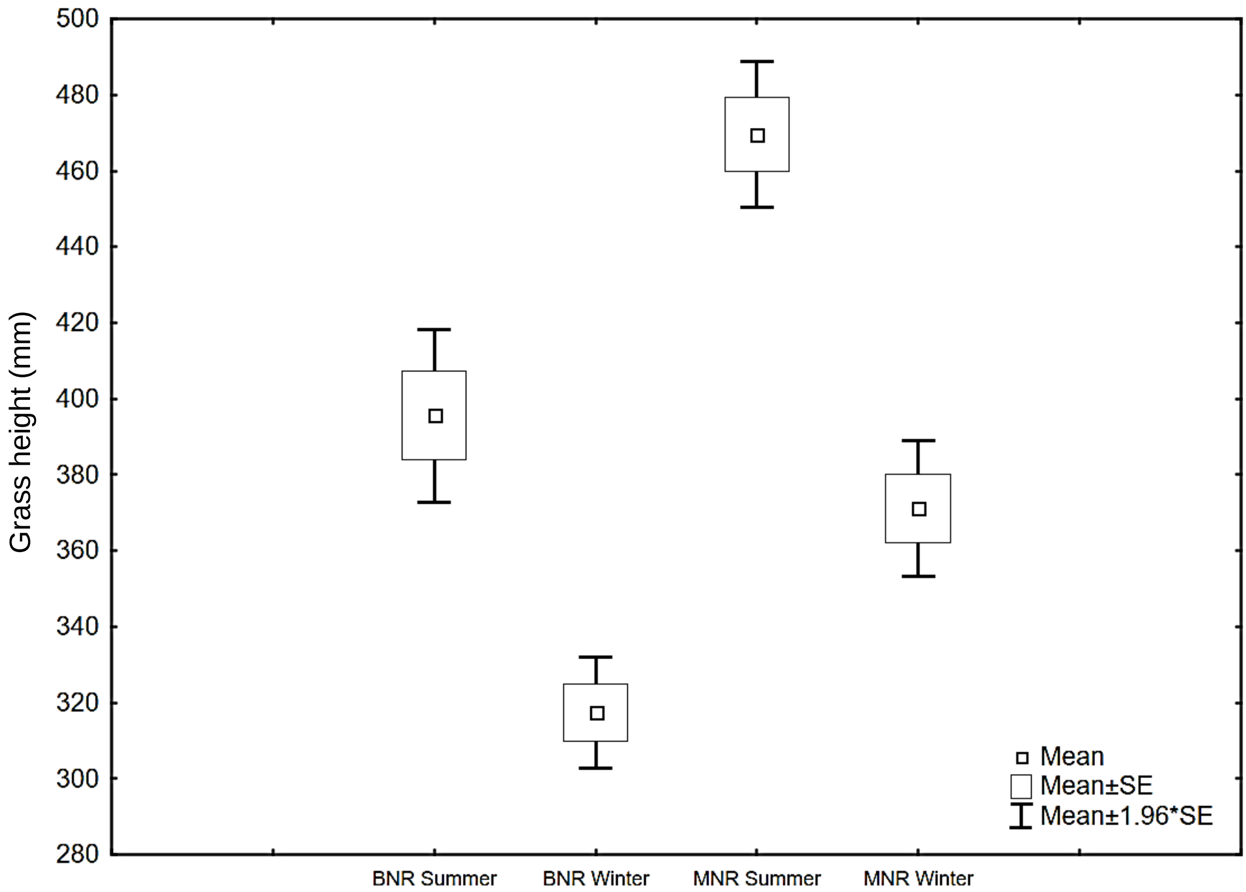

Figure 5.4: Representation of the difference in grass tuft heights between summer and winter in BNR and MNR.

5.4.4 Vegetation Index (VI)

Limietberg Nature Reserve had the highest Vegetation Index amongst all the reserves (Table 5.6). In comparison, MNR had the second highest (0.26) with GNR having (0.1) and lowest was BNR (0.03). Vegetation Index scores were positively correlated with percentage grass coverage of the reserve.

Table 5.6: The Vegetation Index scores of each reserve with the presence of CMZ or not.

Reserve	Vegetation Index (VI)	Cape Mountain Zebra Present
LNR	1.00	No
MNR	0.26	No
GNR	0.10	No
BNR	0.03	Yes

5.5 Discussion

Ungulates will favour habitats which maximize their rate of nutrient intake, which is determined by the availability of food resource species and water (Owen-Smith, 1985). A difference was found in the availability of food sources between BNR and MNR. In general, MNR had a higher percentage of grass coverage (19%), which is favourable for CMZ (Winkler, 1992; Smith *et al*., 2011), and restio species dominated the habitat. Results from Chapter 3 suggest that CMZ will utilize a wide range of restio species, and indicates that such species would play an important role if CMZ were reintroduced into MNR. It was found that MNR had a higher abundance of palatable grass species such as *E. calycina* (8.8%) and *S. namaquensis* (3.2%) as compared to BNR. *Helicrysum dasyanthum* was more abundant in BNR (4.1%) as compared to MNR (1.4%). It is important to take note of this species as it made up >10% of the annual CMZ diet in BNR. However, the lack of palatable grasses may be driving the increase in acceptability of *H. dasyanthum* (Chapter 3). If higher abundances of palatable grasses were present, the acceptability of *H. dasyanthum* may actually decrease. Results indicate that MNR had a higher number of sites with >20% grass coverage as compared to BNR. In Mountain Zebra National Park, CMZ generally avoided areas with 0-16% grass coverage and preferred areas with grass coverages of >50% (Novellie & Strydom, 1987). Weel *et al* (2015) found that CMZ preferred areas with 36% grass coverage in Baviaanskloof Nature Reserve. In BNR, only two sites had grass coverage of >20% and were situated in the Asteraceous Fynbos habitat on the top plateau, which consisted largely of *M. stricta*. In Mountain Zebra National Park, rocky slopes had high grass coverage (31%); however, the CMZ tended to avoid these areas as they are dominated by the unpalatable *M. stricta* (Novellie & Strydom, 1987). Smith *et al* (2011) found that CMZ will concentrate their foraging in a limited number of habitats. Owen-Smith (2003) stated that habitat suitability depends fundamentally on the abundance of palatable food resources. Matjiesrivier Nature Reserve consists of less *M. stricta* (1.8%) and generally has a higher grass coverage than BNR. Thus, results from this study suggest that MNR would be a more suitable habitat for CMZ due to the higher abundance of palatable grass species.

Grass coverage and heights also varied between BNR and MNR. Penzhorn & Novellie (1991) found that CMZ favour grasses between 50-150mm. However, results from this study found very few grasses in both BNR and MNR within this height range, with the majority of grasses being in excess of 150mm. Bakkrans Nature Reserve only hosts two large herbivores which are CMZ and the Oryx. Thus, the low grazing pressure could be a driver to longer grasses being present within the reserve. In MNR, there was a paucity of short (50-150mm) grasses (Summer = 2.1%, Winter =11.4%); however, there are no bulk grazers present in the area to put pressure on grass sward heights. Cape mountain zebra in BNR accepted taller grass swards than has been reported in other studies (Chapter 3). Most of these swards were in the range of >150mm, which would suggest that grass species on both BNR and MNR may be accepted regardless of their taller heights.

A Habitat Suitability Index (HSI) can serve as an important tool to detect decreases in grass availability, as areas may experience intense grazing pressure over time (Novellie, 1994). These indexes were based on the quality of a certain habitat to the focus species. Novellie (1994) stated that high quality CMZ habitat will have an HSI of >20, moderate quality habitat an HSI of 11-20 and poor quality habitat an HSI of <10. The HSI range of below 10 for all sites in BNR suggests that the reserve has highly unsuitable habitat for CMZ. This concurs with other HSI analyses carried out in the typically dystrophic Cape Floristic Region (Watson & Chadwick, 2007; Strauss, 2015; Weel *et al*., 2015); however, the scores recorded in BNR were still lower than those in other areas. In comparison, Strauss (2015) recorded higher HSI scores (1.7 to 28.7) in Bontebok National Park, while Watson & Chadwick (2007) found that HSI scores in Kammanassie Nature Reserve varied from 0.0 to 50.0 with three out of eight sites with good quality habitat and another three with moderate quality habitat. Weel *et al* (2015) found that HSI scores varied from 1.3 to 20.2 in Baviaanskloof Nature Reserve. In the Gamka Mountain Nature Reserve, five out of ten HSI scores were >20 whilst the rest was all < 10 and consisted of poor quality habitat. In the Mountain Zebra National Park, outside of the Cape Floristic Region, HSI scores ranged from 13 to 44, which is very favourable and explains why CMZ populations are thriving in the area (Novellie, 1994). The Matjiesrivier Nature Reserve also had very low HSI scores, with only one site scoring >10, with the rest scoring <10. This suggests that the overall quality of habitat in the Cederberg Wilderness Area is generally poor for CMZ. Contributing factors could be the typically dystrophic Cape Floristic Region in which the area lies, the low grass coverage, lack of palatable grasses, too infrequent fires, and low rainfall in the area. Watson & Chadwick (2007) found that frequent fires are a key factor in areas dominated by Mountain Fynbos habitats because they stimulate the growth of grasses. Owen-Smith (2003) found that habitat suitability is dependent on a combination of all three habitat essentials – food, shelter and security. A species might use areas with lower quantities of palatable food sources in order to gain more protection and shelter from predators and environmental conditions. In this study, CMZ generally preferred to utilize the low lying Succulent Karoo habitat in BNR (Chapter 2); however, this area had the lowest HSI scores. Although the low lying Succulent Karoo habitat might be less suitable, it provides protection and shelter from harsh environments, with winter temperatures often dropping below zero. Additionally, this area also has access to abundant water sources. Watson & Chadwick (2007) found that a small population (one male, four females) of horses in high lying Mountain Fynbos habitats struggled to reproduce; however, once they were relocated to the low lying areas all four mares gave birth to foals within the first year and again two years later. Weel *et al* (2015) found that CMZ will prefer low lying areas because these habitats are much more suitable to them.

Slow CMZ population growth rates have historically been linked to unsuitable habitats emphasizing how important good quality habitats are for CMZ management (Lea *et al*., 2016). This study revealed that the BNR population growth and structure exhibits similar trends (Chapter 2) and certain environmental factors are driving poor population performance in these areas. Weel *et al* (2015) found that extended phosphorous deficiencies may be driving poor population performance in Baviaanskloof Nature Reserve, while Watson *et al* (2005) stated that limited suitable grassy habitats will drive poor performance among CMZ populations. This study and others (Watson *et al*., 2005; Lea *et al*., 2016) highlight the poor mountain zebra population growth rate in the Cape Floristic Region. Therefore, it is important to properly assess a habitat before further reintroductions are made. This will minimise the time at which the population is at risk, while maximizing initial population growth (Commers & Kurman, 2000). Results from this study suggest that MNR has more suitable habitat for CMZ when compared to BNR; however, the habitat quality is still poor (Novellie, 1994). As MNR borders BNR there were many similarities in vegetation between the two reserves. The zebra population is not doing well in terms of demographics in BNR, and similar results may be found if CMZ are reintroduced into MNR. Management have suggested dropping the fence between the two reserves and the possibility of reintroducing 14 additional zebra. The initial population size of BNR was 15 and has exhibited slow population growth and skewed demographics, being extremely male biased (Chapter 2). Thus, it has been recommended that additional females are introduced to counteract the male biased population; however, if poor habitat quality is driving a male biased birth rate, then the additional females may face similar problems in the future. It could be assumed that the population will once again become male biased with time, and management plans will have to be reassessed. It is therefore not advised to reintroduce more CMZ into an area which has resulted in a poor population performance, without first mitigating contributing factors.

Results from the Vegetation Index analysis indicate that LNR may have the most suitable habitat for CMZ. The contributing factor to this result is the abundance of palatable grasses which are found in the reserve. Hawequas Sandstone Fynbos covers the majority of the reserve (86%) and is dominated by grasses such as *E. calycina, T. triandra* and *E. curvula,* which are highly favourable grasses both in BNR (Chapter 3) as well as in previous studies. In Baviaanskloof Nature Reserve, *T. trianda* formed 27.5% of the annual CMZ diet (Weel *et al*., 2015), while Strauss (2015) found that *T. triandra* was favoured most in Bontebok National Park contributing to >20% of the annual diet, with *E. curvula* also being a principal species contributing 13.3% to the annual diet. Van Oudtshoorn (2014) found that both *T. triandra* and *E. curvula* are palatable grasses and play an important role in herbivore diets across South Africa. Limietberg Nature Reserve also consists of 9.3% Swartland Shale Renosterveld and Watson & Chadwick (2007) found that Renosterveld habitats were favourable for CMZ in Kammanassie Nature Reserve.

Grootwinterhoek Nature Reserve had a lower Vegetation Index when compared to LNR as well as MNR. As the HSI results from this study indicated, MNR is an unsuitable area for CMZ, and it follows that GNR will also have unsuitable habitat for CMZ reintroductions. This is due to the majority of the reserve (89%) consisting of Winterhoek Sandstone Fynbos, which is dominated by *Pentachistis* grass species (Mucina & Rutherford, 2006). In comparison, Strauss (2015) found that *Pentaschistis* species in Bontebok National Park were not favoured with the two present species contributing <2% to the annual diet. Similarly, Weel *et al* (2015) found that *P. setifolia* only contributed to 2.5% of the annual CMZ diet in Baviaanskloof Nature Reserve. A small portion (4.5%) of the reserve also consists of Northern Inland Shale Band vegetation which is also dominated by *Pentaschistis* species as well as *Merxmuellera* species which are unpalatable (Mucina & Rutherford, 2006; Van Oudtshoorn, 2014). Bakkrans Nature Reserve, the only reserve that has an established CMZ population, had the lowest VI as well as HSI scores. This may indicate that new management strategies should be developed for this population, in the form of additional land or ultimately the relocation of the CMZ population to a more suitable area.

5.7 Conclusion

One of the limiting factors in CMZ conservation is the habitat association with the species name (Cape and mountain) (Weel *et al*., 2015). In general, areas are often thought of as suitable for a species, due to the previous occurrence of a species in the area; although, there is not sufficient historic evidence to support these statements (Owen-Smith, 2003). Cape mountain zebra appear to have preferred open grasslands in the past, until climatic changes forced them into mountainous areas (Faith, 2012). Lea *et al* (2016) stated that the problem is a result of poorly informed perceptions of the historical distribution and ecology of CMZ. This is evident in the current study, which was undertaken in Mountain Fynbos habitats that have been widely classified to fall within the historic distribution range of CMZ. Results suggest that the habitats in BNR, as well as MNR, are of poor quality for CMZ. This is driven by the lack of palatable grasses and overall grass coverage. Only LNR has suitable habitat for the long-term persistence of CMZ, if they were reintroduced into the area. This reserve is prone to frequent fires which will drive the regrowth of palatable grasses and the size of LNR will also provide a high biomass of palatable grasses. Due to the poor habitat quality in BNR, a high level of importance should be placed on the future management of this population. As the quality of habitats in the Cederberg Wilderness Area is of poor quality for CMZ, management will need to make calculated decisions with regards to the removal or addition of CMZ in this environment.

Results from this study have provided an in depth understanding of the required habitat for CMZ, and the drivers affecting such habitats; however, future research could address the following:

1. Assessing habitat types at a finer scale. Both BNR and MNR fall under the Swartruggens Quartzite Fynbos vegetation type; however, once on the ground there are clear differences in habitat types. A detailed map of each habitat type

should be created through the use of GIS tools and ground-validated measurements.

2. Habitat Suitability Index and Vegetation Index assessments should include browse species. As CMZ in this study browsed extensively (Chapter 3), browse should be included in the assessments. These should include any browse species that CMZ might accept, such as restio species and small shrubs. This will allow the development of a more detailed HSI of the Cederberg Wilderness Area and other semi-arid areas where CMZ are present.
3. Fire regimes should be assessed in all of the reserves. Both Watson *et al* (2005) and Van Wilgen *et al* (1992) emphasised how important fire is within Fynbos habitats because it drives the regrowth of palatable grasses. This will play an important role in the Cape Floristic Region as palatable grasses become moribund with low nutritional value in the absence of fire (Bond *et al*., 2003). As a result, fire would increase the habitat quality as well as suitability for CMZ in these areas.
4. The acquisition of additional land should be assessed outside of the Western Cape. Weel *et al* (2015) recommended that growing populations should be established within the grassy habitats of the Karoo and Eastern Cape where sufficient population growth can be achieved. Landowners in these areas should be approached with the option of stocking CMZ on their reserves to help increase sustainable populations. However, if plains zebra are present on the reserve, they will have to be removed to avoid hybridisation. Thus, landowners may be hesitant to stock CMZ if they would have to remove their plains zebra.
5. Annual rainfall and natural water sources should be taken into consideration. In semi-arid areas, rainfall plays an important role in determining habitat quality and suitability for large grazing ungulates (Walker, 1993). This will give an indication of available surface water to CMZ within the reserve and any other natural water sources that may be present. It is expected that higher rainfall areas will have more suitable habitats for CMZ, especially in the Cape Floristic Region.
6. The calculation of carrying capacity should be implemented. This will give an indication of the stocking rate of each reserve and inform managers if the reserve has reached carrying capacity or is nearing it (Traill & Bigalke, 2006).

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Chapter Six

Research findings, conclusion and management recommendations

6.1 Overview

Expanding human settlements, climatic changes and habitat fragmentation have confined Cape mountain zebra (*Equus zebra zebra*) (CMZ) populations to a limited number of isolated environments. Conservation efforts are now focusing on reintroductions to recover species numbers in habitats which they historically occupied. This study aimed to understand CMZ demographics, diet, artificial water point use, and habitat suitability in Bakkrans Nature Reserve (BNR) 17 years after their initial reintroduction. The results from this study have contributed to a better understanding of the ecology of CMZ in arid and semi-arid environments, which will assist in the development of a successful conservation management plan for this and future populations. The following is a summary of the key findings in the study and their management implications.

6.2 Research findings

Chapter Two: Demographics and habitat preference of Cape mountain zebra

- A total of 21 CMZ were formally identified in BNR using photographs to identify individual stripe patterns.
- The population structure consisted of 90.4% adults (>24 months), 4.8% yearlings (12-24 months) and 4.8% foals (<12 months). The adult CMZ sex ratio in BNR was 1:0.27 (male:female). The population consisted of 15 adult males, four adult females and both the single yearling and foal were males.
- Family band size ranged from two to five individuals (mean = 3.5 ± 1.50 [SE]). Family bands each consisted of a dominant adult male and one to three females (2.0 ± 1.00 [SE]), zero to one yearling (0.5 ± 0.50 [SE]) and zero to one foal (0.5 ± 0.50 [SE]).
- Bachelor males either occurred on their own or in bands of two to nine individuals (3.5 ± 1.62 [SE]).
- There was no difference in family and bachelor band stability. Members of both family and bachelor bands were seldom seen within new groups and tended to stay with original members throughout the entire study period.
- The formation of herds (multiple bands together) was never observed.
- Cape mountain zebra dispersed throughout the entire reserve with densities increasing towards the lower lying Succulent Karoo habitat type. Individual CMZ occurred at a density of 0.36/km^2 and family bands at 0.072/km^2.

Chapter Three: Dietary preference of Cape mountain zebra

- Microhistological analysis revealed that CMZ diet consisted of a total of 25 species. Of these, seven grass species contributed to 41.5% of the annual diet, seven restio species contributed 16.4%, one sedge species contributed 3.8%, seven dicotyledons species contributed 29.3%, and three geophyte species contributed a total of 3.1%.
- Three grass species, *Ehrharta calycina, Merxmuellera stricta* and *Stipagrostis obtusa* accounted for >5% of the annual diet, of which *E. calycina* was consumed the most (21.6%). Of the browse species, *Helichrysum dasyanthum* contributed the most annually (10.7%).
- Annually, leaf utilization was preferred over other plant parts with the highest acceptability being in the cool, early wet season (71%) and lowest in the cold, late wet season (49%).
- Green plant parts were favoured throughout all four seasons, with highest use in the moderate, early dry season (79.3%) and lowest during the cool, early wet season (61%).
- Cape mountain zebra preferred to graze on longer swards during the warm, late dry season (mean=340mm), and the shortest swards were utilized during the cold, late wet season (mean=156mm).
- Cape mountain zebra relied on a substantial amount of browse as grass abundance was very low in BNR. The total quantity of browse consumed was highest in the cool, early wet season (63.5%) and lowest during the moderate, early dry season (51.8%).
- There were high levels of plasticity towards browse species. Careful management of semi-arid habitats is necessary if CMZ are to persist in these areas.

Chapter Four: Artificial waterhole dependency of Cape mountain zebra

- Artificial watering points were used more during the dry season as compared to the wet season, and use was highest in the early dry season.
- Cape mountain zebra visited artificial watering points (AWP) during each hourly interval over a 24 hour period. However, CMZ utilized AWPs primarily at dusk with peak times being 19:00h and 20:00h.

- Peak visitation times varied between seasons as dusk moved from later in summer (dry season) to earlier in winter (wet season). The strongest correspondence in each season was 17:00h during early dry, 21:00h during late dry, 18:00h during early wet and 18:00h during late wet.

Chapter Five: Habitat suitability for Cape mountain zebra

- Matjiesrivier Nature Reserve (MNR) had higher grass coverage (19%) when compared to BNR (14%) while more restios were present in MNR (18%) as compared to the 7% in BNR.
- *Ehrharta calycina* was more abundant in MNR (8.8%) when compared to BNR (5.9%). There was also a difference in the availability of *H. dasyanthum* (which is a favoured browse species) as BNR had higher availability (4.1%) compared to MNR (1.3%). *Merxmuellera stricta* showed a slight difference in availability between BNR (2.9%) and MNR (1.8%). Another unpalatable grass, *Aristida diffusa*, was more abundant in MNR (3.2%) when compared to BNR (0.8%). The availability of *S. namaquensis*, a palatable grass, was much higher in MNR (3.2%) when compared to BNR (0.4%).
- Habitat Suitability Index (HSI) transects indicated that MNR (mean HSI = 3.2) had a more suitable habitat than BNR (1.6). However, both of these reserves were still classified to have poor quality habitat for the CMZ as HSI scores were < 10.
- A higher abundance of taller grasses (>150mm) were found in MNR when compared to BNR. Bakkrans Nature Reserve had more grasses at intermediate height (50-150mm), which are favoured by CMZ, when compared to MNR.
- Vegetation Index (VI) scores indicated that Limietberg Nature Reserve (VI = 1) had the most suitable habitat for CMZ reintroductions. The other three reserves were all deemed to have poor habitat quality for reintroductions with low VI scores: Matjiesrivier Nature Reserve (VI=0.26), Grootwinterhoek Nature Reserve (VI=0.1) and Bakkrans Nature Reserve (VI=0.03). There was a positive correlation between percentage grass coverage and VI scores.

6.3 Critical assessment of research findings

In Chapter one, it was stated that the primary aim of this study was to determine how the CMZ in BNR have performed, 17 years after an initial reintroduction. This information provides critical insights toward future reintroductions and strengthens our knowledge on how pioneer CMZ populations establish themselves within a new environment. The study also aimed to assess the factors which influence resource utilization and provide data that will help managers to calculate the carrying capacity of current and future populations (Mentis, 1977).

This study provided important information on how the BNR population of CMZ are performing. It was found that the initial population has successfully persisted in the reserve; however, biotic and abiotic factors have resulted in extremely skewed sex ratios, and social structure and organization differ from other established populations. These findings support the results on resource limitation and it is recommended that future reintroductions of CMZ into this area should not be implemented without substantial mitigation measures, such as, increased habitat and better fire regimes.

Results from this study have also improved our understanding of resource utilization by CMZ in a semi-arid environment. It was established that CMZ favoured grasses, while browse contributed significantly to their diet. The contribution of browse increased throughout the wet season as grasses became senescent and less abundant. Due to the low abundance of grass and general unpalatability of available grasses, CMZ showed high levels of plasticity towards browse. As a result, meticulous management of semi-arid environments is necessary if CMZ are to persist in these areas, in particular during climate-driven changes. Conservation efforts must provide zebra with additional habitat that will expand foraging areas and expose them to more abundant resources. If not, supplementary feeding might be necessary in years of extreme drought.

Cape mountain zebra preferred to utilize artificial watering points at dusk, peaking at 19:00h and 20:00h. The usage of waterholes varied between seasons, with the frequency increasing during the dry season when compared to the wet season. These results indicate that artificial watering points are important to counter act the lack of surface water and rainfall in semi-arid environments. Additionally, it prevents mortalities of CMZ and other large mammals in BNR as there would be high levels of inter - and intraspecific competition surrounding the one natural water source.

During this study, the suitability of CMZ habitat was determined in four private reserves. Both BNR and MNR had poor habitat suitability, with Habitat Suitability Index scores that were much lower than those determined in other studies. This is due to the extremely low abundance of grass in BNR and MNR. . Vegetation Index scores indicated that Limietberg Nature Reserve would be most suitable for CMZ reintroductions due to the presence of palatable and semi-palatable grasses. The remaining three reserves, Grootwinterhoek, Matjiesrivier and Bakkrans Nature Reserve have all been deemed as unsuitable habitats for CMZ. The unsuitability of these habitats demonstrates the importance of the management and conservation of CMZ within these areas.

This study achieved its primary aims; however, future research can address additional problems and provide a more in-depth analysis of CMZ within these areas and the rest of South Africa.

6.4 Management recommendations

Kerley *et al* (2003) found that the protected conservation areas within the Cape Floristic Region are inadequate to support large mammal populations, and emphasized the need to understand mammal distribution and abundance and the factors which influence this. This can be done by incorporating demographic, dietary and habitat suitability knowledge in conservation efforts to ensure the persistence of wildlife in these areas and counteract the destructive effects of habitat fragmentation and climatic changes (Boyd *et al*., 2016; King *et al*., 2016). Conservation regions in the Cape Floristic Region are generally biased towards mountainous areas, while suitable lowland habitat is limited (Rouget *et al*., 2003). Thus, it is important to incorporate the findings from this study into management action plans for CMZ in these areas.

The most recent assessment of CMZ on the IUCN Red List classified the species as Least Concern (Hrabar *et al*., 2019). This emphasises the need for conservation, especially as CMZ populations have performed poorly in the past within the Western Cape (Weel *et al*., 2015; Birss *et al*., 2016; Lea *et al*., 2016). In order to develop sound management action plans, conservation agencies need to understand the relationships between a species and the environment, as well as human needs (De Vos, 2017). This will indicate if a species is able to cope with changes in its environment, and if not, what human interventions are needed and should be implemented (Curio, 1998).

Although conservation actions have led to the steady increase in CMZ population numbers, the effects of a population genetic bottleneck threatens the survival of this species throughout their natural range (Birss *et al*. 2016). Hrabar & Kerley (2009) also stated that there is a shortage of protected areas, of suitable size and habitat quality, for CMZ. Consequently, a Biodiversity Management Plan was develop for CMZ within the Western Cape to ensure their survival and future conservation (Birss *et al*., 2016). This conservation management plan should strive towards a realistic goal and vision for the future. For this management plan to be successful, it needs to be reviewed annually and adjusted where necessary. This management plan can also be adapted to suit other large herbivores in the Western Cape and private sectors. Currently, this Biodiversity Management Plan states its four objectives as:

1. That genetic diversity is maintained in the CMZ meta-population.
2. That research and monitoring is implemented to help adaptive management.
3. That regulations, legislations, guidelines and policies be implemented.
4. That communication, collaboration and coordination is maintained between all stakeholders to ensure CMZ conservation.

In order to assess whether human intervention is needed, the conservation and management plan for CMZ in BNR requires an in depth understanding of the reserve's carrying capacity and population growth rate. However, this may be challenging as carrying capacity will fluctuate over time due to changes in the abundance and availability of resources, and environmental stochasticity (Ransom *et al*., 2016). This assessment requires defensible and statistically sound survey techniques to determine population estimates. To date, this study is the first to conduct a thorough survey on population numbers in BNR. No record has been kept of births and deaths on the reserve or the fluctuation in population numbers each year; thus, it is unlikely that sufficient information for the calculation of population growth rate and the carrying capacity is possible. If a reserve requires data on carrying capacity, annual population surveys should be conducted, and the age of each zebra estimated.

It is clear that the BNR population is increasing at a very slow rate as only two foals were born in the last four years. Seventeen years after reintroduction there is still no rapid increase in population growth rate, which may indicate resource limitations. A short term, internal, study of BNR in 2000 suggested that carrying capacity can be determined through the agricultural Large Stock Unit method (LSU), as described by Novellie (1998). However, converting a stock unit into equivalent wild herbivore units in terms of biomass does not, for example, take into account the differences in degree of selection between herbivore species (Mentis, 1977). The use of the LSU method is a simplified practical approach for an initial game management programme. Although this was a rough estimate, the LSU in BNR determined a stocking rate of a maximum of 9.5 (10) CMZ in the reserve; however, this was in addition to at least 52 Springbok (*Antidorcas marsupialis*), 12 Eland (*Taurotragus oryx*) and 19 Oryx (*Oryx gazella*) (BNR management plan, 2001). It is clear that the 21 CMZ in BNR is more than initially recommended, and to date, there is only one springbok and approximately 20 Oryx present. The low densities of other herbivores may explain the increased population size of CMZ, releasing from reduced interspecific competition. Another explanation may be that the CMZ population have reached carrying capacity and that the initial founder population of 15 might have initially been close to the CMZ carrying capacity of the reserve. A thorough carrying capacity study will have to be conducted to determine if the population has, after all, reached carrying capacity. Close monitoring and management is required to further help managers assess the need to control the zebra population. Such action plans have been recommended by Hack *et al* (2002) and Stears *et al* (2016) on the management of plains zebra populations, and stated that:

1. The population growth and demographics continue to be monitored.
2. An annual risk assessment should be conducted.
3. The genetic diversity of the population should be determined and managed accordingly.
4. Fences between conservation areas should be removed with the establishment of corridors to allow the migration of zebra.

5. There should be variation in the artificial watering point distribution in order to maintain habitat heterogeneity across the landscape.

There are numerous management actions that may assist with the issues identified in this study. A combination of these suggestions should be practiced to successfully manage the CMZ population in BNR as well as other areas of the Western Cape. The following management options are recommended:

6.4.1 Translocations and reintroductions

Hrabar & Kerley (2013) defined reintroductions as “human-assisted movement of animals among small, isolated populations managed as one meta-population, with the aim to reinforce population size or enhance or maintain genetic variability”. In addition, the IUCN has set up a “Guidelines on Reintroductions and Other Conservation Translocations”, which guide implementation, oversee and plan all reintroductions (IUCN/SSC, 2013; Kaczensky *et al*., 2016). However, these introductions could be very challenging and have negative effects logistically andfinancially, and on the animal population (Harrington *et al*., 2013).

In BNR, the CMZ have successfully persisted post reintroduction. In 2001, 15 CMZ (six Males, nine Females) were reintroduced in the reserve from Mountain Zebra National Park in the Eastern Cape. Since then, the population has exhibited extremely slow population growth and with a resultant skewed sex ratio. Currently, the population consists of 21 individuals and has a male to female ratio of 1:0.27. Smith *et al* (2007) stated that excess males could contribute to declines in population growth. CapeNature has suggested that additional females should be introduced in order to counteract the male biased sex ratio. However, habitat suitability results suggest that the habitat associated with the Cederberg Wilderness Area and the Cape Floristic Region may be driving male bias in populations (Smith *et al*., 2007; Lea *et al*., 2016). As a result, the additional females will temporarily solve the problem, but similar population structures will arise in the future. Thus, it is recommended that the population be relocated to a more suitable area. Weel *et al* (2015) suggested that CMZ populations should be concentrated in the grassy Eastern Cape regions. As the study population originated from Craddock in the Eastern Cape, it might be suitable for them to be moved back into that area. Another option could be to move the population, with additional females, into Limietberg Nature Reserve. This reserve has the most suitable habitat (Chapter 5) for CMZ within the region and it may be a good opportunity to establish a population in this reserve. Novellie *et al* (2002) suggested that CMZ males can be translocated to reinforce small isolated populations. Alternatively, males could be introduced into new conservation areas, in addition to females from another population to strengthen genetic diversity (a minimum of four males and ten females are required) (Novellie *et al*., 1996). It may take 3-5 years for stable bands to form after introductions as individuals are unfamiliar with each other (Novellie *et al*., 1996). Watson *et al* (2005) stated that a CMZ population should be established in areas where the population can grow to a size large enough to serve as a source for translocations. The minimum size for such a population is 90 individuals as this will not hinder population structure (Watson & Chadwick, 2007). To maintain genetic diversity, Soule (1980) determined that a total of 78 animals were required to maintain a population of 50 animals where less than 1% of genetic diversity is lost per generation.

Once translocated, a population will require intense monitoring and management (Novellie *et al*., 2002). There is a risk of mortalities during translocation due to small population sizes, capture myopathy, fighting and transport. Watson & Chadwick (2007) stated that seven out of nine CMZ were lost when they were captured in Kammanassie Nature Reserve. Therefore, it is recommended that translocations be conducted with the plan of strengthening the meta-population and increased genetic diversity. It is fundamental that such subpopulations are monitored and managed effectively. Conservation managers can ensure that populations continue to grow to a size where translocations can be made to new founder populations (Smith *et al*., 2007). This process should be driven through an active CMZ management plan to ensure the long-term survival of CMZ. Translocations should only be used as a last resort; however, as other management options seem unlikely in BNR, management should strongly consider the translocation of the population. Managers must decide what option will give CMZ the best possible chance of survival, while still being cost effective.

6.4.2 Sales and trades

In order to remove excess males, managers may consider the selling or trading of the males. Novellie *et al* (2002) suggested that CMZ males can be translocated to reinforce small isolated populations. Thus, the excess males in BNR could be sold, and with the profit, additional females can be bought to even out the male biased population. Alternatively, the males could be traded for females. Females from another reserve should be moved into BNR while the males from BNR are moved to that reserve. This will also strengthen the genetic diversity of both populations and minimize inbreeding (Novellie *et al*., 1996).

This option should be practiced with caution given the inherent risks in translocation of zebra. The capture and release of CMZ in BNR will also be very costly due to its remote location. Thus, management will have to consider if this will be a feasible option, financially and for the CMZ, as the habitat provided by the reserve is well below the optimum habitat for a CMZ population (Chapter 5).

6.4.3 Fire regimes

Fynbos habitats typically burn at intervals of 12-15 years while shorter intervals favour resprouters such as grasses, and eliminate woody plant material (Van Wilgen *et al*., 1994; Watson *et al*., 2005). This will promote a mosaic of recently burnt veld which is important to CMZ population growth (Watson & Chadwick, 2007). Heelemann *et al* (2008) stated that burning should happen at appropriate intervals and seasons which will allow the regrowth of sufficient grass within the area. This is important as palatable grasses in dystrophic areas become moribund with low nutritional value in the absence of fire (Mentis & Tainton, 1984; Bond, Midgley & Woodward, 2003). Previously, Fynbos habitats have been managed as a natural fire zone under the assumption that the resulting fire regime will promote biodiversity (Van Wilgen *et al*., 1994). Consequently, management in these areas should be shifted from a natural fire zone to prescribed block-burning (Watson & Chadwick, 2007).

Although attractive, this option does not seem to be viable for BNR. In the Gamka Mountain Nature Reserve, fynbos covered >20000ha which is large enough to prescribe block burning (Watson *et al*., 2005). However, BNR only consists of roughly 1900ha of fynbos habitat which may be too little for a successful fire regime to be established. The terrain in BNR is very rugged and does not allow for the implementation of such a regime; however, if fences between reserves are dropped it may increase the total available habitat to a size where fire regimes can be implemented.

6.4.4 Reserve Expansion

A big emphasis has been placed on the contribution of the private sector towards the conservation of CMZ (Hrabar & Kerley, 2013); however, greater stakeholder engagement from private landowners is still needed in the Cape Floristic Region (Knight, Cowling & Campbell, 2006). The aim of these engagements should be to establish biodiversity stewardship agreements between the involved parties (Gallo *et al*., 2009) that will form part of the Cape Floristic Region conservation plan (Kerley *et al*., 2003) and ensure the long term survival of CMZ in the Western Cape. These initiatives will also increase overall biodiversity (Weel *et al*., 2015).

Cape mountain zebra are migratory animals and will follow the abundance of grasses as seasons change (Penzhorn, 1984; Smith *et al*., 2007). However, fencing and habitat fragmentation hinder migration routes (Naidoo *et al*., 2014). Penzhorn & Novellie (1991) stated that conservation areas should be large enough for both summer and winter feeding sites. As BNR is approximately 5000ha in size with very limited resources, it may appear that the conservation area is not sufficient in size. Therefore, a recommendation would be to expand the size of the reserve. Weel *et al* (2015) stated that mountain Fynbos habitats are less suitable for CMZ and that reserves should allow them access to low lying areas. It has been suggested by CapeNature that the fences between BNR and MNR be dropped to increase reserve size by an additional 2500ha. This will allow the CMZ access to additional land and a higher abundance of grasses. Other stakeholders in the area may also be approached to consider fence dropping. Cedar Rock Reserve, which also neighbours BNR, has a small population of 5-7 CMZ; however, landowners are often reluctant to sell or share property. Watson & Chadwick (2007) suggested that land should be leased as this is a common practice between landowners. The establishment of conservancies on neighbouring reserves will have the least financial impact of BNR management. If an agreement can be made to drop the fences, the additional zebra will add to the population and expand the total conservation area for the whole population. However, the habitat suitability results suggest that the Cederberg Wilderness Area has poor quality habitat for CMZ and it is unlikely that the expansion of the reserve will substantially improve population performance.

6.4.5 Supplementary feeding

Due to poor environmental conditions in BNR, management may have to consider providing supplementary feed to the CMZ population. The IUCN red list guidelines indicate that a population directly dependant on human intervention would no longer be considered “wild”. However, if it is to save a population from extinction it may be considerd by reserve managers. This will be particularly important during periods of severe drought. It is clear from the dietary results (Chapter 3) that there is not a sufficient amount of quality food sources available in BNR, as CMZ exhibited high levels of plasticity towards browse. Penzhorn (1984) found that CMZ are bulk grazers and will only turn to browse when conditions are unfavourable. Weel *et al* (2015) found that grassy environments are more suitable for CMZ. Lea *et al* (2016) found that low grass abundance within the Cape Floristic Region is directly related to poor performance and male biased populations of CMZ. Similar results were found in the demographic study (Chapter 2). Thus, management could use supplementary feed to increase the nutritional intake of CMZ.

Supplementary feeding is a technique used for the management of large herbivores. It can assist in maintaining high densities of herbivores, boost the reproductive success of a species, enhance their overall body condition and provide animals with food during critical times (Kowalczyk *et al*., 2011). The use of supplementary feed could thus relieve the stress which is caused by the limited abundance of grasses in BNR. The additional nutrition from supplementary feed may help the CMZ to reproduce at a male to female sex ratio of 1:1; however, if not managed correctly it could lead to unnatural population growths (Nunez *et al*., 2016). The use of supplementary feed can also very costly (Nunez *et al*., 2016), especially on a reserve like BNR which is situated in a remote location. Therefore, supplementary feed should be used with caution and only as a last resort (Kowalczyk *et al*., 2011). If managers decide to use supplementary feeding, it should consist of high quality grasses which are favoured by CMZ.

6.4.6 Habitat heterogeneity: Rotational opening and closing of watering points

Artificial watering points (AWP) are frequently used in semi-arid environments as a conservation technique (Smit *et al*., 2007). Such AWPs have the potential to increase species densities and provide animals with water in arid and semi-arid environments

(Owen-Smith, 1996; Redfern *et al*., 2005). However, an increase in species activity around these points can lead to habitat destruction, increases in predator-prey interactions and habitat homogenization (Cain *et al*., 2011; Chamaille-Jammes, *et al*., 2016). Therefore, AWPs should be carefully managed whilst having defined visions and goals with sustainable action plans (Smit & Grant, 2009).

Smit & Grant (2009) suggested that AWPs should be opened and closed at alternating times in order to maintain habitat diversity. Chamaillé-Jammes *et al* (2016) found that this management option can be successful if: 1) the application of an adaptive management framework is implemented; 2) the distribution of herbivores can be predicted through management scenarios; and 3) the water provision policy can be adjusted with any changes in herbivore distribution and environmental conditions. As it is difficult to decide which AWPs to open and close, management should try and mimic that of a natural system (Chamaille-Jammes *et al*., 2007).

Owen-Smith (1996) stated that watering holes should be located in low lying areas and not along an altitudinal gradient because increased activity may cause soil erosion. Three of the watering points in BNR are situated in low lying areas and one is on the top of the plateau close to the edge; however, this watering point was least used, and the area not active enough to cause soil erosion. There are additional closed watering points in the reserve that are still in a working condition. These points will be able to be used as a management tool to rotate waterhole use. Smit *et al* (2007) stated that waterholes should be spaced at least three times the distance that a species would travel daily to water. As plains zebra (*Equus quagga*) generally travel 5km to water, it has been recommended that AWPs should be spaced at intervals of 15km (Owen-Smith, 1996). Artificial watering points in BNR are spaced approximately 1.5 – 2km apart and the reserve is too small for such large distances between watering points. Thus, fewer watering points should be opened at a time and an additional one or two should be constructed in the furthest points of the reserve to better disperse animals to those areas. Water holes should be relocated by at least 5km annually to combat the effects of erosion and overgrazing (Ayeni, 1977, Du Toit, 2003). However, the piosphere theory suggests that heterogeneity will be maintained, up to 5km, around watering points in a small scale reserve such as BNR (Chammille-Jammes *et al*., 2009). If these AWPs are managed correctly, it will maintain habitat heterogeneity and allow veld recovery in these areas (Kampf, 2002). Ultimately, it will improve habitat quality for CMZ and other large herbivores.

6.4.7 Reassessing Cape mountain zebra location

An alternative option would be to reassess if BNR and the Cederberg Wilderness Area should be a key protected area for the conservation of CMZ. The current study and others (Watson *et al*., 2005; Watson & Chadwick, 2007; Weel *et al*., 2015) emphasis the poor CMZ population performance in the Cape Floristic Region. This is supported by historical evidence that CMZ mainly utilized grassland areas and that changes in climate drove them into the mountains (Faith, 2012). Hrabar & Kerley (2013) stated that the biggest factor limiting CMZ conservation is the association with its name. The continuous efforts to try and introduce this species into mountainous fynbos habitats without sufficient access to low lying areas may be futile (Weel *et al*., 2015).

This study found that three of the four assessed areas were not suitable for CMZ. Limietberg Nature Reserve contained the most suitable habitat in the study area due to the presence of palatable grasses (Chapter 5). If managers decide to reintroduce CMZ, it should be in areas consisting of Swartland Shale Renosterveld habitat. Watson & Chadwick (2007) found that Renosterveld habitats were favourable for CMZ in Kammanassie Nature Reserve. However, most of the Limietberg Nature Reserve consists of mountainous habitat with very few low lying areas and it is unlikely that CMZ will thrive within this reserve as mountainous areas have been associated with poor equine population performance (Watson & Chadwick, 2007; Weel *et al*., 2015). Consequently, it is recommended that efforts are focused on establishing populations within the grassy Karoo and Eastern Cape areas where sufficient population growth can be achieved (Weel *et al*., 2015).

6.5 Conclusion

Data from this study suggests that a combination of management techniques is required to successfully manage CMZ in BNR as well as other areas of the Western Cape. A Conservation Management plan should be compiled with clear visions and goals to ensure that the best possible strategies are identified and implemented. As decisions may sometimes be difficult, it is important to include all stakeholders to ensure that all costs and benefits are weighted concurrently with the feasibility and efficiency of decisions (Nunez *et al*., 2016).

The information gained from this study has provided an in depth understanding of the ecology of CMZ and the factors that influence population performance. This will play a fundamental role in the further conservation of the species; however, for research to be effective it needs to be put into action. Thus, it is important that these recommendations are implemented into conservation efforts. Continuous research and solutions to the stated problems are needed to ensure the long term sustainability of this species. Nevertheless, increased efforts towards the conservation of CMZ provide hope for the species and its persistence in the Western Cape and South Africa.

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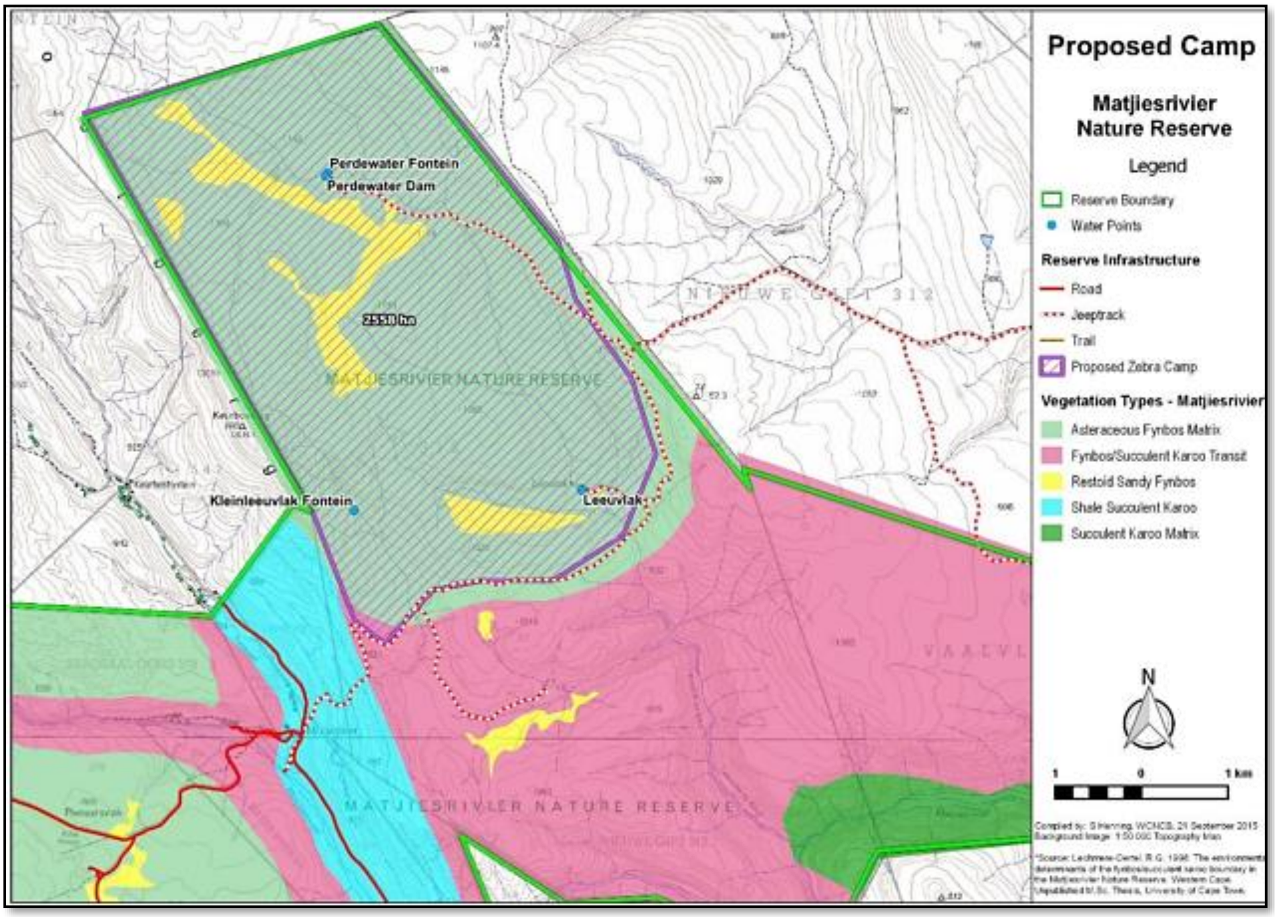
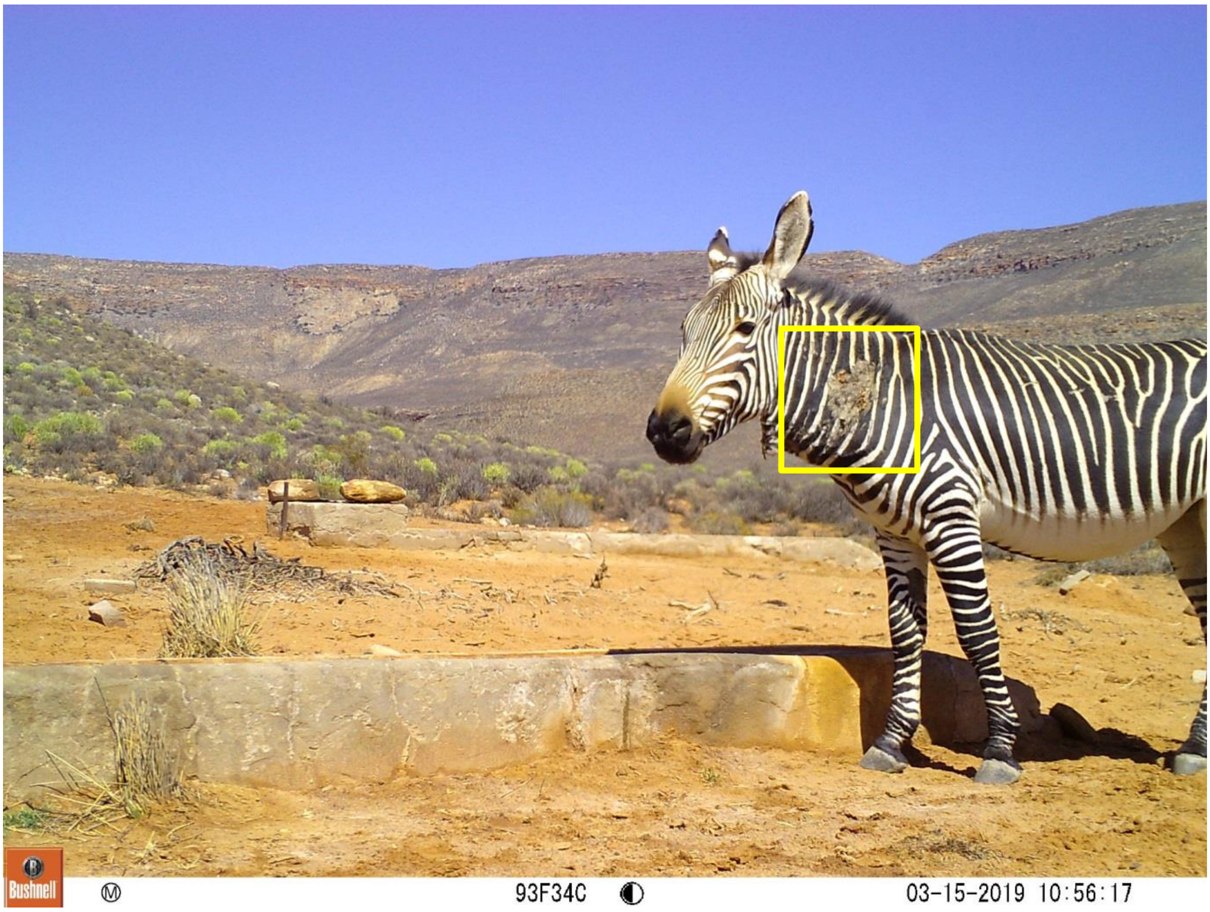
Appendix 1

Map of Matjiesrivier Nature Reserve and the proposed camp for the reintroduction of Cape mountain zebra. Maps from CapeNature (Pty) Ltd.



Appendix 2

A photo from what is believed to be a sarcoid tumour on one of the males. These occur through wounds from fighting with other males and are often fatal. Such tumours are common within equine species. This could be the result of excess males in the reserve which would increase aggression and fighting amongst them.

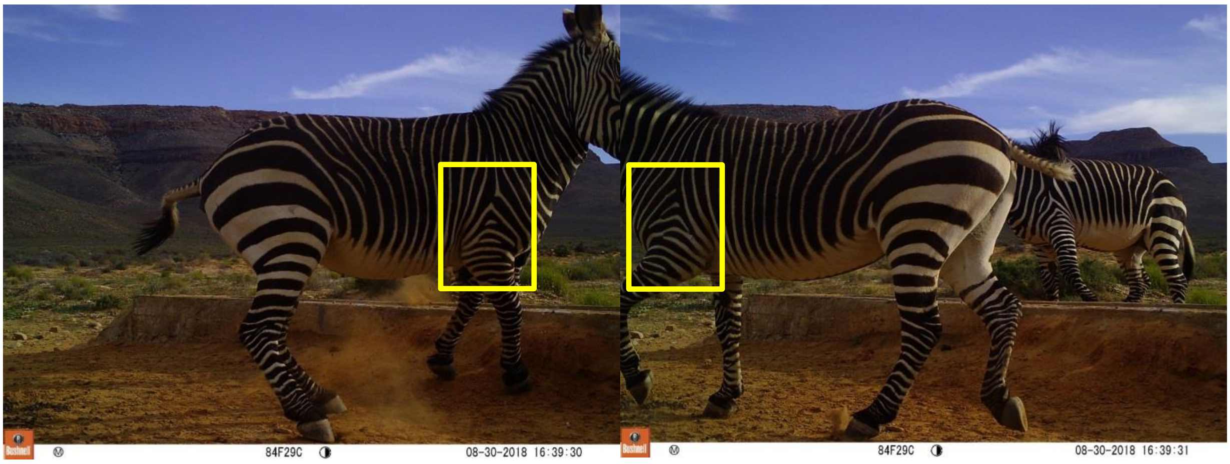


Appendix 3

These photos represent the stripe pattern on the shoulder of an individual Cape mountain zebra. A unique pattern is identified on both the left and right shoulder of each zebra. This was used to identify each individual Cape mountain zebra in Bakkrans Nature Reserve. The photos below is of one of the males and females in the reserve.

Male:

Female:



Appendix 4

An example of the form that was used to record the utilization of plant parts, greenness and sward height.

Date______________________________

Species	Greenness	Plant parts eaten	Height

Appendix 5

An example of the Habitat Suitability Index form that was used. The total number went to 200 for the 200 point method that was used.

Habitat suitability

Date____

GPS____

Habitat____

Season____

Number	Species	Grass/Shrub	Height
1.			
10.			
20. etc			