Are Desert Rodents a Suitable Indicator for Assessing Change in Ecosystem Health in the United Arab Emirate’s Inland Deserts?

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Contents

TABLES

FIGURES

Abstract

Given their reliance on vegetation for feeding and shelter, and importance as prey species, rodents present a potentially useful bioindicator of arid desert ecosystem health. The study aims is to build on the existing research conducted by the Dubai Desert Conservation Reserve in the area of inland desert of the United Arab Emirates. The study aims to investigate whether the enclosure of a protected desert reserve and implementation of land-use management practices ten years ago has improved ecosystem health in the reserve. Utilizing data on rodent abundance, the study attempts to attempt to determine whether there is a discernable difference in ecosystem health inside and outside the reserve.

Using a stratified random sampling approach, a total of 39 sites were identified and surveyed using live trapping with baited Sherman traps deployed from dusk until dawn. The data was collated and subjected to statistical analysis. The study shows a discernable difference in rodent abundance and species diversity within the DDCR compared to the NR areas outside of the reserve. The generalist *Gerbillus cheesmani* dominated the trap results, and were the only species recorded in traps set in sand dune habitat. Species richness and diversity was higher on gravel plain habitat within the DDCR, suggesting that recovery of the vegetation following exclosure allows for the support of a more diverse small mammal community. Further study would be warranted to determine seasonal variations and survey effort may need to be adjusted to target species that may not have been fully represented using the rapid transect methods employed in this study.

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Special thanks must go to my wife, Xunawei Chen, for tolerating me trudging sand into the house after late night trap deployments and the pre-dawn alarms. Both Xuanwei and Liz were on hand to slog through the dunes at dawn to collect in the traps and provide valuable support in the more remote sites. And finally, to my parents who gave us the chance to develop a love for the desert. There really is no better place in the world as the sun sets.

Chapter 1 – Introduction

Desert ecosystems exist in a fragile state. Species that have adapted to survive the extreme arid conditions exist at the range of tolerance. These fragile ecosystems are easily disturbed and can often take tens of years to recover from disturbance, such is the paucity of resources that are available. Desert ecosystems can be relatively simplistic and, as such, they have been the focus of ecological study in many parts of the world. This is not the case in the southern deserts of the Arabian Peninsula. Whilst ecological research has certainly not been neglected, the body of research is limited and there remain many aspects of the different desert ecosystems that remain comparatively poorly studied.

The UAE has experienced rapid economic development since the discovery of oil in the 1970s. This has been accompanied by rapid urbanization and a boom in population. The rapid development in the UAE has placed an increasing stress on the fragile ecosystems that exist in the inland deserts of the UAE. As the country continues to develop and the areas of desert are further encroached upon it seems important to develop an understanding of key ecological resources and identify potential bioindicators that could be used to track ecosystem health.

Given their reliance on vegetation for feeding and shelter, and importance as prey species, rodents present a potentially useful bioindicator of arid desert ecosystem health. The overall aim of this study is to build on the existing research and investigate whether the enclosure of a protected desert reserve and implementation of land-use management practices ten years ago has improved ecosystem health in the reserve. The study aims to utilize data on rodent populations to attempt to assess whether there is a discernable difference in ecosystems inside and outside the reserve.

Chapter 2 - Literature Review and Research Aims

Climate

Desert environments are diverse and distributed from the sub-tropical to the polar regions. Classified by Köppen-Geiger as areas that receive less annual precipitation than the potential annual evapotranspiration (Kottek et al, 2006), desert regions across the globe share a common unifying trait, water scarcity. The United Arab Emirates (UAE) is located at the south west of the Arabian Peninsula, within the hot, arid desert ecological zone of the Tropical Deserts (Simmons et al, 2001). The majority of the country is classified as hyper-arid with a narrow coastal zone that is moderated by proximity to the Arabian Gulf (Middleton and Thomas, 1997).

Mean annual precipitation in the UAE is very low at 100 mm (Böer, 1997), with patterns of rainfall showing distinct temporal and spatial variation. Data recorded at Sharjah Airport between 1934 and 2004 ranged from 3.1 mm to 345.4 mm, with an annual mean of 103 mm (Fuelner, 2006). Rainfall is also highly localised, even during significant rainfall events, with marked variations over relatively short distances. As such, the resident flora and fauna of the hyper-arid desert environments have had to develop physiological and behavioural adaptations to cope with periods of extended drought.

Hyper-arid Desert Flora

As primary producers, the floral communities of the hyper-arid inland deserts of the UAE provide the foundation upon which all higher terrestrial ecology depends (Brown and Böer, 2005). The environmental parameters that most strongly restrict plant development in the hyper-arid desert ecosystems are high soil and air temperatures coupled with unpredictable rainfall (Ehleringer, 1985). It is not uncommon for total precipitation to be lower than the annual average, resulting in extended periods of drought. As such, growth productivity and flowering are usually closely linked to short time periods where adequate soil moisture is available (Bhatt et al, 2016). Given the extreme climatic conditions, vegetation cover in the UAE's inland deserts is typically sparse and dominated by key perennial species that have broad ecological tolerances (Brown, 2009).

Rodents in Arid Environments

Rodents are the most diverse mammal group in the UAE (Aspinall et al, 2005). The hyper-arid inland deserts of the UAE are characterized by low stature, dispersed vegetation forms and extremely low, sporadic rainfall. Rodents are faced with scattered, unpredictable food resources, a persistent shortage or absence of free water and lack of continuous cover to aid predator avoidance (Eisenberg, 1975). Rodents have subsequently developed a series of physiological and behavioural adaptations to cope with these unique challenges.

The majority of desert rodent species are primarily granivorous. This is advantageous as seeds are produced in abundance, relatively easy to find and are easy to store. Seeds are also rich in carbohydrates which, compared to fats and proteins, generate the most net metabolic water per gram consumed (Kotler 1988, Frank 1988). Species of Gerbillus and Meriones present in the in the deserts of the UAE exhibit caching behaviour with seeds stockpiled in their burrows (Baker and Amr 2003, Cunningham 2008). This mirrors behaviour observed in rodent species in the USA (Brown, 1979, Scoles-Scuilia et al 2009) and the Negev Desert of Israel (Brown et al, 1994). In addition to providing a cache of food, it also helps meet water demand as seeds absorb water from the relatively humid air of the burrow, increasing seed succulence (Milicent, 2000). Diversity, density and reproduction of desert rodent populations have been shown to be dependent upon seed abundance (Johnson and Jorgensen, 1981). The annual productivity of a desert habitat has been positively correlated with rodent species diversity in deserts of America (Brown 1973) and Israel (Abramsky et al, 1985).

Desert rodents in the UAE are generally entirely nocturnal or crepuscular. Daily changes in temperature and predatory risk encourage desert rodent species to take refuge in burrows complexes during the day (Kotler et al, 1988). The entrances to the burrows are typically plugged with sand to maintain a constant temperature and level of humidity within the burrows (Kinlaw 1999, Baker and Amr, 2003). This also makes it harder to detect presence of burrows in sandy areas. Rodents emerge at night to forage on seed resource patches. In sand dune habitats, resource patches are renewed daily from the redistribution of sand and seed by strong afternoon winds and are subsequently depleted by nocturnal foraging activity (Kotler et al. 2002). During times of resource scarcity, rodents are forced to increase their levels of foraging effort and the range over which they forage from their burrows, with subsequent increases in the risk of predation (Kotler et al. 1994).

In habitats with sparse vegetative growth and extensive areas of open ground, foraging effort carries an increased risk of predation. Optimal foraging theory predicts that animals should preferentially exploit patches with the highest harvest rate. Given that predatory risk influences harvesting rates, it also directly effects habitat use (Kotler, 1984). The presence of increased lunar illumination has been shown to result in changes in desert rodent population behaviour, with both time of foraging and areas covered shown to change during periods of peak illumination (Price et al 1984, Daly et al 1992, Kotler et al, 2010). During periods of resource abundance, rodents can choose to be more selective with timing and duration of foraging activity, whereas during periods of resource scarcity rodent populations might be forced to increase activity during periods when they are more visible to predators, thereby increasing the risk of predation.

Rodents as Bioindicators

Desert rodents play an important role in arid environments through seed dispersal and as prey species for carnivorous mammals, reptiles and birds (Blaum et al, 2006). As granivores, they consume significant quantities of the seeds produced by desert flora. The mass consumption of seeds in the upper layers of the soil profile has been recorded in the deserts of the USA, Israel, Australia and South America (Gutterman, 1994). Certain species of desert rodents are compulsive hoarders with gathered seeds stored in larders in the burrow complex or in small, shallow caches buried in the surface layers of the soil profile (Brown, 1979). As such, granivorous rodents have a dramatic influence on the distribution of seeds and, by association, the distribution and abundance of plant communities (Brown et al, 1979).

A review of published studies emphasizes the importance of rodents in the diets of a number higher trophic level carnivores. Cunningham and Aspinall (2001) report that an analysis of Desert Eagle Owl (*Bubo (b.) ascalaphus*) and Barn Owl (*Tyto alba*) pellets in Abu Dhabi found predominantly rodent remains in the owl pellets analysed. Analysis of droppings of both Arabian Red Fox and Ruppell's Fox (*Vulpes ruppelli*) in central Saudi Arabia found that small mammals, along with beetles, were the most important prey (Lenain et al. 2004). Harrison and Bates (1991) and Sausmann (1997) describe the diet of Sand Cats (*Felis margarita*) consisting almost predominantly of small rodents. An analysis of the stomach contents of Horned Vipers (*Cerastes gasperetti*) in Saudi Arabia found 70% of the contents to consist of rodent remains (Al-Saldoon and Paray, 2016). As important prey, the abundance of rodent populations will also exert a strong influence on the distribution, abundance and species diversity of predators.

Anthropogenic Disturbance of the UAE's Inland Desert

It is estimated that 90% of the total land area on the Arabian Peninsula suffers from some form of desertification, and 44% is severely degraded (Peacock et al. 2003). In the UAE, excessive grazing by a rapidly expanded national camel herd is recognized as being the single greatest threat to the ecology of the inland deserts (Gallacher and Hill, 2006a). In Saudi Arabia (Barth, 1999), Kuwait (Zaman, 1997) and the UAE (Oatham et al, 1995), exclosure of livestock was reported to result in a rapid recovery in plant biomass (Gallacher and Hill, 2006a). With the rapid expansion of the human population in the UAE since the 1970s, negative impacts associated with recreational off-road driving, rangeland mismanagement excessive groundwater abstraction and direct habitat loss have subsequently increased (Aspinall, 2010).

Protection and Management of the DDCR

The Dubai Desert Conservation Reserve (DDCR) is a 225 km^2 inland desert reserve in the Emirate of Dubai (UAE). A desert recovery programme was initiated in 1999 with an area of 27 km^2 enclosed and protected from camel browsing. The DDCR was established in 2003 and complete removal of camel livestock was effected in 2008. The impact of camel grazing on the native flora was severe in areas of gravel substrate and significant in areas of sand dune habitat. There has been a distinct difference in grazing pressure reported between camels and the herds of gazelle and oryx (Gallacher and Hill, 2006b). Where camels remove the majority of above ground biomass with little discrimination, the smaller herds of oryx and gazelle are more selective in the vegetation they take and largely feed from fodder stations, further reducing grazing pressure.

The recovery rates following exclosure were significant, with vegetation cover on gravel substratum increasing 100 fold between 1999 and 2005 (Gallacher and Hill, 2006b). A later survey conducted by Khafaga (2009) reported a doubling of the number of species recorded on the protected gravel plains between 2004 and 2009. Changes on sand substrata were less dramatic but still notable within the relatively short period of time between exclosure and survey. Between 2004 and 2009 the number of species doubled in sand dune areas, with both annual and perennial species numbers increasing in the areas protected from livestock grazing (Khafaga, 2009).

Aims and Research Questions

This study aimed to undertake a comparative investigation of the status of rodent communities within a protected wildlife reserve and in areas that are not subject to any form of regulation or protection.

The research questions are as follows:

1. Does rodent abundance and species richness vary between sand dune and gravel plain habitats inside the footprint of the DDCR;
2. Does rodent abundance and species richness vary between sand dune and gravel plain habitats outside of the footprint of the DDCR;
3. Is there a significant difference between rodent abundance and species diversity inside and outside of the DDCR; and
4. Is there a significant difference in trapping success during the new moon and full moon phases of the lunar cycle?

Chapter 3 – Study Areas and Survey Methodology

Precipitation

As detailed in Chapter 2, rainfall is highly localised with marked variations over relatively short distances. There is currently no data available for the DDCR during 2017 or 2018, however data supplied by the DDCR collected in Al Faqa'a, to the south of DDCR, is presented in Figure 1. A large rainfall event was recorded in March 2017, however there have been no further significant rainfall events since then.

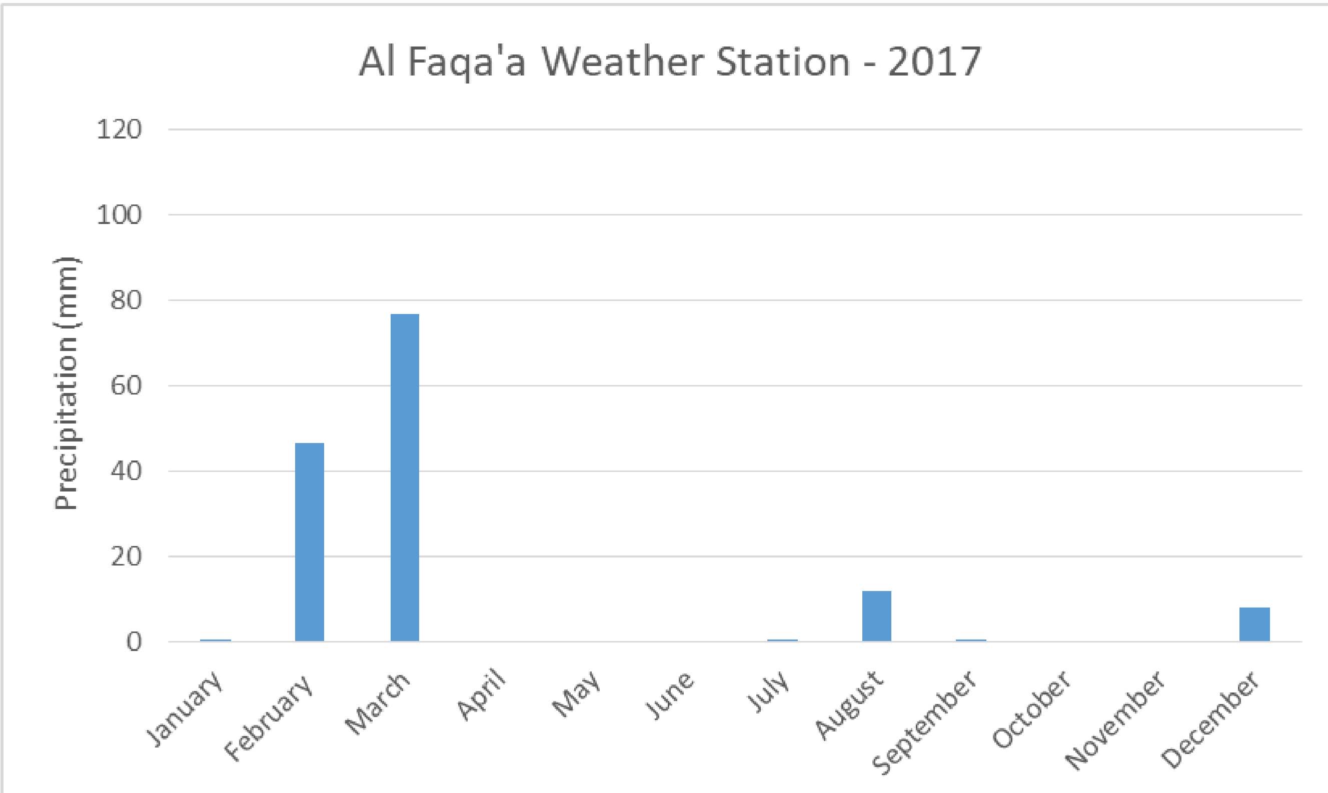

Figure 1 2017 Precipitation Data From UAE National Centre for Meteorology Weather Station at Al Faqa'a

Survey Sites in the DDCR

The DDCR is situated approximately 50 km south east of Dubai in the Emirate of Dubai (Figure 2). The area consists predominantly of aeolian siliceous sand dune habitat interspersed with expanses of exposed gravel substratum (referred to hereafter as gravel plains). Sand dune areas are composed of active, mobile dune systems and more stabilized, inactive areas of sand sheet.

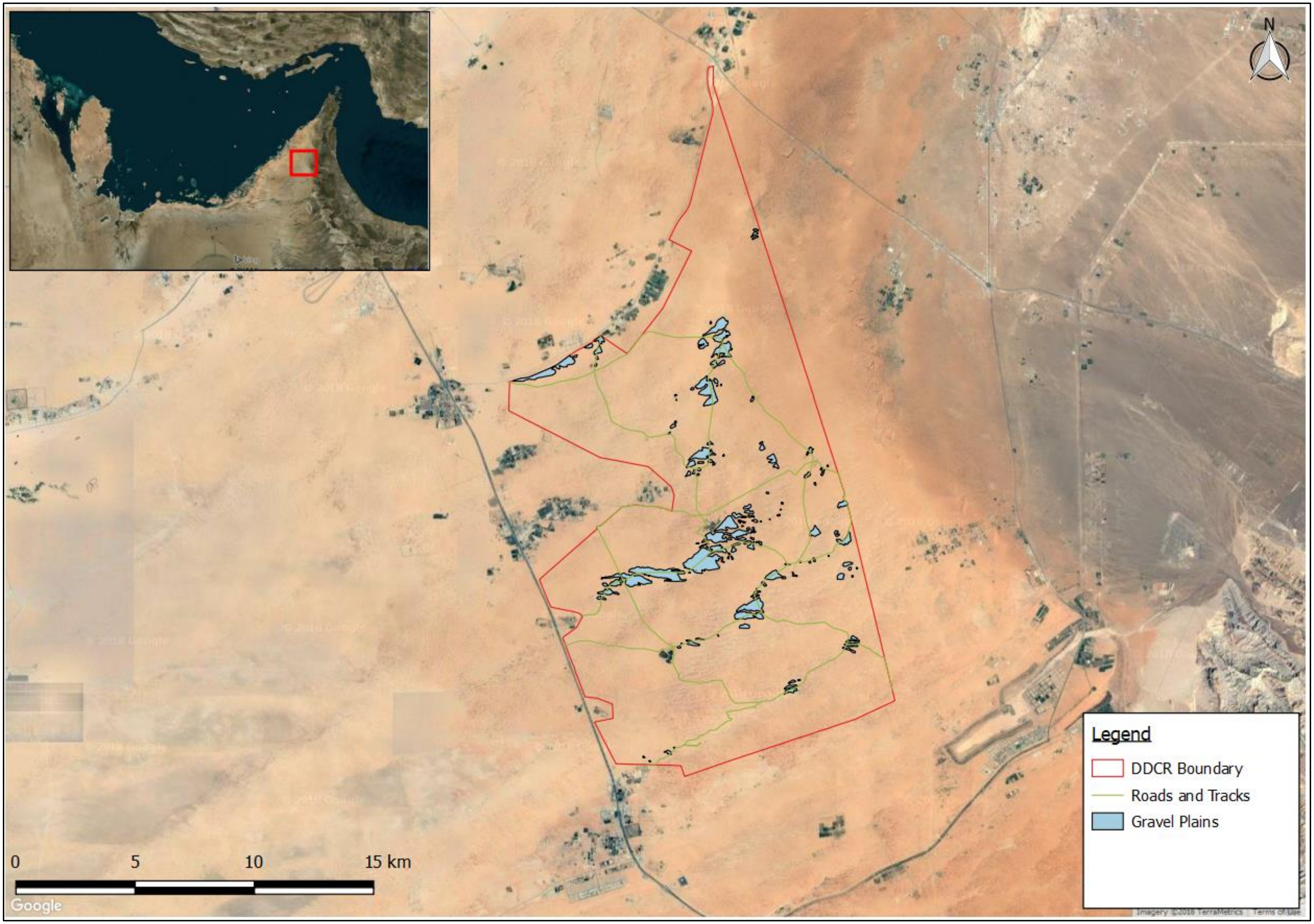

Figure 2 Regional Setting of the Dubai Desert Conservation Reserve (DDCR)

Vegetation throughout the sand dune habitat is dominated by the perennial *Leptadaenia pyrotechnica* (Figure 3) with the perennial dwarf shrubs *Haloxylon salicornicum*, *Limeum arabicum*, *Indigofera colutea*, *Dipterygium glaucum* and the perennial sedge *Cyperus conglomeratus* all locally common. The sandy desert soils are characterized by low availability nutrients, high porosity and low salinity (Gallagher and Hill, 2006a). Vegetation coverage is sparse (Figure 4).

Figure 3 DDCR Sand Dune Habitat With Leptadaenia pyrotechnica The Dominant Vegetation

Figure 4 Typical Sand Dune Habitat Inside the DDCR

The gravel plain habitat consists of low profile areas of exposed sandy, gravel substrate. Ranging in size from 0.001 km^2 to 1.118 km^2, this habitat type is predominantly distributed throughout the centre of the DDCR (Figure 5). The substrate supports sparse growth of vegetation with the perennial dwarf shrub *Fagonia indica* dominant in areas to the north of the DDCR. In the centre of the reserve, where exclosure of camels has been in place for the longest, percentage cover is higher and the perennial *Heliotropium kotschyi* dominates (Figure 6) with *Fagonia indica*, *Rhanterium epappsum* and *Monsonia nevia* also common (Khafaga, 2009). On the southernmost gravel plains small areas of exposed substrate are dominated by the perennial *Moltkiopsis ciliata*. Vegetation on the majority of the gravel plains appears very dry and, though not dead, was in a state of dormancy as a consequence of the very low precipitation that has fallen over the last two years.

Figure 5 Gravel Plain Habitat With Fagonia indica Dominant

Figure 6 Gravel Plain Habitat With Heliotropium kotschyi Dominant

Non-Reserve - Al Marmoum

The most remote of the Non-reserve (NR) study areas, Al Marmoum is located approximately 60 km south of Dubai and eight km west of the DDCR boundary (Figure 8). An extensive interdunal gravel plain approximately 9 km^2 is surrounded on all side by aeolian sand dunes. The gravel plain supports a few sparsely distributed camel camps and private farms and is utilized as rangeland during the day, with camels returning to the camps at feeding times (Figure 7). All areas show signs of anthropogenic disturbance with numerous off-road vehicle tracks crossing the gravel plains, waste from abandoned and active camel camps and, on weekends, off-road safaris using the area for recreational use.

Figure 7 Camel Camp At The Boundary of the Gravel Plain Habitat in Al Marmoum

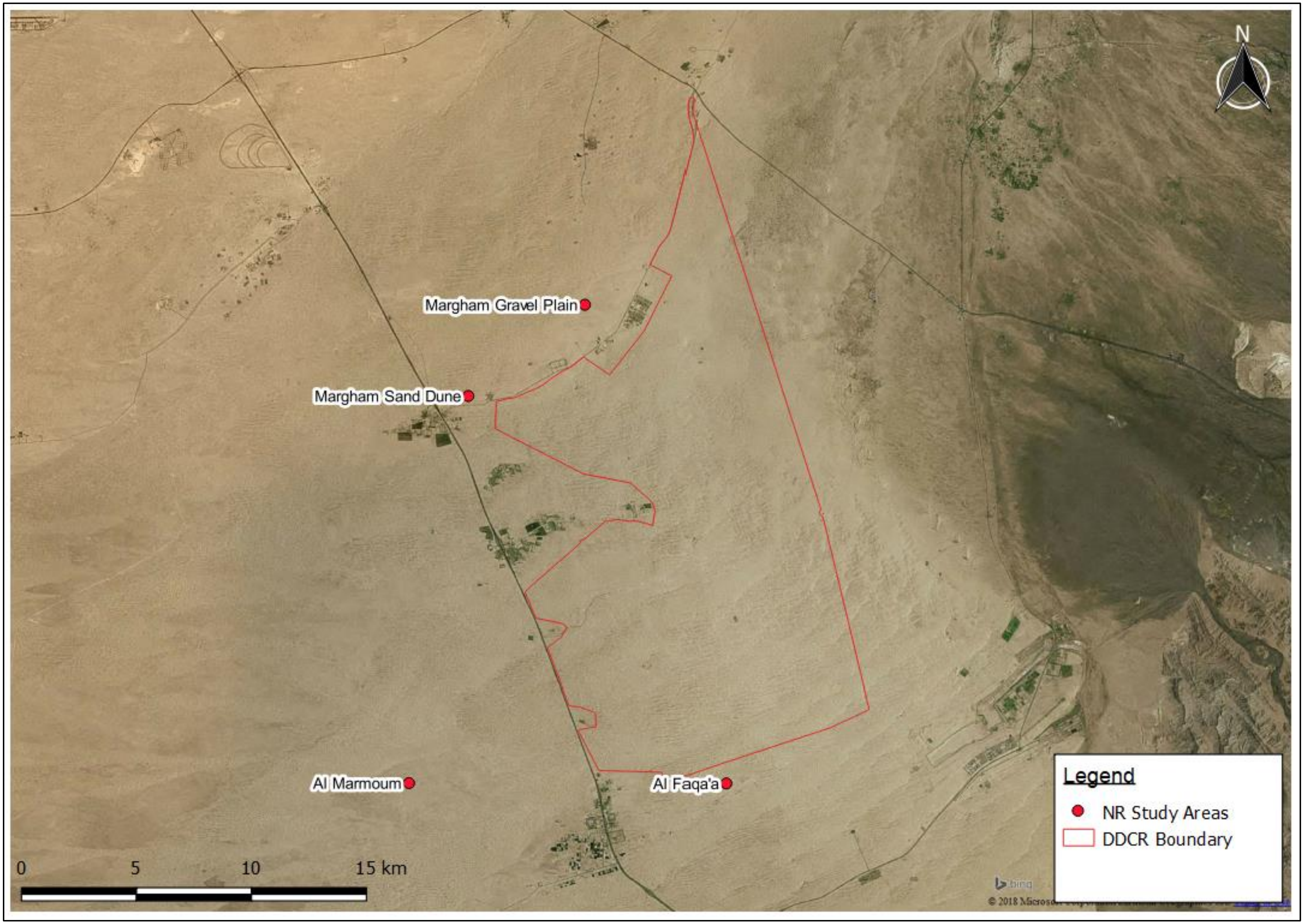

Figure 8 Regional Setting of Non-Reserve Survey Sites

Vegetation cover in the sand dune habitat is very low with the sedge, *Cyperus conglomeratus*, the dominant vegetation. Isolated *Prosopis cineraria* trees are also evident in the sand dune areas bordering the gravel plains (Figure 9).

Figure 9 Characteristic Gravel Plain (left) and Sand Dune (right) In The Al Marmoum Study Area

Non-reserve - Al Faqa'a

Situated within 1 km of the southern fenceline of the DDCR, the Al Faqa'a study area is heavily disturbed by camel farming. The site is characterized by low profile sand sheet with comparatively small interdunal gravel plains of approximately 0.05 km^2.

Vegetation cover was very low in the sand dune areas whilst camel grazing has stripped the gravel plains of above-ground biomass. Sand dune habitats were dominated by the perennial shrub *Calitropis procera* (Figure 10) with scattered *Cyperus conglomeratus* and the desert squash (*Citrullus colocynthis*) also abundant. The prevalence of these species is indicative of a desert habitat that has been highly disturbed by camel farming activity.

Figure 10 Characteristic Low Lying Sand Sheet With An Abundance of Calitropis procera at Al Faqa'a

Non-reserve - Margham

The gravel plain at Margham covers an area of approximately 0.9 km^2 and supports a number of camel camps. Anthropogenic activity in the area is highest of all sites surveyed, with regular off-road vehicle traffic accessing the farms. The gravel plain is heavily disturbed and is largely devoid of vegetation cover (Figure 11).

Figure 11 Camels Being Exercised at Margham Gravel Plains

The sand dune area surveyed in Margham consists of relatively low profile sand sheet with small mobile dunes (Figure 12). There is evidence of overgrazing with perennial dwarf shrub cover noticeably lower than areas inside the DDCR fenceline. *Calitropis procera* is the dominant vegetation and *Cyperus conglomeratus* is also present.

Figure 12 ***Margham Sand Dune Habitat With Calitropis Procera The Dominant Vegetation***

Survey Procedure

As detailed in Chapter 1, desert rodents are predominantly nocturnal and hard to detect. As such, the most commonly utilized method for assessing the abundance of small mammal species is through live trapping (Blomberg and Shine, 2006). It is recognized that line trapping provides a relatively coarse measure of abundance. A more detailed rationale for selection of the survey protocol is provided in the attached Survey Proposal (Appendix A).

Using a stratified random sampling approach, a total of 39 sites were identified and surveyed. Quantam GIS (QGIS) and aerial imagery from Google Earth were used to generate approximately 200 random points within DDCR and NR habitat classes. A selection of these were then randomly selected and ground-truthed to confirm suitability for survey.

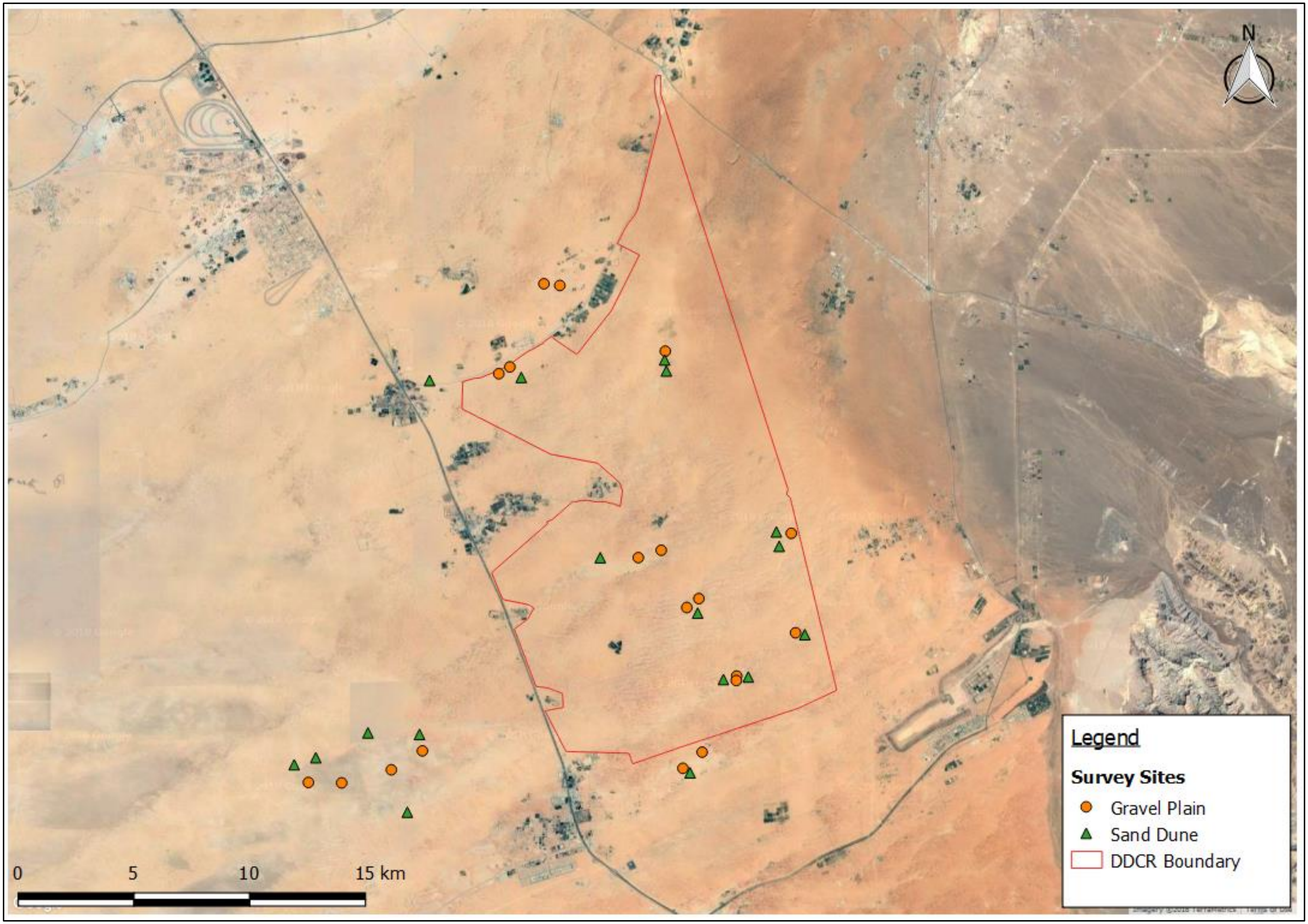

Figure 13 Distribution of Gravel Plain and Sand Dune Habitat Survey Sites

A total of 21 sites inside the DDCR were surveyed, of which 10 were in sand dune habitat and 11 in gravel plain habitat. A total of 18 sites were surveyed in the NR areas with 10 sites in each of the sand dune and gravel plain habitat classes. Figure 13 presents the survey locations.

Sites were surveyed over 15 nights between 18th April 2018 and 3rd July 2018. Effort was made to survey during either the full moon or new moon lunar phases. Where this was not logistically feasible, the lunar phase was noted as waxing or waning.

Three sites were surveyed each night with a combination of sand dune and gravel plains targeted. At each site Sherman traps were set at intervals of 20 metres along a 220 metre transect line, with 11 traps deployed at each site. The transect heading was randomly selected and, in undulating sand dune habitat, followed the contours of the habitat. Each trap was baited with a mixture of peanut butter and oats mixed at a weight ratio of 1:2. Traps were set close to vegetation cover, where feasible (Figure 14). All traps were set at dusk to ensure that no open traps were accessible during the hotter daylight hours.

Figure 14 Sherman Trap Set in Sand Dune Habitat in the DDCR

Traps were recovered at dawn and just after sunrise. Closed traps that showed signs of rodent activity (Figure 15) were targeted as quickly as possible. Where a trap was successful, the animal was gently decanted into a clear, zip-lock plastic bag. The individual was identified to species level, sexed and weighed using a spring balance. All data were recorded on a pre-prepared data recording sheet (Appendix B). Handling was kept to a minimum and, when necessary, animals were held by the scruff of the neck. Following completion of measurements, individuals were released at the point of capture or under vegetation cover nearby.

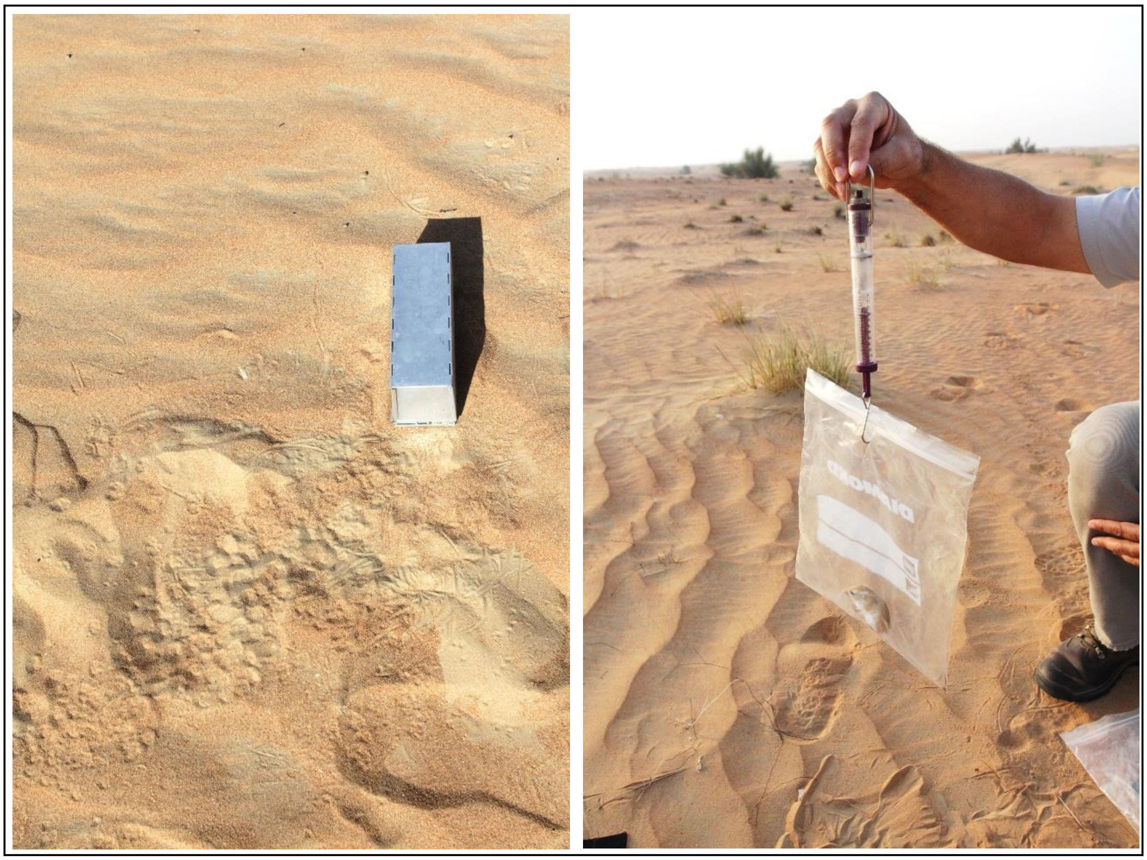

Figure 15 Rodent Tracks Around A Closed Trap (left) and Processing a Captured Cheesman's Gerbil in DDCR (right)

Data was catalogued and descriptive statistics were generated in Microsoft Excel. Statistical analysis was conducted using QED Statistics (Pisces Conservation Ltd, 2012) and Primer v.7 (Clark and Gorley, 2015). Univariate analysis of the abundance data described the data using the Margalef Species Richness (d), Pielou Eveness (J'), Shannon-Weiner (H') and Simpson's Index of Diversity (D) indices. Frequency data were compared using the Chi-sqaure test or, where expected frequencies were <5, using Fisher's Exact test. Level of statistical significance was set at 5%.

Chapter 4 - Results

A total of 54 captures were made over the course of 429 trap nights (trap rate of 12.6%). Within both the DDCR and the NR areas trap success rate was higher in sand dune habitats compared to areas of gravel plain (Table 1). In both the DDCR (χ^2 = 3.670, df=1, P=0.54) and the NR areas (χ^2 = 1.1, df=1, P=0.294), the relationship between trap success and habitat class is not statistically significant.

Table 1 Summary of Trap Deployment and Trap Success

Area	Habitat	Trap Nights	Captures	Trap Success Proportion	
				Habitat Class	Area
DDCR	Sand Dune	121	13	10.7%	5.6%
	Gravel Plain	110	5	4.5%	2.2%
	Area Total	231	18	-	7.8%
NR	Sand Dune	99	21	21.2%	10.6%
	Gravel Plain	99	15	15.2%	7.6%
	Area Total	198	36	-	18.2%
TOTAL		**429**	**54**	**12.6%**	

Despite lower survey effort, the total number of captures in NR areas (36) was double that within the DDCR (18) with a trap rate of 8.4% compared to 4.2% (Figure 16). The difference in trap rate between the DDCR and NR areas was statistically significant (χ^2 = 10.459, df=1, P=0.001).

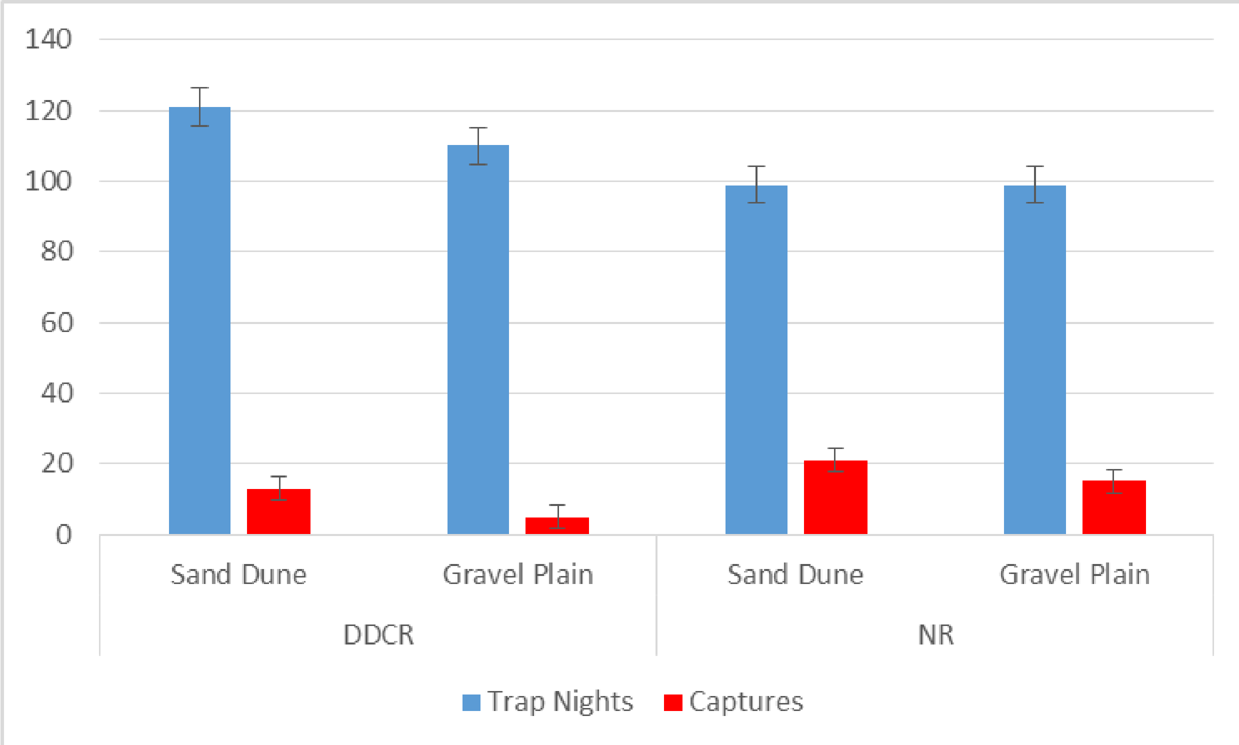

Figure 16 Traps Nights and Trap Success By Area and Habitat Class

Table 2 shows the number of captures on transects in each of the four habitat classifications whilst Figure 17 shows the spatial distribution. Within the DDCR, the proportion of transects with 0 or 1 capture was higher (SD = 70%, GP = 64%) than in NR areas (SD = 22%, GP = 44%). Within the DDCR, the difference between sand dune and gravel plains is not statistically significant (χ^2 = 5.708, df=3, P=0.126). The same is true in NR areas (χ^2 = 3.778, df=4, P=0.437).

When comparing between frequencies in the DDCR and NR areas, the difference between captures on sand dune habitat (χ^2 = 13.652, df=5, P=0.048) and gravel plain habitat (χ^2 = 9.841, df=3, P=0.02) are statistically significant.

Table 2 Frequency of Trap Success Per Transect in Each Area and Habitat Class

Captures per Transect	DDCR SD (10 Transects)	DDCR GP (11 Transects)	NR SD (9 Transects)	NR GP (9 Transects)
0 Captures	3	7	0	0
1 Capture	4	3	2	4
2 Captures	0	1	5	4
3 Captures	3	0	0	1
4 Captures	0	0	1	0
5 Captures	0	0	1	0

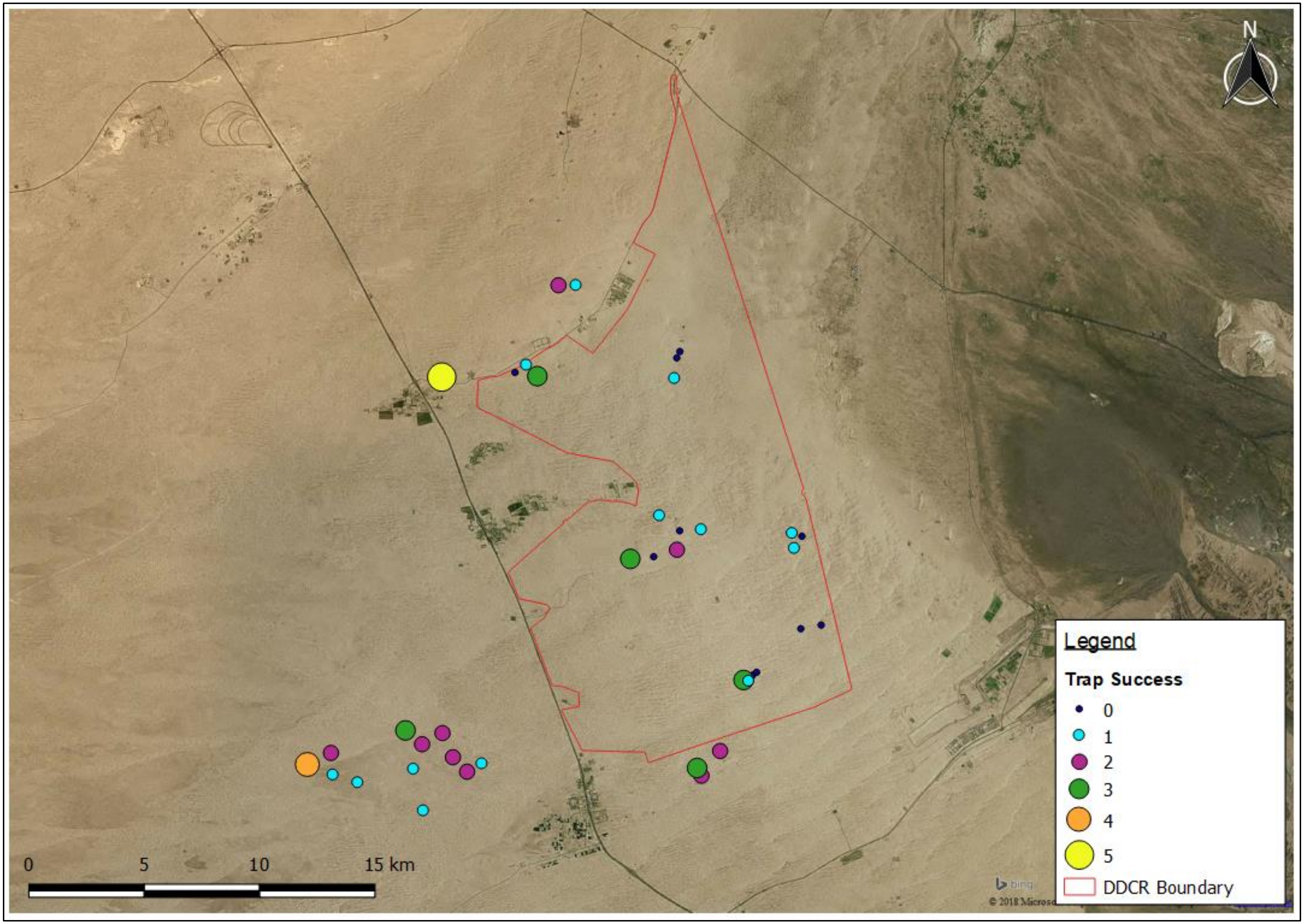

Figure 17 Spatial Distribution of Trap Success on Each Transect

The survey recorded four (4) species of rodent, of which Cheesman's Gerbil (*Gerbillus cheesmani*) was the most dominant. *G. cheesmani* represented 96% of the total trapped individuals and were recorded in both sand dune and gravel plain habitat classes in the DDCR and the NR areas (Table 3 and Figure 18).

Table 3 Summary Data Relating to Captured Individuals in the DDCR and NR Areas

	Species				
	Cheesman's Gerbil	Baluchistan Gerbil	Sundevill's Jird	House Mouse	Total
DDCR SD Count	13	0	0	0	**13**
DDCR GP Count	2	2	1	0	**5**
NR SD Count	21	0	0	0	**21**
NR GP Count	13	1	0	1	**15**
Total Count	**49**	**3**	**1**	**1**	**54**
M/F Ratio	40 : 7	1 : 2	1 : 0	0 : 1	--
Male Mean Weight (N)	28.0g (38)	24g (1)	81g (1)	--	--
Female Mean Weight (N)	24.4g (15)	23g (2)	--	12g (1)	--

The ratio of *G. cheesmani* captured on the sand dune habitat and gravel plains habitat in the DDCR was significantly different (χ^2 = 6.667, df=1, P=0.009). This was not the case, however, in the NR areas (χ^2 = 10.441, df=1, P=0.23). The low counts of the other three species recorded do not allow for statistical comparison.

The ratio of male to female captures was higher in favour of males (42:10), noting that two individuals were not sexed. The relationship between *G. cheesmani* sex and habitat in both the DDCR (Fisher's Exact = 0.133, P = 0.133) and NR areas (Fisher's Exact = 0.399, P = 0.399) is not statistically significant.

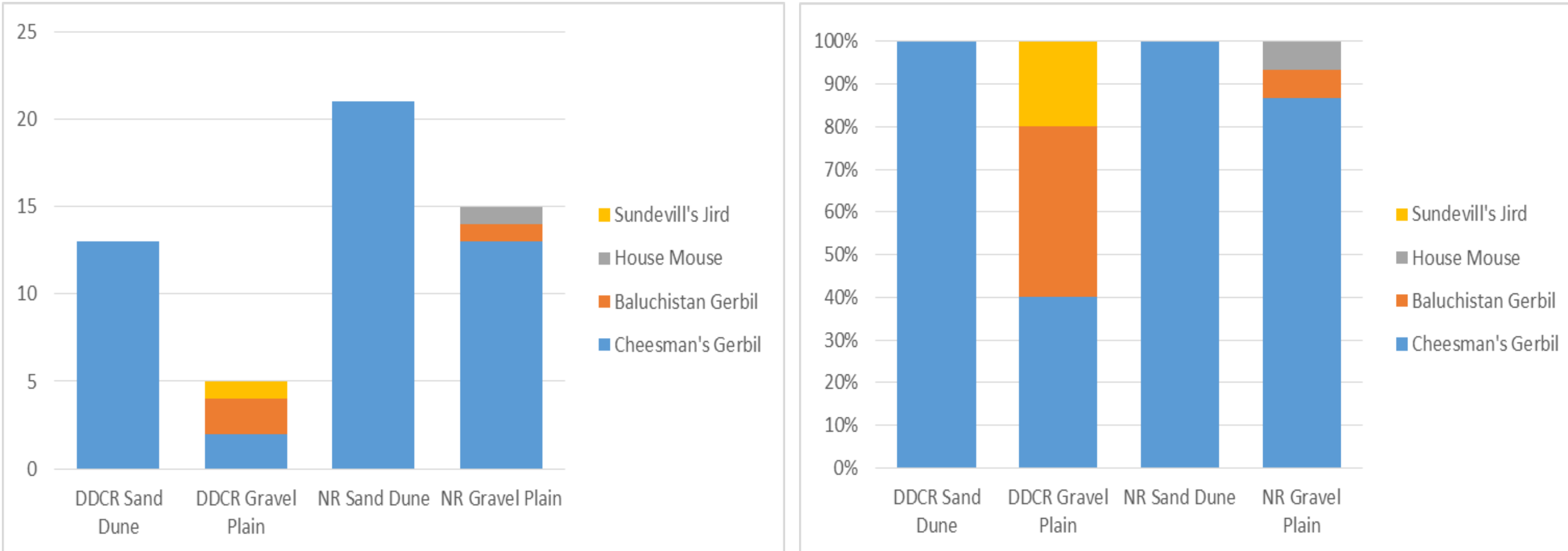

Figure 18 ***Plots Showing Total Species Counts (left) and Proportion of Total Captures (right) By Area and Habitat Class***

Table 4 ***Summary of Results of Univariate Analysis***

Study Area	S	N	Margalef Species Richness (d)	Pielou Evenness (J')	Shannon-Weiner Diversity (H')	Simpson's Index of Diversity (D)
DDCR SD	13	1	0	--	0	0
DDCR GP	5	3	1.243	0.960	1.055	0.80
NR SD	21	1	0	--	0	0
NR GP	15	3	0.739	0.441	0.485	0.26

Table 4 presents the results of univariate analysis of the count data. On sand dune habitat only a single species (*G.cheesmani*) was recorded. Both inside the DDCR and in NR areas, species richness and diversity was subsequently higher in areas of gravel plain habitat.

The diversity indices show that, though abundance on the gravel plain habitat within the DDCR is lower, the rodent community has a greater species richness (d = 1.42) than in the NR areas (d = 0.739). The community appears more balanced in the DDCR (J' = 0.96) than in the NR areas (J' = 0.74) where *G. cheesmani* dominate. The DDCR gravel plains subsequently also exhibit greater diversity (D = 0.8) than the NR areas (D = 0.26).

Table 5 presents a summary of the trap success during the full moon and new moon phases of the lunar cycle. In all study areas but NR GP, the proportion of trap success is greater in the new moon phase. The proportion of trap success during new moon (21%) was greater than during the full moon (14%) in the DDCR compared to 10% during new moon and 6% during full moon phases in the NR areas (Figure 19). The relationship is, however, not statistically significant:

- DDCR (χ^2 = 1.285, df=1, P=0.257);
- NR (χ^2 = 0.925, df=1, P=0.336).

Of total traps set, there was a trap success of 13% during full moon and 10% during the new moon. The relationship was not significant (χ^2 = 0.925, df=1, P=0.336).

Table 5 Summary of Trap Success During Full Moon and New Moon Phases of the Lunar Cycle

Study Area	Lunar Phase	Survey Nights	Traps Deployed	Trap Success	Proportion of Trap Success
DDCR SD	New	3	44	7	18.9%
	Full	5	66	6	10.0%
DDCR GP	New	3	55	3	5.8%
	Full	3	66	2	3.1%
NR SD	New	1	22	6	37.5%
	Full	3	55	8	17.0%
NR GP	New	1	11	1	10.0%
	Full	3	44	6	15.8%

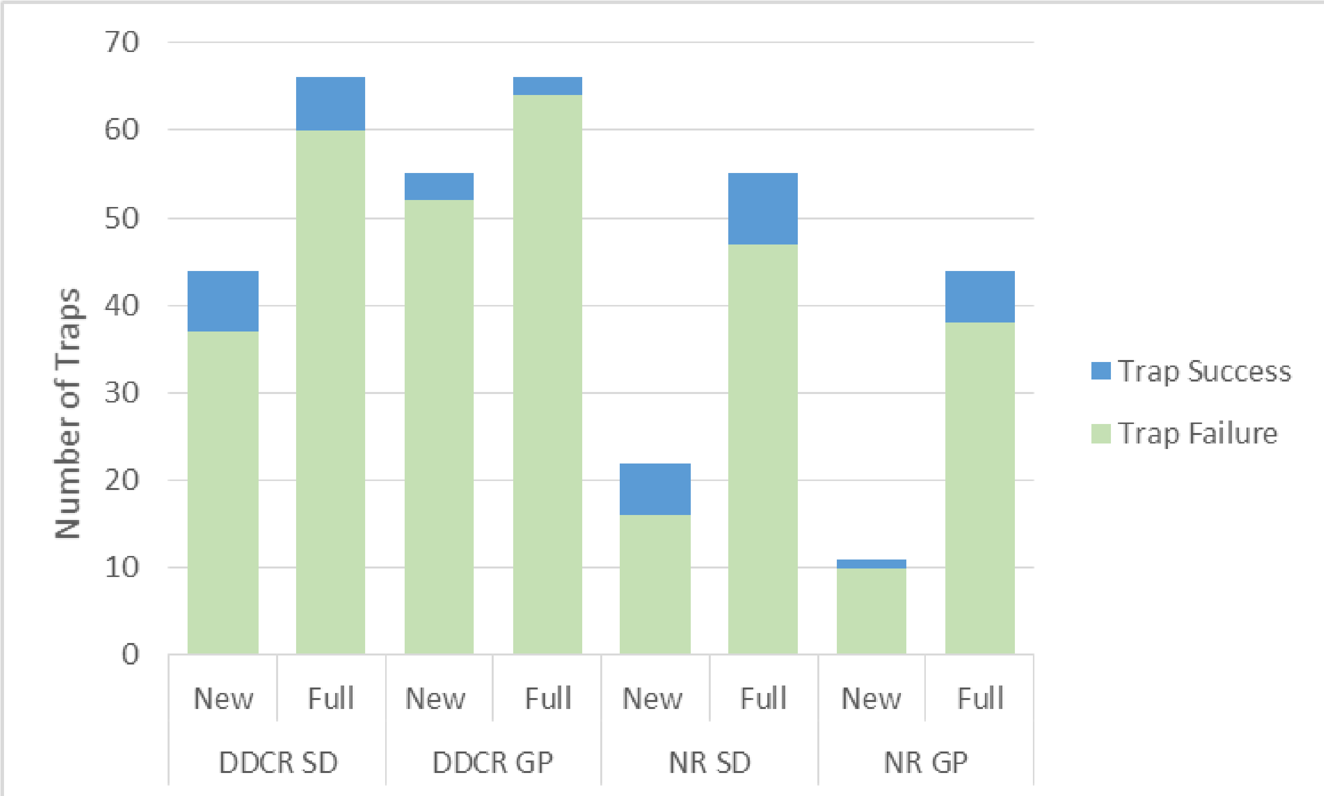

Figure 19 Proportion of Trap Success and Trap Failure During New and Full Moon Phases of the Lunar Cycle

Chapter 5 - Discussion

The survey results provide a similar picture of the rodent community within the DDCR as was reported by Khafaga and Bell (2012). Both surveys trapped three species of rodent on the two habitat classes. *Gerbillus cheesmani* (Figure 20) was the most frequently trapped rodent, though the 2012 survey did trap a higher proportion on gravel plains. The frequency of *G.cheesmani* captures on sand dune habitat compared to gravel plains habitat in this study was statistically significant. This would appear to confirm that *G.cheesmani* favour the sand dune habitat over gravel plain habitat. The lower rate of trapping *G.cheesmani* on gravel plains in this study may be attributable to the continued improvement in the diversity and coverage of sand dune vegetation that was reported after exclosure of livestock grazing (Gallacher and Hill 2006a, Gallacher and Hill 2008, Khafaga, 2009). The availability of improved resource patches on the favored sand dune habitat would limit the requirement for extended foraging trips over areas of gravel plain.

Figure 20 ***Gerbillus cheesmani Pictured in the DDCR***

Where *G.cheesmani* is a generalist, the two other species captured on the gravel plains, *Gerbillus nanus* and *Meriones crassus*, have more specific habitat requirements. They lack the hairy feet that aid *G.cheesmani* with locomotion in areas of sandy substrate (Figure 21) and are more typically recorded on flat plains or, in the case of *G.nanus*, on low profile consolidated sand sheet (Cunningham, 2008). Each species was recorded in a specific area of the reserve with *G.nanus* recorded in the central core of the DDCR and *M.crassus* in the south of the reserve. Both gravel plains had a comparatively high covering of vegetation. *G.nanus* were recorded at a site where *Heliotropium kotschyi* was dominant whilst *M.crassus* was recorded in an area where *Moltkiopsis ciliate* stands had allowed wind-blown sand to accumulate around the base of the shrub. Burrow openings in these plains were abundant, though sand is not necessarily a pre-requisite for presence (Harrison and Bates, 1991). It has been suggested that *M.crassus* may require longer than one night to trust the presence of traps and, by trapping for only a single night per site, the data may underrepresent the abundance of this species (Khafaga, pers comm).

Figure 21 Gerbillus nanus With Characteristic Hairless Soles of Feet

In NR areas a greater number of individuals were captured with less trapping effort expended. The individuals captured were predominantly *G.cheesmani* and they again accounted for all individuals captured in sand dune habitat. All transects deployed in both sand dune and gravel plain sites returned at least one trap success, with the maximum catch rate of 45% recorded on the transect in the Margham sand dunes to the north of the DDCR (Figure 22). Vegetation in all sand dune areas surveyed show signs of significant disturbance. In areas where resources are scarce, it seems likely that rodents are expending greater energy and ranging over greater distances to find food (Brown 1979, Kotler 1984, Dickman et al, 2010). As such, the catchment area around these transects in the NR areas is likely to be wider than in the DDCR where vegetation is in better condition.

Figure 22 ***Margham Sand Dune Site With Calitropis procera Abundant***

The high proportion of *G.cheesmani* captured on transects situated on gravel plains in the NR areas was notable. This may be also be attributable to the degradation of the sand dune habitats that surround the gravel plains and rodents in these areas foraging over greater distances. The record of a House Mouse (*Mus musculus*) in the centre of the extensive gravel plain in Al Marmoum was unexpected (Figure 23). *M.musculus* is not a native species in the UAE but has become naturalized in urban areas. It is considered likely that the individual was imported with along with a camel fodder delivery. The only other record that was not a *G.cheesmani* was a single *G.nanus* in the Al Marmoum area. The capture was at the most remote of the NR sites and it may be that the generalist *G.cheesmani* is outcompeting *G.nanus* in areas that are subject to anthropogenic disturbance (Schoener 1983, Witchell et al 1990, Heske et al 1994).

Figure 23 M. musculus Captured On Gravel Plain In Al Marmoum

Mammalian communities in hyper-arid deserts tend to be relatively simplistic and are often dominated by one or two species (Melville and Chaber, 2016). The annual productivity of a desert habitat has been positively correlated with rodent species diversity in deserts of both America (Brown 1973) and Israel (Abramsky et al, 1985). All areas that have been surveyed as part of this study have been subjected to an extended period without any notable rainfall. As such, rodents are faced with scattered, unpredictable food resources. Males accounted for a notably higher proportion of the individuals captured. This is indicative of previous studies that have surveyed rodents using live trapping (Khafaga and Bell, 2012) and reflects the fact that traps are selective and the sample collected does not necessarily mirror the precise composition of the entire population (Sutherland, 2006). Neither the DDCR nor the NR areas recorded the presence of the Lesser Jerboa (*Jaculus jaculus*). *J.jaculus* are notoriously trap-shy and are subsequently frequently under-reported in trapping surveys (Brown et al. 1994, Scott and Dunstoe, 2000). Further surveys would warrant the inclusion of spotlight surveys to confirm presence / absence of this species.

It is also speculated that a contributing factor to the lower trap success in the DDCR may be attributable to predator-prey relationships. The DDCR supports a large population of Arabian Red Fox (*Vulpes arabicus*) (Bell, 2011). Also present within the DDCR are stands of *Prosopis cineraria* trees that provide valuable habitat for the Desert Eagle Owl (*Bubo (b.) ascalaphus*). Though not specifically counted as part of the survey data collection, tracks were frequently recorded in the DDCR confirming the presence of predators such as *V. vulpes arabicus*, Arabian Sand Boa (*Eryx jayakari*) and Horned Viper (*Cerastes gasperetti*) (Figure 24). It is suggested that a more diverse and abundant predator population within the DDCR may be working to regulate rodent numbers (Owen,1988, Kotler et al, 2002). *V. vulpes arabicus* were present in NR areas, as evidenced by two occasions where foxes attempted to prey on rodents trapped in the Sherman traps. This species has been highly successful in adapting to the presence of humans, and it is posited that other predator species are not as abundant in the NR areas.

Though the majority of sites show a proportionally higher rate of trapping success during the new moon phases of the lunar cycle, the relationship is not statistically significant. The presence of increased lunar illumination has been shown to result in changes in desert rodent population behaviour, with both time of foraging and areas covered shown to change during periods of peak illumination (Price et al 1984, Daly et al 1992, Kotler et al, 2010, Khafaga and Bell, 2012). It is considered likely that the number of replicates collected, most notably NR areas during the new moon phase, are not sufficient to provide an accurate indication of variation during the lunar cycle.

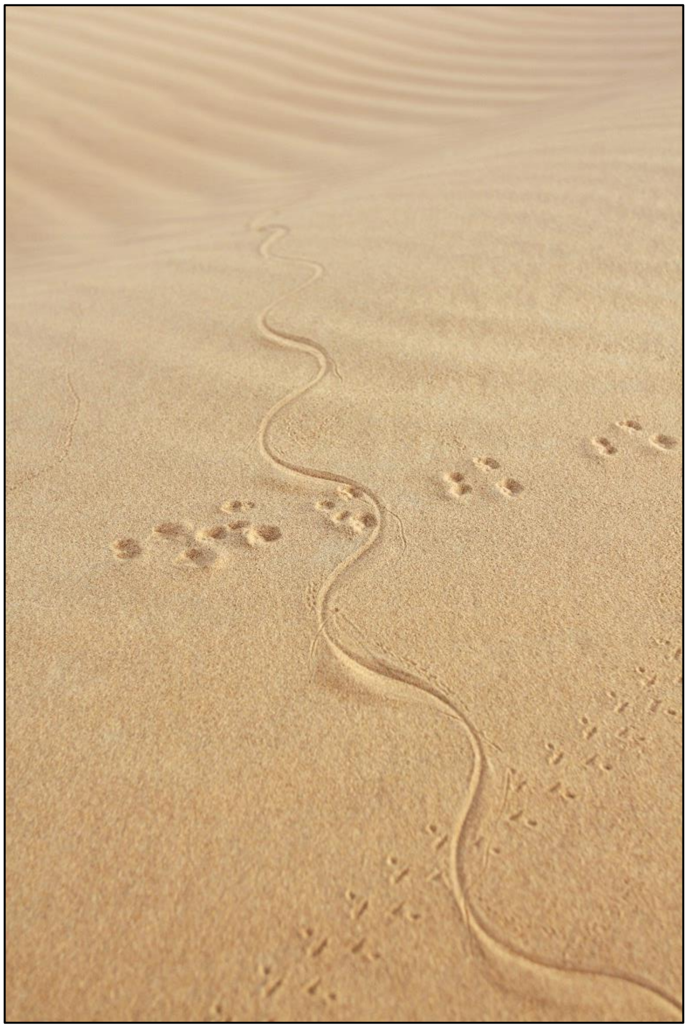

Figure 24 Sand Boa and Cheesman's Gerbil Tracks Alongside Transect In DDCR

Chapter 6 - Conclusions

The study showed a discernable difference in rodent abundance and species diversity within the DDCR compared to the NR areas outside of the reserve. The dominant species in all areas was the generalist *Gerbillus cheesmani*. The DDCR is still in the process of being allowed to rehabilitate after severe degradation of vegetation by livestock grazing. In contrast all of the areas outside of the reserve are heavily impacted by anthropogenic activity. Despite all areas suffering from an elongated period without a heavy rainfall event, the vegetation composition and coverage in the NR areas is noticeably less diverse and coverage is typically lower. The survey results suggest that in areas of gravel plain species richness and diversity increase with habitat regeneration. Given the mono-dominance of *G.cheesmani* in sand dune habitats, it was not possible to compare diversity between DDCR and the unprotected sites. Abundance was lower in the reserve and it is suggested that this may represent a combination of resource scarcity in the NR areas forcing individuals to expend greater effort to find resources as well as a more mature predator population in the DDCR moderating the abundance of *G.cheesmani*.

The study suggests that rodents can be a useful indicator of ecosystem health, albeit as a relatively coarse measure. Further study would be warranted to determine seasonal variations and survey effort may need to be adjusted to target species that may not have been fully represented using the rapid transect methods employed in this study. Spotlight transect surveys dusk and just after sunset would be recommended to determine presence : absence of the Lesser Jerboa (*Jaculus jaculus*) and extended effort in specific areas of gravel plains may improve the resolution for determining abundance of less common species.

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Appendix A – Survey Protocol

Postgraduate Certificate in Ecological Survey Techniques
Field Project Proposal

Completed forms should be returned to est@conted.ox.ac.uk

Student name	David McGrath
Agreed Project tutor	Dr. Rachel Grant
Date submitted	7th March 2018

I confirm that I have read and understood the University of Oxford's Code of Practice and Procedure: Academic Integrity in Research
http://www.admin.ox.ac.uk/personnel/cops/researchintegrity/ Yes ☒

Student Signature: D. McGrath

1. Project title (max 15 words)
Effects of habitat degradation and lunar phases on small mammal abundance and nocturnal activity

2. Background and justification[1] (200 words maximum)

Compared to insects and reptiles, mammals are relatively poorly represented in the arid environments of the United Arab Emirates (UAE) (Perry, 2008). Of those present, rodents are the most diverse mammal group in the UAE, successfully occupying all terrestrial habitats represented (Aspinall, 2005). Despite this, indigenous species of rodents remain poorly studied with little published literature available (Perry, 2008).

Small mammals such as rodents play an important role in arid and semi-arid environments through seed dispersal and as prey species for carnivorous mammals and birds (Blaum et al, 2006). Give their reliance on vegetation for feeding and shelter and importance as prey species, rodents and small mammals present a useful bioindicator of arid desert ecosystem health (Hoffman and Zeller, 2005). An ecological disturbance in habitat is often associated with decreases in rodent diversity. Rodents can also be sampled within localised areas using quick and relatively inexpensive methods (Avenant, 2011).

The Dubai Desert Conservation Reserve (DDCR) is a 225 km^2 inland desert reserve. Historically, the ecosystem health in the DDCR was severely degraded as a result of intensive livestock (camel) grazing. A desert recovery programme was initiated in 1999 with 27 km^2 of formerly grazed desert enclosed. The DDCR, covering a significantly larger area, was established in 2003 with all livestock removed in 2008. Areas outside of the reserve boundary continue to be freely utilised for livestock grazing and recreational activities.

Research conducted by the DDCR in 2012 (Khafaga and Bell, 2012) surveyed the rodent community in the DDCR. Results indicate differences in species abundance and diversity in different habitats in the DDCR. The study also recorded difference in rates of trapping success during different phases of the lunar cycle with higher levels of activity indicated during new moon phases.

[1] Background establishes how the project fits into the wider picture (practical or theoretical) with justification of the research. The proposal needs to fulfil the criterion of an independent and original piece of research that relates to the study programme. If you are hosted by another organisation, then please state in this section.

References:
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3. Aims and research questions (200 words max)

The objective of the study is to build on the research conducted by Khafaga and Bell (2012). Through sampling rodent populations both inside and outside the footprint of the DDCR, I aim to investigate whether there are significant differences in rodent diversity in the protected habitats compared to the unprotected, more heavily disturbed habitats. As there is currently no research published in the UAE that specifically investigates the difference in rodent activity during different phases of the lunar cycle, this will also be investigated.

Research questions are as follows:

1. Does species richness vary between sand dune and gravel plain habitats inside the footprint of the DDCR;
2. Does species richness vary between sand dune and gravel plain habitats outside of the footprint of the DDCR;
3. Is there a significant difference between species diversity inside and outside of the DDCR; and
4. Does rodent activity vary during the new moon and full moon phases of the lunar cycle?

4. Research methods and techniques (300 words max)

Rodents that inhabit the arid habitats of the DDCR are largely nocturnal and hard to detect. Given the fact that rodent species are cryptic and hard to survey through remote observation, the most commonly utilized method for assessing the abundance of rodent species is through live trapping (Sutherland, 2006).

I propose to carry out live trapping using Sherman traps, with site selected using stratified random sampling. Randomly generated points within areas of sand dune and gravel plain habitat will be surveyed using line trapping. An identical number of locations will be sampled inside the DDCR as outside the DDCR. Trapping will be conducted during the new moon and full moon phases of the lunar cycle.

At each site, 10 traps will be deployed along a single transect with traps spaced 20 metres apart. Line trapping is considered preferable to utilising a grid pattern as it requires less effort per site in terms of setting out traps and processing captured individuals, and allows sampling of a number of sites within a given night. Flowerdew et al (2004) state that it is an excellent means of obtaining presence / absence data with good spatial resolution.

Whist line trapping provides a relatively coarse measure of abundance, I am not attempting to collect data that relates to species density or population structure. As such, it is considered preferable to obtain replicate data from within the two habitat types rather than conduct more detailed trapping at a smaller number of locations. The objective is to ensure enough data is collected to allow for statistical analysis of the data and confidence limits to be constructed (Magurran, 2013) within the available timeframe.

References:

Flowerdew, J.R., Shore, R.F., Poulton, S. and Sparks, T.H., 2004. Live trapping to monitor small mammals in Britain. *Mammal review*, 34(1-2), pp.31-50.

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5. Details of study location (with map if applicable) (100 words max)
The DDCR is located in the Emirate of Dubai in the United Arab Emirates, approximately 70 km southeast of the city of Dubai (Figure 1).

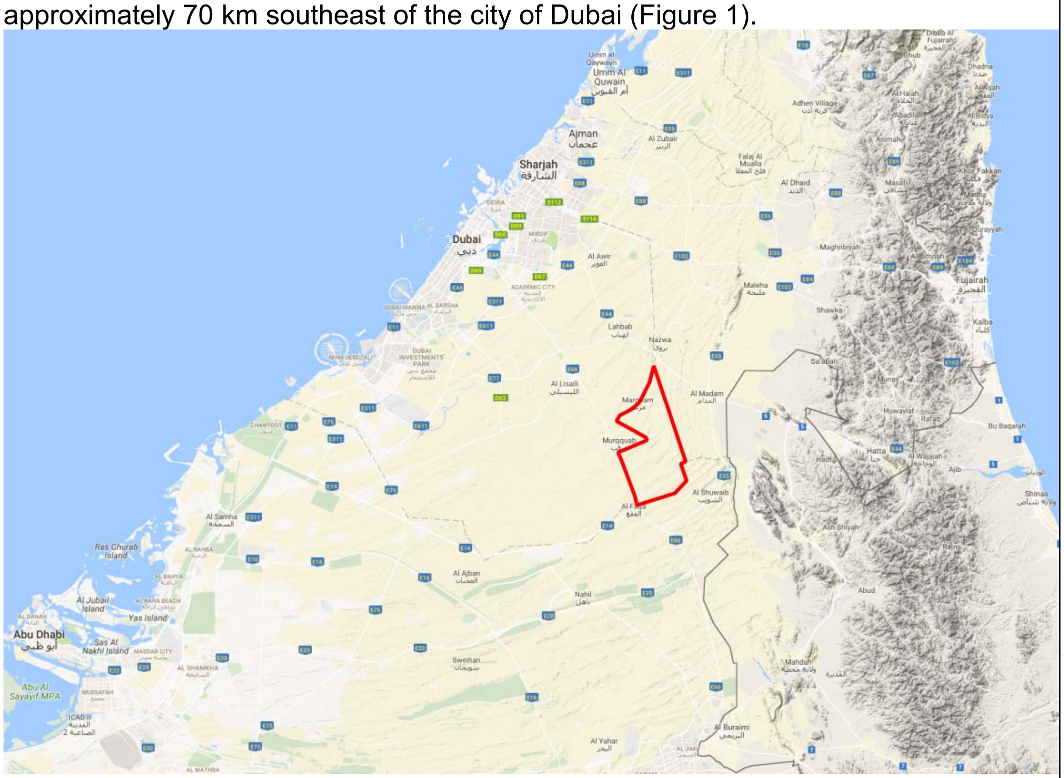

Figure 1 Regional Setting of DDCR

The DDCR consists predominantly of aeolian sand sheets and dune habitat interspersed with interdunal gravel plains (Figure 2). Land use within the reserve is limited to small-scale tourism and the Al Maha Luxury Resort, a 40 room luxury hotel set within an artificial and irrigated desert oasis.

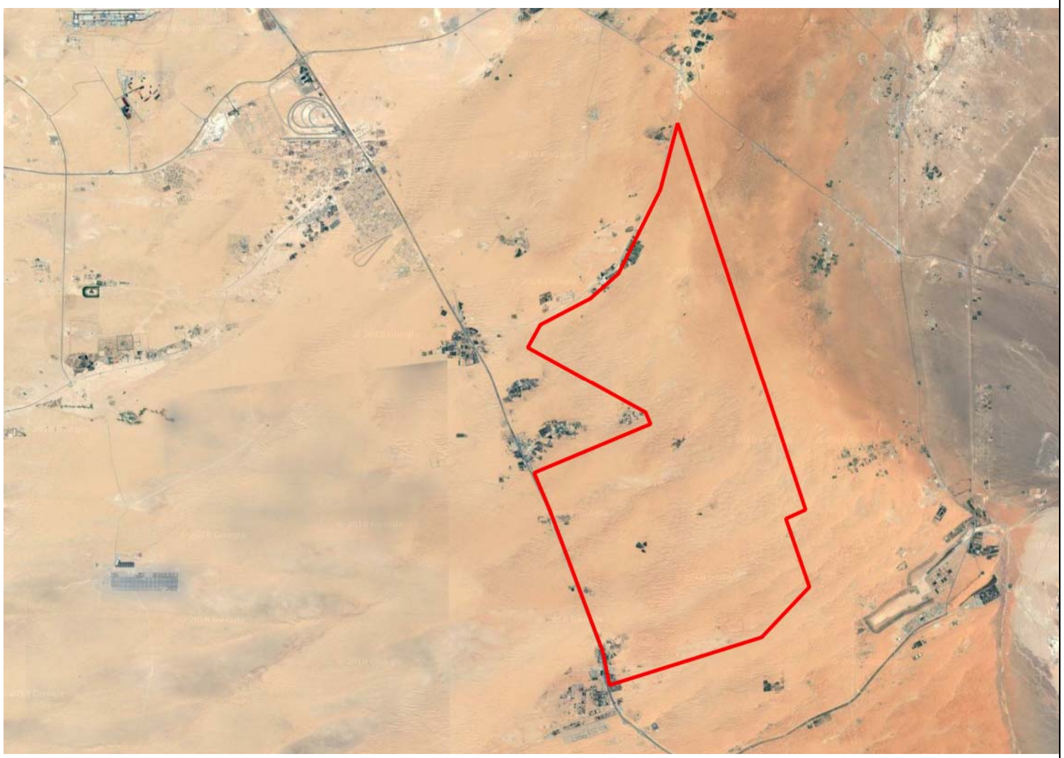

Figure 2 Aerial Image of DDCR (Google Earth, 2018)

6. Timing of field work, travel arrangements, accommodation (100 words max)

Survey work will be conducted from mid-March to mid-May 2018. As a consequence of the elevated summer temperatures, all survey works must be completed before the middle of May to protect the welfare of the animals that are being studied.

Travel to and from the site and within the DDCR will be carried out using my personal 4-wheel drive. Travel within the DDCR will be predominantly via ungraded tracks, so a minimum of two 4x4 vehicles will travel to all survey sites. Each car will have a Garmin GPS, mobile and satellite phone and emergency equipment including first aid kits, tow ropes and sand ladders. Temporary accommodation during the period between trap deployment and trap recovery will be provided by the DDCR.

7. Assumptions[2]

All works will be carried out under the supervision of the DDCR ecological team with trapping and animal handling requirements in accordance with best practice guidance such as the Guidelines of the American Society of Mammalogists for use of wild mammals in research (Sikes et al. 2011). The principal issue faced is the onset of summer with the high temperatures that accompany this period. Though temperatures in the desert are significantly cooler in the night, it is generally

[2] Assumptions identify any logistical, financial, data access, stakeholder cooperation, health, institutional, political or any other factors that could threaten successful completion of the project.

considered best practice to cease live trapping by mid-late May. As such, there is a limited window in which data can be collected. In the event a lunar window (i.e. full or half moon) are missed, then the best course of action would be to proceed without collecting data specific to the lunar phases.

DDCR have approved the survey methodology and confirmed that they will be able to provide field support / supervision and assist with provision of Sherman traps, scales and GIS data. Equipment such as traps, gloves, tape measures, disinfectant and other consumables will be sourced personally.

Sikes, R.S., Gannon, W.L. and Animal Care and Use Committee 1 of the American Society of Mammalogists, 2011. Guidelines of the American Society of Mammalogists for the use of wild mammals in research. *Journal of mammalogy*, 92(1), pp.235-253.

8. Risks and ethics (approvals required as part of your proposal submission)

8.1 Attached risk assessment as part of health & safety form (individual or group fieldwork)

Yes ☒

8.2 Attached ethics form (people, animals and plants-based research)

Yes, have filled in a form ☐

No, I don't need to fill in a form ☐

For office use

Course Director comment:

Date:

Approved / Revision needed (please circle)

Appendix B – Field Data Recording Sheet

DDCR Small Mammal Survey Data Recording Sheet

DATE			**SURVEYOR**		
SITE ID			**TEMP**		**HUMIDITY**
			LUNAR PHASE		**CLOUD**

TRAP #	CAPTURE	SPECIES	M / F	BODY LENGTH (mm)	TAIL LENGTH (mm)	HIND FT (mm)	WEIGHT (g)	PARASITES	NOTES
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									

NOTES

CG	Cheesman's Gerbil	BG	Baluchistan Gerbil	LJ	Lybian Jird	ESM	Egyptian Spiny Mouse
LJ	Lesser Jerboa	SJ	Sundevall's Jird			PS	Pygmy Shrew

SITE OBSERVATIONS / NOTES