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Spatial behaviour of reintroduced male buffalo and their response to predators

By

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Abstract

Understanding spatial behavior of reintroduced animals is critical for better informed management decisions. Rapid growth of human population has caused human and wildlife species conflict over the years. Exploitation of resources for human consumption destroys and fragments natural habitats, decreases species diversity and distribution and fast-tracks the rate of extinction. Large herbivores are often translocating and reintroduced as a process of re-establishment. Reintroduction success depends on numerous factors, which include; the handling and capturing procedure, availability of food, habitat quality, the interaction of the species at the release location, and most importantly, post release monitoring. The adaptive local convex hull (a-LoCoH) was applied to study home range establishment and utilization of the two-male buffalos in the Dinokeng Game Reserve, South Africa from 2012 to 2014.

Movement patterns were similar between the two-male buffalo over the same time period, with home range establishment in the core and 95% reaching 4.11 km^2 and 19.36 km^2 for male buffalo 427 and 6.20 km^2 and 41.79 km^2 for male buffalo 455, respectively. Stabilization of movement pattern became apparent after 180 days of reintroduction suggesting change in movement pattern/behavior from large scale exploration to small scale exploration. Furthermore, the buffalo's showed avoidance and seasonal avoidance of built-up and lion probability of occurrence areas, respectively. The study shows the importance of biotic and abiotic factors that influence buffalo movement pattern and resource selection.

Declaration

I declare that this thesis represents my own work, except where due acknowledgement is made, and that is has not been previously included in a thesis, dissertation or report submitted to this University or to any other institution for a degree, diploma or other qualifications.

Signed ----------

Nkanyiso Cele

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Table of Contents

Declaration 2

Acknowledgements 3

List of Figures 6

List of Tables 8

Chapter 1 - Introduction 9

1.1 General Introduction 9

1.2 Problem Statement 10

1.3 Research Questions 11

1.4 Aim of study 11

1.5 Objectives of study 11

Chapter 2 – Literature Review 12

2.1 African buffalo biology and ecology 12

2.2 Habitat selection 12

2.3 Landscape of fear theory 13

2.4 GIS and Remote Sensing in animal ecology 14

Chapter 3 - Material and Methods 17

3.1 Study Area 17

3.2 Data acquisition 19

3.2.1 Reintroduction and post-release monitoring 19

3.2.2 Other datasets 19

3.3 Data analysis procedures 21

3.3.1 Home range analysis 21

3.3.2 Remote sensing based phenological monitoring 22

3.3.3 Resource selection analysis 23

Chapter 4 – Results 26

4.1 Home Range Analysis 26

4.1.1 Cumulative home range 26

4.1.2 Total home range 27

4.2 Remote sensing based phenological monitoring 30

4.2.1 Home range seasonal mean NDVI 30
4.3 Resource selection analysis 33
4.3.1 Features related to predator probability 34
4.3.2 Features related to resource availability and accessibility 35
4.3.3 Features related to human disturbance 36
Chapter 5 – Discussion 37
5.1 Home Range Analysis 37
Chapter 6 – Conclusion and Recommendations 41
6.1 Summary 41
6.2 Limitations 42
6.3 Recommendations and future research 42
Appendices 43
Topography of the Dinokeng Game Reserve 43
Buffalo 427 seasonal home range 44
Buffalo 455 seasonal home range 45
Predicted probabilities of lion occurrences 46
Normalised Difference Vegetation Index 47
Road Density 49
References 50

List of Figures

Figure 1. Study area, the Dinokeng Game Reserve (DGR). 18

Figure 2. Landsat image footprint for the Dinokeng Game Reserve (DGR). 20

Figure 3. Cumulative home range size of the two-male buffalo in Dinokeng Game Reserve, 2012-2014. 27

Figure 4. Total home range size of the two-male buffalo in Dinokeng Game Reserve, 2012-2014..... 28

Figure 5. Home range overlap between the buffalos and lions in Dinokeng Game Reserve, 2012-2014. 29

Figure 6. Mean NDVI values of the two-male buffalo in Dinokeng Game Reserve, 2012-2014..... 31

Figure 7. Mean precipitation values in Dinokeng Game Reserve, 2012-2014 (Climate Engine, nd). 32

Figure 8. Relationship between mean NDVI and mean precipitation values for both core and 95% home range in Dinokeng Game Reserve, 2012-2014. 32

Figure 9. Lion probability of occurrence selection within 50% and 95% home range by both buffalos and Individual buffalo 455 (from February 2014) using GLMM and GLM regression estimates respectively in Dinokeng Game Reserve, 2012-2014 are presented. 35

Figure 10. Resource availability and accessibility selection within 50% and 95% home range by both buffalos and Individual buffalo 455 (from February 2014) using GLMM and GLM regression estimates respectively in Dinokeng Game Reserve, 2012-2014 are presented. 36

Figure 11. Resource selection based on human disturbance within 50% and 95% home range by both buffalos and Individual buffalo 455 (from February 2014) using GLMM and GLM regression estimates respectively in Dinokeng Game Reserve, 2012-2014 are presented 36

Figure 12. Maps of elevation (m) in the Dinokeng Game Reserve, 2012-2013 derived from ASTER DEM at 30m resolution. 43

Figure 13. 50% and 95% seasonal home ranges for buffalo 455 in Dinokeng Game Reserve, 2012-2014. 44

Figure 14. 50% and 95% seasonal home ranges for buffalo 455 in Dinokeng Game Reserve, 2012-2014 45

Figure 15. Maps of the predicted probabilities of occurrence of lions in the Dinokeng Game Reserve, 2012-2013. 46

Figure 16. Maps of the Normalized Difference Vegetation Index (NDVI) in the Dinokeng Game Reserve, Oct 2012- Dec 2014..... 49

Figure 17. Map of road density (km/km2) in Dinokeng Game Reserve, 2012-2014. 49

List of Tables

Table 1. August 2012 helicopter-based aerial census of total area counts of antelope species in the DGR (Data source: Dinokeng Management Association 2012).....18

Table 2. Data availability for the two-male buffalos 19

Table 3. Summary of data used in the study 20

Table 4. Landsat 7ETM and 8OLI satellite image specifications 20

Table 5. Environmental variables and a prior model set used for estimating the resource selection function (RSF) of buffalo in Dinokeng Game Reserve, 2012-2014.....24

Table 6. The 50% core and 95% seasonal and total home range size (km2) of the two-male buffalo in Dinokeng Game Reserve, 2012-2014 28

Table 7. The 50% core and 95% seasonal mean NDVI values of the two-male buffalo in Dinokeng Game Reserve, 2012-2014.....33

Table 8. The 50% core and 95% seasonal p-values for the two-way ANOVA of the two-male buffalos in Dinokeng Game Reserve, 2012-2014.....33

Table 9. Environmental variables and a prior model set used for estimating the resource selection function (RSF) of buffalos in Dinokeng Game Reserve, 2012-2014. 34

Chapter 1 - Introduction

1.1 General Introduction

Rapid growth of human population has caused human and wildlife species conflict over the years. Exploitation of resources destroys and fragments natural habitats, decreases species diversity and distribution, and accelerates the rate of extinction (Happold, 1995; Sitati *et al*., 2003; Thuiller *et al*., 2006). As a result, re-introductions (re-establishment of species into their natural habitat after being extirpated) and translocations (the movement of wildlife from one range location to another) are becoming common conservation practices that are being applied in order to maintain existing populations of species in their remaining habitat or re-establish population of species in areas that are historically within their historical range (IUCN, 1998; Ripple and Beschta, 2003; Armstrong and Seddon, 2007).

Reintroduction success depends on numerous factors, which include; the handling and capturing procedures, availability of food, habitat quality, the interaction of the species at the release location, and most importantly, post release monitoring. Post release monitoring helps assess habitat utilization and the influence of environmental factors that might affect survival and population dynamics of the animal; this in turn indicates the progress of the animal in adapting to a new environment (Boyd and Bandi, 2002; Nichols and Armstrong, 2012). As a result, the information collected during this process is crucial for making informed management decisions.

Large predators shape prey behavior through direct predation and indirect predation risk effect (Creel and Christianson, 2008; Tambling *et al*., 2012). Risk effect influences the behavior of the prey and could have a greater impact on the reproduction and survival of the prey than direct predation. For instance, ungulates have been documented to change their activity patterns such as spending less time on foraging quality food and more time on vigilance. The

well documented example is that of Elk in Yellow Stone National Park after the reintroduction of wolves (Laundré *et al*., 2001). Therefore, reintroduction of large predators provides a framework to explore responses of prey species to predators (Valeix *et al*., 2009). In this respect, two male African buffalo that were reintroduced along with two herds (number of each herd was below 30) in the DGR were studied to understand biotic and abiotic factors that influence their behaviour. The African buffalo is one of the most successful grazers in Africa with large distributional range across the savannahs of Africa. With habitat selection and foraging ecology of African buffalo being relatively well studied; they prefer a habitat with dense cover, such as reeds and thickets, but can also be found in open woodland (Pienaar, 1969; Ryan *et al*., 2006). While not particularly demanding with respect to their habitat, they require water daily, and therefore depend on perennial sources of water. Herds of buffalo mow down grasses and make way for more selective grazers (Pienaar, 1969; Prins and Iason, 1989; Prins, 1996).

The use of tracking device technologies enables conservation managers to collect movement data on reintroduced animals at various spatiotemporal scales with ease (Berger-Tal and Salz, 2014). Therefore, these technologies have become valuable tools for evaluating and managing reintroduction projects (Berger-Tal and Salz, 2014).

1.2 Problem Statement

In African ecosystems, ungulate communities are largely structured by the presence of predators (Tambling *et al*., 2012). Most studies have primarily focused on population control, diseases, inbreeding and human wildlife conflicts of ungulates and flagship carnivores in South Africa, whereas information on post release movement remains limited (Tambling *et al*., 2012; Yiu *et al*., 2015). Animals typically perform exploratory movements in a new area before deciding on settling. These movements essentially allow animals to compare habitat distribution and quality of competition environment and predators (Bonte *et al*., 2012; Yiu *et*

al., 2015). Because of these exploratory movements, animals can experience fitness reduction and increased mortality risk due to unexpected misadventures (Fortin *et al*, 2005; Berger-tal and Saltz, 2014). Thus, for animals to maximize benefits gained in dispersal they need to strike a balance between the time and energy spent trying to explore and exploit the environment (Bonte *et al*., 2012; Yiu *et al*., 2015). It is also important to note that individual movement decisions do not only affect individual fitness, but also affect behavior and interaction of sympatric and conspecific species, which may possibly have implications on population dynamics and community structure (Fortin *et al*., 2005; Hawkes, 2009; Morales *et al*., 2010). Therefore, the study of individual movement patterns, especially of large ungulates, is a crucial aspect in understanding spatial movement patterns and population processes (Tambling *et al*., 2012; Yiu *et al*., 2015).

1.3 Research Questions

1. How does reintroduced male buffalo adapt to the new environment?
2. Are there any seasonal variations in habitats?
3. What are the influencing factors that determine their home range and habitat selection?

1.4 Aim of study

The aim of this study is to assess the habitat selection patterns of buffalos and evaluate factors influencing their movement patterns in the Dinokeng Game Reserve, South Africa, from 2012 to 2014.

1.5 Objectives of study

1. To map movement patterns of two reintroduced male buffalo.
2. To map seasonal variations of habitats.
3. To investigate the factors (biotic and abiotic) influencing buffalo resource selection.

Chapter 2 – Literature Review

2.1 African buffalo biology and ecology

Understanding Buffalo biology and ecology is important in understanding their seasonal movement pattern and habitat selection, as these factors play a crucial role in reintroduction success of African buffalo (Ryan *et al*., 2006). African Buffalo can reach shoulder heights of up to 1.5 m and a mass of 750 kg. Both sexes have horns, however, bulls are characterized by a heavy boss and upward curved horns (Pienaar, 1969). Also, individual buffalos have been spotted browsing leaves of a variety of woody shrubs. Although these species are attracted in green burns and fresh young grass like most ungulates, they are less partial on fresh young grass, short grass than most grazing animals, and will feed on old, curled grass (Prins and Iason, 1989; Prins, 1996). Buffalo herds are known to range over very large areas and hardly roam areas with little vegetation. In their nomadic grazing routines, herds have been found to roam more than 17 kilometers away from their water sources (Pienaar, 1969).

2.2 Habitat selection

Animal habitat selection is a core concept in understanding animal behaviour responses to varied environments and is a central topic in spatial ecology studies (Johnson, 1980; Van Der Merwe and Marshal, 2012; Yiu *et al*., 2017). Predation risk and food availability are known to be one of the most determining factors of habitat use of ungulates. African ungulates must learn the changing resource availability over time and space as a resort to maximise food intake or to maintain a certain degree of water accessibility (Johnson, 1980; Van Der Merwe and Marshal, 2012; Yiu *et al*., 2017).

Home range is defined as the area where animals live and move on a periodic basis (Burt, 1943; Yiu *et al*., 2017). Recent habitat selection studies have shown that ranging behaviour of animals can be complex depending on a variety of factors such as landscape structure, population

density, climate and social structures (Schradin *et al*., 2010). For herbivores, habitats and anti-predator behaviour such as distance from predators, vigilance in detecting predators and using habitat surroundings to evade or hide from predators, influence the location and size of home ranges (Hebblewhite *et al*., 2005; Van Der Merwe and Marshal, 2012). Animals optimize their movement and space use by varying their frequency and duration visits in different locations to maximise fitness and survival, resulting in changes of their overall home ranges (Yiu *et al*., 2017). African buffalo generally prefer vast open landscapes for grazing purposes, such as savannah grassland where the grass is often long. Furthermore, according to Sinclair (1977), Prins (1996) and Nowak and Walker (1999), African buffalo are often found in river beds or reed as they are reliant on good fresh water supply and their home ranges can span from 50km^2 to over 1000km^2 depending on factors, such as; amount of water and grass, and interspecific competition (Grimsdell, 1969; Mloszewski, 1983).

2.3 Landscape of fear theory

Direct lethal effects of predators on prey have been used as a common measure of predation role (Valeix *et al*., 2009). However, predator-prey interactions can also have nonlethal effects (Tolon *et al*., 2009), because often prey try to avoid the risk of predation by changing their behaviour (Coleman and Hill, 2013). Even in the absence of predators or imminent attack, prey maintain a level of caution due to the persistent risk of predation (Laundré *et al*., 2001). As a result, almost every aspect of prey behaviour and ecology is affected (Tolon *et al*., 2009). Predation risk therefore creates a 'landscape of fear' which affects population dynamics and could potentially cascade into environmental changes (Brown *et al*., 1999; Laundré *et al*., 2010; Tambling *et al*., 2015). For instance, in response to increased predation risk, animals can change activity patterns, vigilance levels or group size, as a result incurring energetic cost (Tolon *et al*., 2009). Such behaviour has been documented in a study conducted by Mao *et al*. (2005) whereby elk (*Cervus elaphus*) in Yellowstone Nation Park changed their use of habitat

by increasing their vigilance and group size in response to reintroduction of wolves. As a result, there was reduction in the quality of diet.

African buffalo form a crucial component of lion diet in Africa and are known to be a formidable prey due their large size and their aggression. Anti-predator behaviour adaptation methods vary depending on the type of risk, the most obvious type of behaviour is their congregation in large herds in order to increase vigilance and minimise any likelihood of any member of the herd being isolated (Prins and Iason, 1989; Prins, 1996). There are six main anti-predator categories that African buffalo resort to: (1) heightened caution, (2) flight, (3) preventive aggression, (4) reciprocal aggression, (5) scrutiny, and (6) auditory-olfactory examination (Prins and Iason, 1989; Prins, 1996). However, recent studies such as that of Tambling *et al*. (2015) have indicated that African buffalo can change their habitat use in response to predation (lions and hyena's) risk. Their results suggested that buffalo were more likely to be active during the day than at night as a form of avoiding possible interaction or overlap with nocturnally active predators, as this is the period in which prey species experience predation. According to Valeix *et al*. (2009) increased movement pattern during midday is a behaviour employed by most African buffalo as a strategy to avoid high predation risk. Therefore, it is important to assess non-lethal impacts of predators on prey habitat selection.

2.4 GIS and Remote Sensing in animal ecology

Reliable data and information in both small and large scale about animal ecology in general helps in understanding animal movement patterns and behavior (Ryan *et al*., 2006). Such information requires reliable data that can be used in improving management of reintroduced animals in game reserves and therefore increases re-introduction success of animals. At present there is a need of advanced technologies in animal ecology that will propel the effective management of animal reintroduction (Ryan *et al*., 2006; Sianga *et al*. 2017).

Geographic information systems (GIS) and Remote sensing (RS) are map-based techniques that have been widely used to study the distribution, dynamics, and environmental factors that relate to animal ecology (Boone *et al*., 2000; Millington and Osborne, 2013). GIS is a data management system that acquires, stores, organizes and visualizes digital map data from various sources such as RS and helps analyse relationships between mapped features (Boone *et al*., 2000, Millington and Osborne, 2013). RS is the acquiring of information of the surface of the earth using airborne or satellite imagery and transforming this information into meaningful maps or layers of information (Boone *et al*., 2000, Millington and Osborne, 2013). Ground based sensors such as GPS collars (record animal locations) combined with remote sensing imagery (e.g. Landsat, Modis, and NOAA/AVHRR) have been used to better understand animal landscape interaction over small and large areas (Osborne *et al*., 2001; Musiega *et al*., 2004; Handcock *et al*., 2009). Evolution in these technologies have allowed for the acquisition and analysis of field data in ways that were not previously possible. Advancements in Global positioning systems (GPS) have contributed to wildlife research significantly by improving the availability and accuracy of real-time animal-movement studies (Neumann *et al*., 2015). In parallel, remotely sensed data can provide environmental indices (at a wide-range of spatial and temporal resolution) that are crucial in understanding movement patterns of animals by integrating fine-scale data that link the environment with animal movement patterns (Neumann *et al*., 2015). For instance, Turner *et al*. (2000) monitored cattle behaviour and pasture use with GPS and GIS in Canada. Seven cows were collared with GPS tracking devices to acquire their fixed locations at 5-min intervals and animation of the collected data was analysed and displayed using MATLAB. Results suggested that there were definite grazing preferences exhibited by individual cows on pasture. Likewise, Sianga *et al*. (2017) collared 3 buffalos with GPS trackers and assessed their seasonal movement patterns in relation to habitat type. Findings illustrated that buffalos varied their habitat selection

seasonally, with major influencing factors being, vegetation height, biomass, and water availability. GIS and RS techniques have been explored, modified, and implemented to better analyse the above-mentioned factors. In a similar study conducted by Ryan *et al*. (2006) home ranges of buffalo were constructed using more than 10 years of buffalo movement data based on GPS locations. Furthermore, habitat selection analysis was conducted using normalized vegetation index (NDVI). This study illustrated the possibilities of analysing fine spatial and temporal scales of animal movement and behaviour. Results indicated that buffalo preferred predominately areas that were within 1 km of a water source and areas of high vegetation density (i.e. high NDVI).

Furthermore, with the study of spatial relationships of animals and their surrounding environment being a main issue in animal ecology, combining GIS and RS in understanding animal ecology (particularly in habitat selection analysis) has effectively helped gain a better understanding of animal movement and behaviour to surrounding environmental factors and therefore, as a result improved animal re-introduction success (Neumann *et al*., 2015). Development in GIS and RS techniques has therefore, over the last decade expanded possible analysis opportunities and has also given rise to numerous methods of analysis in ecology (Manly *et al.*, 2002). For instance, home range analysis (computation of buffers that indicate a ranging behaviour of an animal within a specified distance) of animal movement behaviour has been widely explored. This type of analysis has been widely used in animal ecology in order to understand animal movement pattern, and as a result gain insight in important animal resources, population dynamics and distribution, and therefore make evidence-based management decisions (Channel and Lomolino, 2000; Chirima and Owen-Smith, 2017).

Chapter 3 - Material and Methods

3.1 Study Area

The Dinokeng Game Reserve (DGR) is a private/public initiative for planning and development initially started in the early 2000s (Dinokeng Game Reserve, nd). It was officially opened on 22 September 2011 after the introduction of the big 5 and is the first and only free-roaming game reserve located in Gauteng (Dinokeng Game Reserve, nd). The game reserve is located in Gauteng and Limpopo in South Africa between latitudes 25°15'28" S and 25°28'12" S and longitudes 28°17'55" E and 28°28'25" E and spans an area of 185km^2 (Figure 1). The reserve is situated within the savannah biome which consists of Kalahari thornveld, mixed Bushveld, and sourish mixed Bushveld. DGR receives mean annual rainfall of 674 mm with distinct dry (October – April) and wet (May – September) seasons. Together with 40 artificial and natural dams the Pienaars River provides the main source of water (Yiu *et al*., 2015). The reserve is situated in South Temperate Climatic Zone, with temperature ranges from 5°C to 30°C and the highest temperatures from the December to February period of the wet season and the lowest temperatures between June and July of the dry season (Figure 2) (New *et al*., 2002).

More than 20 mammal species are supported by the DGR (see table 2). As per the 2012 unpublished DGR aerial census data the most common species are blue wildebeest (*Connochaetes taurinus*) and impala (*Aepyceros melampus*) with over 1000 individuals each, and Burchell's zebra (*Equus quagga burchelli*) and blesbock (*Damaliscus pygargus phillipsi*) with over 600 individuals each. In addition to these mammals, white rhinoceros (*Ceratotherium simum*), African elephants (*Loxodonta africana*) and African buffalo (*Syncerus caffer*) were reintroduced into the reserve in October 2008, October 2011 and August 2012 respectively.

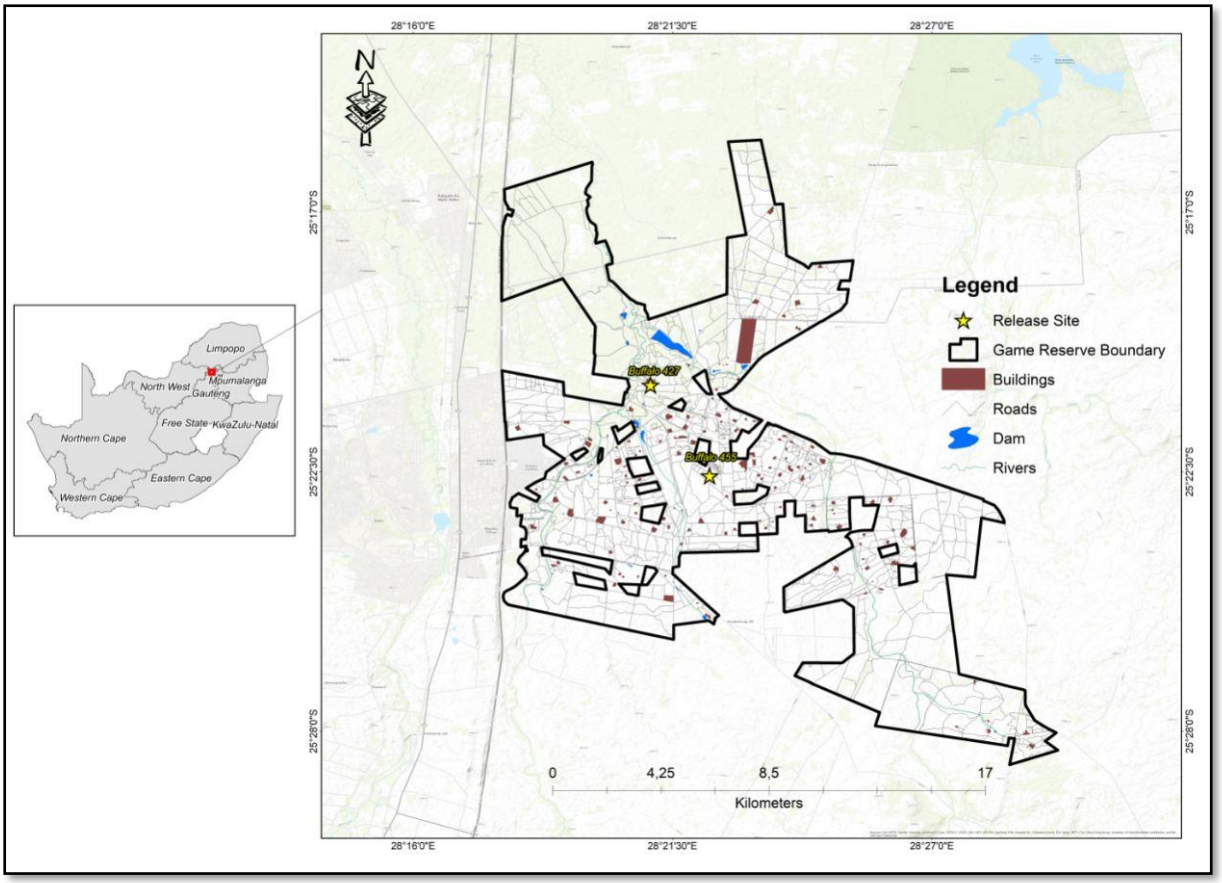


Figure 1. Study area, the Dinokeng Game Reserve (DGR).

Table 1. August 2012 helicopter-based aerial census of total area counts of antelope species in the DGR (Data source: Dinokeng Management Association 2012).

Species	**Count**
Browser	
Bushbuck (*Tragelaphus sylvaticus*)	0
Nyala (*Tragelaphus angasii*)	1
Common duiker (*Sylvicapra grimmia*)	10
South African giraffe (*Giraffa camelopardalis giraffe*)	104
Greater kudu (*Tragelaphus strepsiceros*)	454
Grazer	
Mountain reedbuck (*Redunca fulvorufula*)	0
Gemsbuck (*Oryx gazella*)	6
Hippopotamus (*Hippopotamus amphibius*)	7
African buffalo (*Syncerus caffer*)	9
Bushpig (*Potamochoerus larvatus*)	12
Common reedbuck (*Redunca arundinum*)	15
White rhinoceros (*Ceratotherium simum*)	17
Tsessebe (*Damaliscus lunatus lunatus*)	25
Waterbuck (*Kobus ellipsiprymnus*)	122
Red Hartebeest (*Alcelaphus caama*)	161

Warthog (*Phacochoerus africanus*)	327
Blesbuck (*Damaliscus pygargus phillipsi*)	686
Burchell's Zebra (*Equus quagga burchellii*)	818
Blue wildebeest (*Connochaetes taurinus*)	1635
Mixed feeder	
Steinbuck (*Raphicerus campestris*)	0
Eland (*Taurotragus oryx*)	152
Impala (*Aepyceros melampus*)	1239

3.2 Data acquisition

3.2.1 Reintroduction and post-release monitoring

Two male buffalos collared with Global positioning systems (GPS) manufactured by Africa Wildlife Tracking were introduced in DGR in August 2012. The period August 2012 to December 2014 was used for constructing home ranges and resource selection analysis.

Table 2. Data availability for the two-male buffalos.

Name	**Data format**	**Start Date**	**End Date**
Male 427	GPS coordinates in Excel	01/08/2012	31/01/2014
Male 455	GPS coordinates in Excel	01/08/2012	31/12/2014

3.2.2 Other datasets

Land cover data was used for performing resource selection analysis. These are further elaborated in section 3.3.3. Landsat 7ETM and 8OLI cloud free imagery for the wet (April 2013-2014) and dry (September 2012-2014) seasons was used for the study. Image pre-processing was conducted for all satellite images where the following corrections were made: atmospheric, radiometric, and geometric (see table 2 for specifications and figure 2 Landsat image footprint). These are described in detail in section 3.3.2. Lion probability of occurrence was based on an analysis that was conducted by Yiu et al. (2017) after the reintroduction of lions in the DGR from October 2012 – April 2014. Data used for the analysis is collated in table 2:

Table 3. Summary of data used in the study.

Data	Data Format	Geometry Type/s	Date Acquired	Source	Purpose/Relevance
GPS coordinates, DGR boundary, rivers, dams, roads, buildings	Vector shapefile	Points	11 April 2018	Yiu *et al*., 2017	Home range and resource selection analysis
Land cover map	Vector shapefile	Grid	11 April 2018	Yiu *et al*., 2017	Resource selection analysis
Landsat 7ETM & 8OLI satellite images	Raster image	Grid	02 January 2019	United States Geological Survey (USGS)	Remote sensing based phenological monitoring
Lion Probability of Occurrence	Raster image	Grid	11 December 2018	Yiu *et al*., 2017	Resource selection analysis

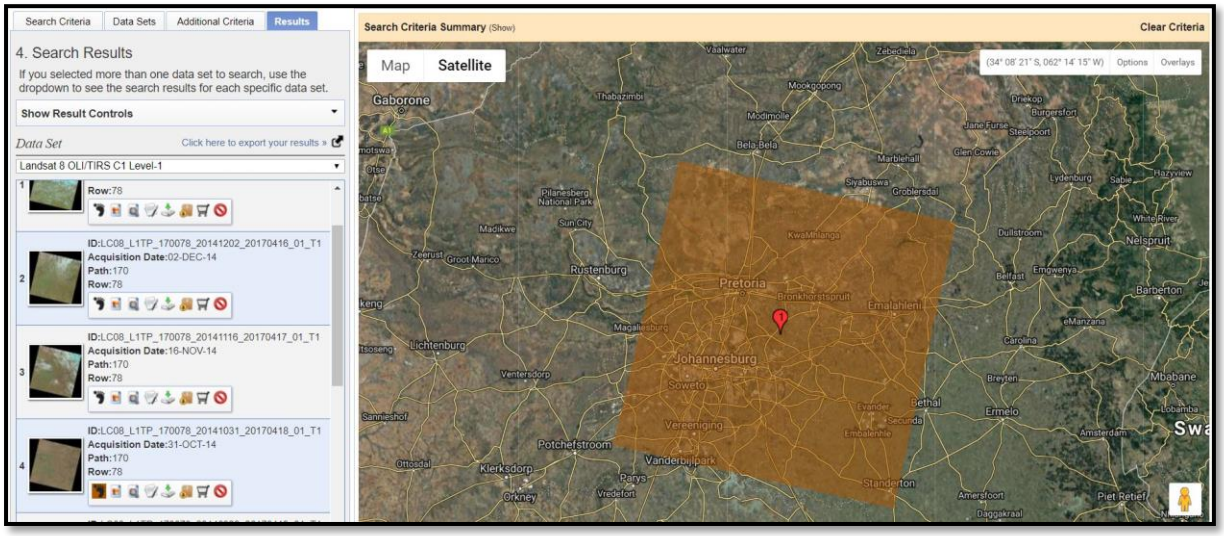


Figure 2. Landsat image footprint for the Dinokeng Game Reserve (DGR).

Table 4. Landsat 7ETM and 8OLI satellite image specifications.

	Landsat 7	Wavelength (mm)	Resolution (m)
Enhanced Thematic Mapper Plus (ETM +)	Band 1	0.45-0.52	30
	Band 2	0.52-0.60	30
	Band 3	0.63-0.69	30
	Band 4	0.77-0.90	30
	Band 5	1.55-1.75	30
	Band 6	10.40-12.50	60*(30)
	Band 7	2.09-2.35	30
	Band 8	52-90	15

	Landsat 8	Wavelength (mm)	Resolution (m)
Operational land Imager (OLI) and Thermal Infrared Sensor (TIRS)	Band 1	0.43-0.45	30
	Band 2	0.45-0.51	30
	Band 3	0.53-0.59	30
	Band 4	0.64-0.67	30
	Band 5	0.85-0.88	30
	Band 6	1.57-1.65	30
	Band 7	2.11-2.29	30
	Band 8	0.50-0.68	15
	Band 9	1.36-1.38	30
	Band 10	10.60-11.19	100
	Band 11	11.50-12.51	100

3.3 Data analysis procedures

3.3.1 Home range analysis

Based on available GPS data, early post-release period is defined as the first wet season (October-April; 2012-2013) and dry season (May-September 2013). Using location records from GPS data various techniques have been developed for assessing range utilization distributions of animals (Chirima and Owen-Smith, 2017). The local nearest neighbor convex hull (LoCoH) method has emphasized the advantage for determining home range delineation (Chirima and Owen-Smith, 2017). For the purpose of this project, the a-LoCoH (Getz *et al*., 2007) method was used to construct 50% core and 95% full home range utilization distributions using R package adehabitat extension in R2.13.0 (Calenge 2006). a-LoCoH constructs local polygons by joining a set of nearby points (Chirima and Owen-Smith, 2017). In constructing local polygons, a-LoCoH method considers all points within a radius *a* such that distances of these points to the reference point amount to a value $\leq a$ (Getz *et al*., 2007; Chirima and Owen-Smith, 2017). According to Getz *et al*. (2007) low values of *a* result in holes (unused areas)

which decrease with increasing value of *a* in HR delineation. As a result, values for *a* were defined based on the minimum spurious hole covering (MSHC) rule, which is based on known topologies (physical features) within HRs. These features were identified using landcover data (rivers, dams, & buildings) that was acquired from Yiu *et al*. (2017).

To estimate cumulative home ranges, home range data for the two male buffalo was modelled by adding the first 30 days of release and subsequently construct home ranges over the study period by adding the locations of the next 30 days, meaning the number of locations was cumulated over time (Yiu *et al*., 2017). Total home ranges were then modelled using all locations. Seasonal home ranges were modelled separately for the wet season and dry season and to evaluate the effects of season on home range sizes a nonparametric two-way ANOVA test was used. The dry and wet season 2014 home range of buffalo 427 was not included in the test since data only ends in January 2014.

Using the adehabitat extension in R, interactions between the buffalos and lions were assessed using Kernohan *et al* (2001) Percent overlap (R Development Core Team, 2011). This method looks at the home range proportion of animal *i* that overlaps with the home range of animal *j*. Subsequently, buffalo GPS locations that fell within the overlap were used to determine the periods at which overlap occurred over the study area.

3.3.2 Remote sensing based phenological monitoring

Normalized Difference Vegetation Index (NDVI) was used to map seasonal variations of habitat of the two-male buffalo. NDVI values were calculated from the Landsat 7 ETM (October – December 2012) and Landsat 8 OLI (January 2013 – December 2014) satellite imagery using ENVI software. Landsat satellite imagery are an established basemap source, has global location accuracy of up-to 30 m spatial resolutions for bands 1 to 7 and 9. Landsat satellite images can be used to estimate vegetation indices such as NDVI and offer a measure

of indices of plant "greenness" or photosynthetic activity using the formula (NIR-VIS)/(NIR+VIS)) (Chynoweth *et al*., 2015). NDVI values range from -1.0 to +1.0, with negative values representative of surfaces with little or no vegetation and positive values indicating increasing amount vegetation greenness (Chynoweth *et al*., 2015).

Prior to the use of satellite imagery particularly for monitoring purposes, such as agriculture or land use studies, it is essential to consider the effects of the atmosphere by applying reliable and efficient atmospheric correction during pre-processing of satellite data (Hadjimitsis *et al*., 2010). Therefore, to receive the true values of the vegetation status Landsat 7 ETM and Landsat 8 OLI satellite imagery were atmospherically corrected using the FLAASH model in the ENVI software. Following this, due to unavailability of August and September 2012 satellite images, 26 time series of NDVI imageries from October 2012 to December 2014 were used for analyses. The mean NDVI for each month was calculated by extracting NDVI values from the satellite imagery into the GPS coordinates of the 50% core and 95% full home range utilization distributions. A two-way ANOVA test was conducted in SAS Enterprise Guide to statistically test if there was significant difference in mean NDVI values between seasons.

Precipitation along with other climatic variables such as temperature, soil moisture, and geomorphology can directly influence and therefore explain NDVI variation over time (Wang and Prince, 2003). As a result, daily rainfall data was acquired from the climate engine website for the equivalent time periods of the NDVI time series analysis (October 2012 – December 2014). Subsequently, the mean precipitation in millimeters for each month was calculated and plotted.

3.3.3 Resource selection analysis

Environmental parameters that could potentially have an influence in habitat selection of the two male buffalo are categorized as follows: predator proximity (predator home range),

resource availability and accessibility (Land cover type, Normalized Difference Vegetation Index [NDVI], distance to nearest rivers and dams), and human disturbances (road density, distance to nearest building) (Hebblewhite *et al*., 2005; Ryan *et a*l., 2006; Van Der Merwe and Marshal, 2012).

Habitat selection of the two male buffalo was assessed by constructing resource selection functions (RSFs) using logistic regression (generalized linear mixed model [GLMM]) (Gillies *et al*., 2007). Models were constructed under the user-availability design, defining the locations of animals as used resources and random points (points were sampled at 1:1 ratio to the number of used location) created within their home ranges estimated by minimum convex polygon (MCP) as available resources (Manly *et al*., 2002). MCP is the simplest way in drawing boundaries of home ranges from location data as it constructs the smallest possible convex polygon around the data (Gillies *et al*., 2007).

Using combinations from the environmental parameters (predator proximity, resource availability and accessibility, and human disturbances), a set of a priori models (Table 4) were constructed for the two male buffalo and for each specified season (wet and dry). Akaike weights was calculated using the Akaike information criterion (AIC) values to assess the quality of each model and therefore identify the model that best describes habitat selection for the two-male buffalo (Burnham and Anderson 2002). Using AIC values calculated from the regression models Akaike weights of the models were calculated, therefore, meaning Akaike weights that were ≥ 0.95 represent the best fit model (Burnham and Anderson 2002).

Table 5. Environmental variables and a prior model set used for estimating the resource selection function (RSF) of buffalo in Dinokeng Game Reserve, 2012-2014.

Feature categories	**Variable**
Predator proximity	Lion predictor probability

Resource availability and accessibility	Distance to nearest water source (dam or river), Normalized Difference Vegetation Index (NDVI)
Human disturbances	Road density, distance to nearest buildings
Model number	**A priori model set**
1	Lion predictor probability
2	Distance to nearest water source (dam or river) + Normalized Difference Vegetation Index (NDVI)
3	Road density + distance to nearest buildings
4	Distance to nearest water source (dam or river) + Normalized Difference Vegetation Index (NDVI) + Road density + distance to nearest buildings
5	Distance to nearest water source (dam or river) + Road density
6	Distance to nearest water source (dam or river) + distance to nearest buildings
7	Normalized Difference Vegetation Index (NDVI) + Road density
8	Normalized Difference Vegetation Index (NDVI) + distance to nearest buildings
9	Lion predictor probability + Distance to nearest water source (dam or river) + Normalized Difference Vegetation Index (NDVI)
10	Lion predictor probability + Road density + distance to nearest buildings
11	Lion predictor probability + Distance to nearest water source (dam or river)
12	

13	Lion predictor probability + Normalized Difference Vegetation Index (NDVI)
14	Lion predictor probability + Road density
15	Lion predictor probability + distance to nearest buildings
16	Lion predictor probability + Distance to nearest water source (dam or river) + Road density
17	Lion predictor probability + Distance to nearest water source (dam or river) + distance to nearest buildings
18	Lion predictor probability + Normalized Difference Vegetation Index (NDVI) + Road density
19 (Global model)	Lion predictor probability + Normalized Difference Vegetation Index (NDVI) + distance to nearest buildings
	Lion predictor probability + Distance to nearest water source (dam or river), Normalized Difference Vegetation Index (NDVI) + Road density, distance to nearest buildings

Chapter 4 – Results

4.1 Home Range Analysis

4.1.1 Cumulative home range

Core and 95% home ranges show a similar trend throughout the time period for both male buffalos, with the highest increase in home range size being visible upon release and stabilizing

over time (Figure 2), signs of long-term stabilization become apparent after 180 to 300 days (From the July period). Also, there is an apparent decrease in core and 95% home range for buffalo 427 from October 2013 to January 2014.

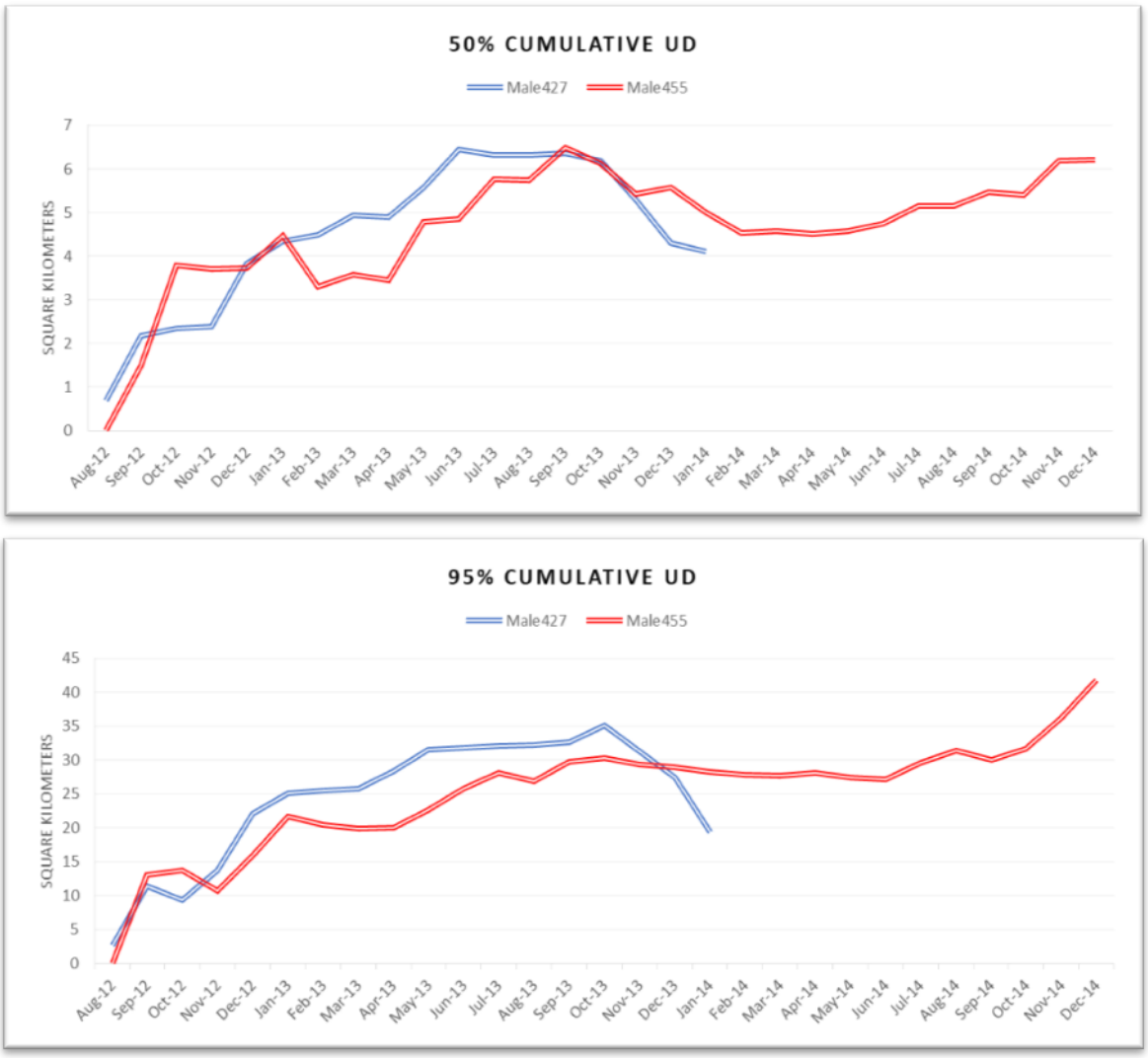


Figure 3. Cumulative home range size of the two-male buffalo in Dinokeng Game Reserve, 2012-2014.

4.1.2 Total home range

Total home range sizes for the 50% and 95% were 4.11 km^2 and 19.36 km^2 for male buffalo 427 and 6.20 km^2 and 41.79 km^2 for male buffalo 455 respectively (Table 5). Core home ranges of buffalo 427 was established exclusively at its area of release, while buffalo 455 established its core home range outside of its area of release (Figure 3).

Table 6. The 50% core and 95% seasonal and total home range size (km2) of the two-male buffalo in Dinokeng Game Reserve, 2012-2014.

Tag	HR (%)	Home Range Size (Km^2)					
		Wet Season 2012 - 2013	Dry Season 2013	Wet Season 2013 - 2014	Dry Season 2014	Wet Season 2014	Total
Male 427	50	4,70	5,74	2,87	-	-	4,11
	95	28,35	28,78	17,02	-	-	19,36
Male 455	50	3,05	5,52	1,87	2,36	6,29	6,20
	95	20,06	24,68	16,22	15,57	32,51	41,79

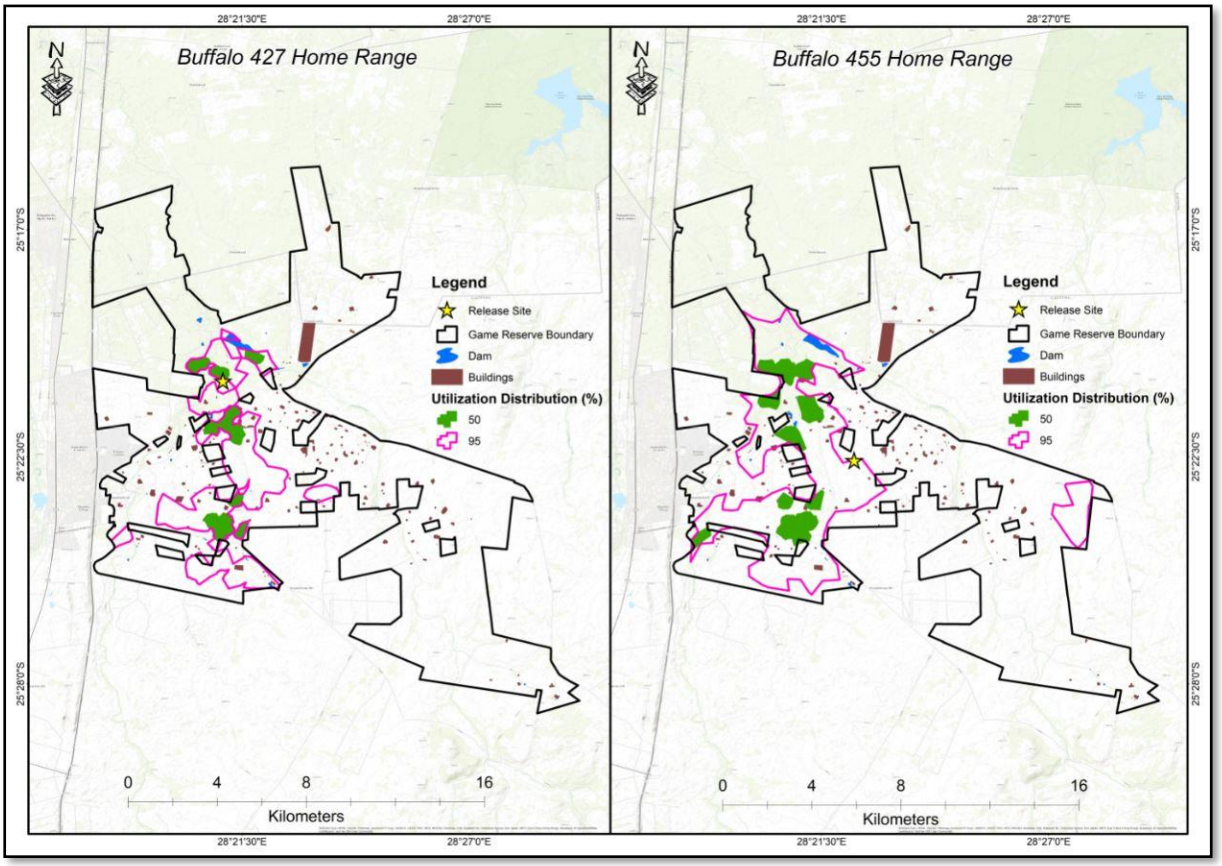


Figure 4. Total home range size of the two-male buffalo in Dinokeng Game Reserve, 2012-2014.

4.1.3 Seasonal Comparison

The core and 95% home ranges of buffalo 427 differed between seasons (50%: p-value= 0.04; 95%: p-value = 0.008). However, home ranges of buffalo 455 only differed for the core range and did not differ for the 95% home range between seasons (50%: p-value= 0.04; 95%: p-value = 0.07) (Table 5).

4.1.4 Home Range Overlap

The percentage overlap between the buffalos and lion home range was calculated to be 6.04%. Majority of overlap occurred in areas that were close to rivers and dams and areas particularly away from buildings (Figure 5).

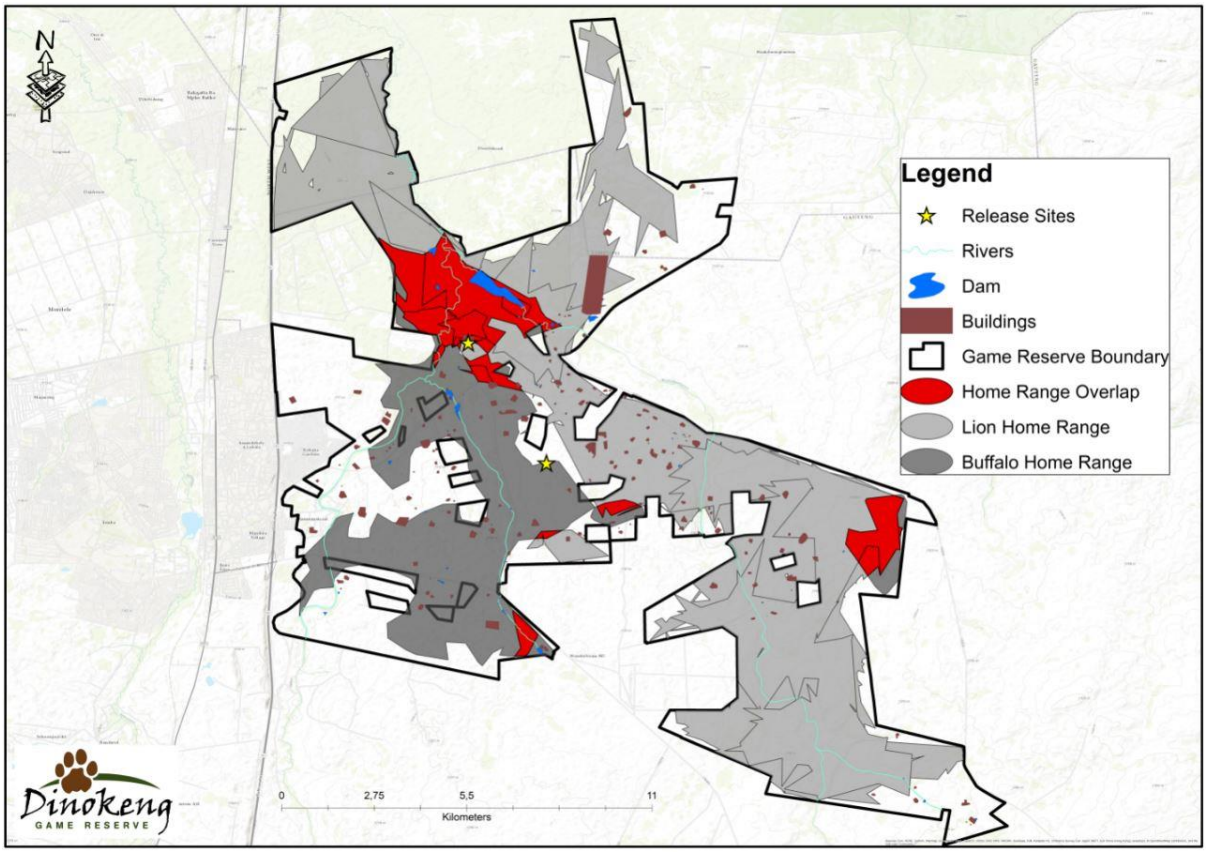


Figure 5. Home range overlap between the buffalos and lions in Dinokeng Game Reserve, 2012-2014.

4.2 Remote sensing based phenological monitoring

4.2.1 Home range seasonal mean NDVI

Mean NDVI values in the 50% and 95% core areas presented comparable seasonal changes in each seasonal range, and differences among 50% and 95% core areas were not significant (P-value; 0.003) (Figure 5). The first wet season (October-April; 2012-2013) showed little variation in mean NDVI value for both buffalo. Mean NDVI values increased at the beginning of the dry season (May 2013) and seemed to level-off from July 2013 for both buffalo. However, NDVI values changed seasonally in each range, for both buffalo the lowest mean NDVI values was experienced in the first wet season (October 2012 – April 2013) in both core and 95% home ranges. The highest mean NDVI for buffalo 427 was experienced in December 2013 and January 2014 (2^{nd} wet season) in the core and 95% home range, respectively. On the contrary, buffalo 455 experienced its highest mean NDVI value in May 2014 and June 2014 (2^{nd} dry season) in both home ranges (Figure 4). The core and 95% home range mean NDVI values differed between seasons for both buffalo (Table 7).

The average precipitation values showed a clear trend for each season. The amount of rainfall in the wet season was substantially high in the wet seasons (October 2012 – April 2013, October 2013 –April 2014, and October 2014 – December 2014) and low in the dry seasons (May 2013 – September 2013 and May 2014 – September 2014). There was, however a very high amount of rainfall that was experienced in the month of May 2014 with a mean average value of 8.54 mm (Figure 6). Figure 6 suggests a weak correlation between mean NDVI and mean precipitation for buffalo 427 (50%: R^2= 0.0356; 95%: R^2=0.0149) and 455 (50%: R^2= 0.0328; 95%: R^2=7E-07) in the core and 95% home range.

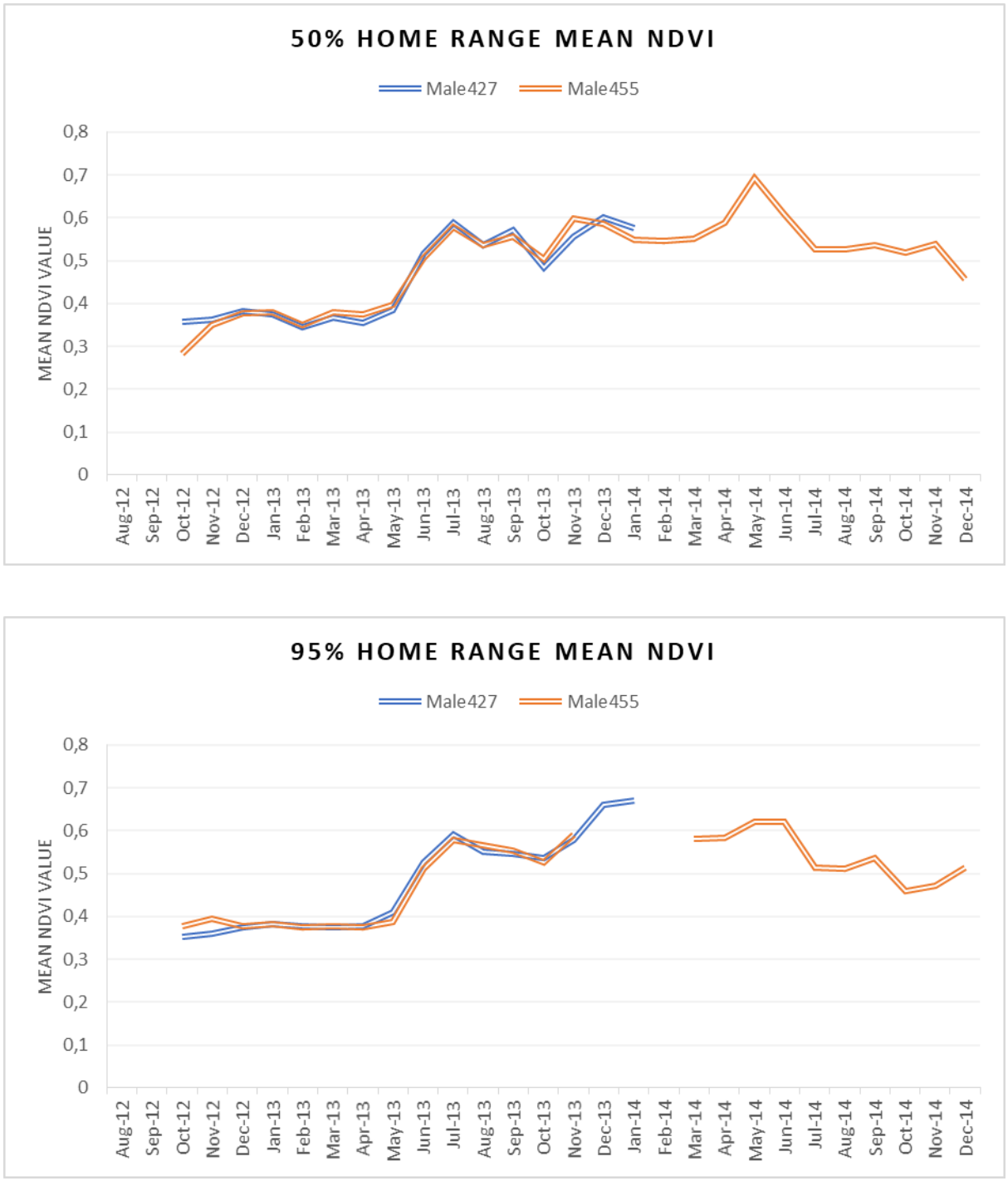


Figure 6. Mean NDVI values of the two-male buffalo in Dinokeng Game Reserve, 2012-2014.

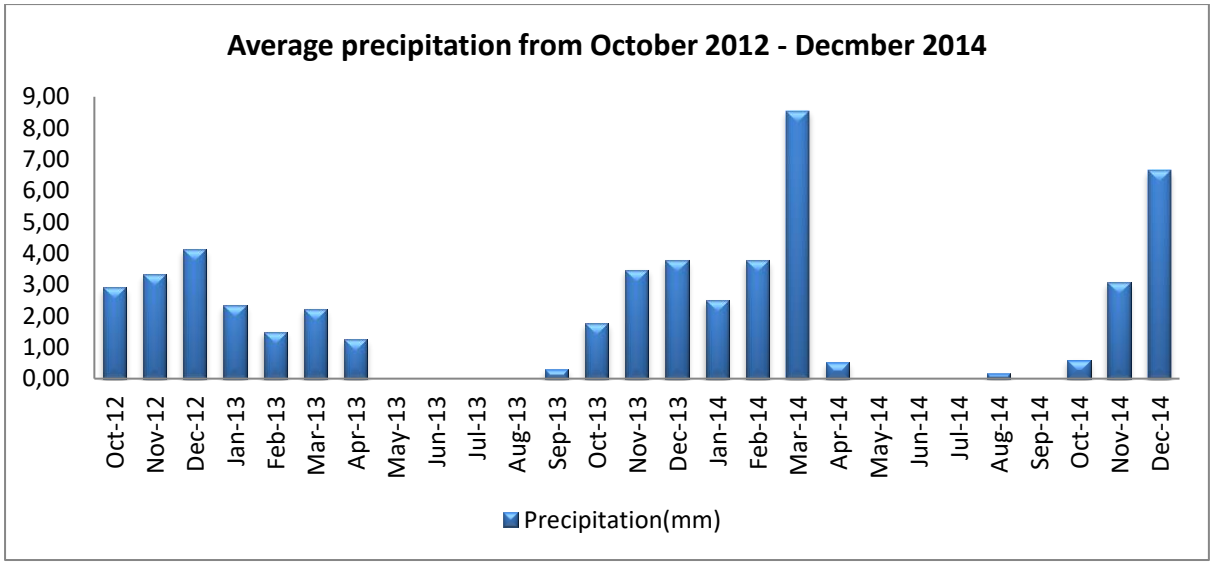


Figure 7. Mean precipitation values in Dinokeng Game Reserve, 2012-2014 (Climate Engine, nd)**.**

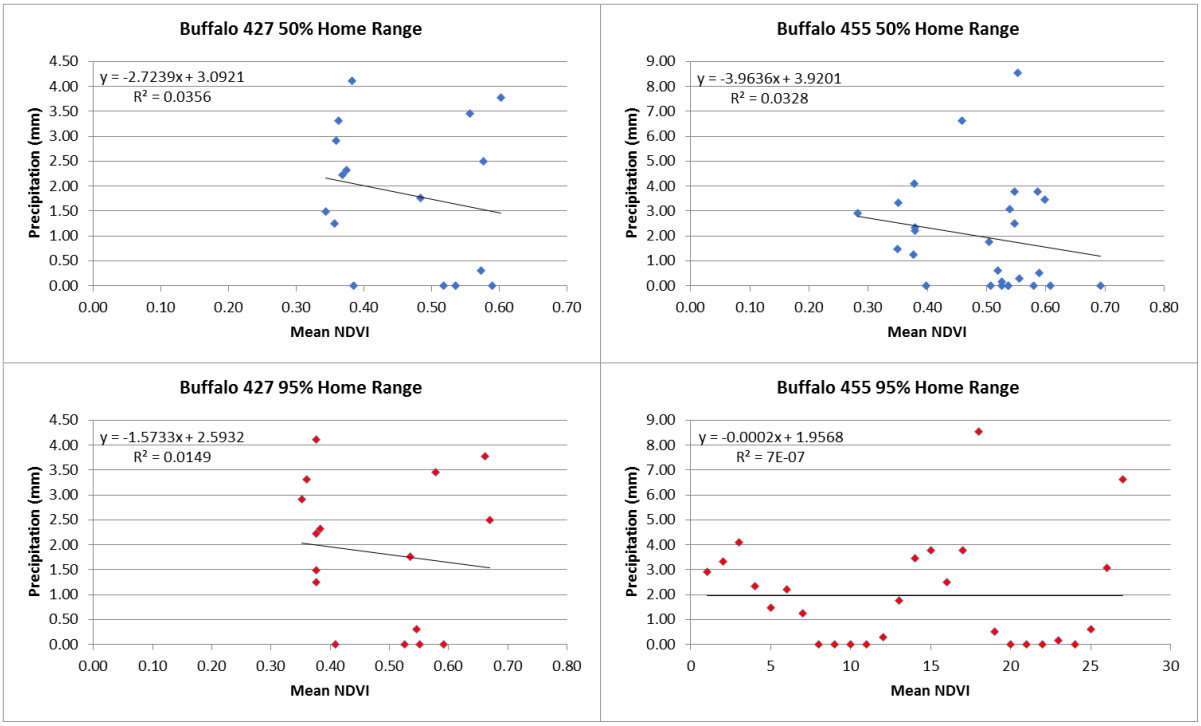


Figure 8. Relationship between mean NDVI and mean precipitation values for both core and 95% home range in Dinokeng Game Reserve, 2012-2014.

Table 7. The 50% core and 95% seasonal mean NDVI values of the two-male buffalo in Dinokeng Game Reserve, 2012-2014.

Tag	HR (%)	Mean NDVI					
		Wet Season 2012 - 2013	Dry Season 2013	Wet Season 2013 - 2014	Dry Season 2014	Wet Season 2014	Total
Male 427	50	0.36	0.52	0.55	-	-	0.46
	95	0.37	0.52	0.61	-	-	0.48
Male 455	50	0.36	0.51	0.56	0.58	0.51	0.50
	95	0.38	0.52	0.57	0.56	0.48	0.49

Table 8. The 50% core and 95% seasonal p-values for the two-way ANOVA of the two-male buffalos in Dinokeng Game Reserve, 2012-2014.

Name	HR (%)	Wet Season – Dry Season 2012 - 2013	Dry Season-Wet Season 2013 - 2014	Wet Season -Dry Season 2013-2014	Dry Season-Wet Season 2014 - 2014
Male 427	50	0.0023	0.0051	-	-
	95	0.0125	0.0063	-	-
Male 455	50	0.0035	0.0016	0.0001	00043
	95	0.0043	0.0035	0.0143	0.0031

4.3 Resource selection analysis

The global model which includes all variables associated with predator proximity (predator home range), resource availability and accessibility (Normalized Difference Vegetation Index [NDVI], and distance to nearest rivers and dams), and human disturbances (road density, and

distance to nearest building) was the best model (ω ≥ 0.99) in explaining habitat selection of both male buffalos (GLMM) from October 2012 – January 2014) and buffalo 455 (GLM) form February 2014 – December 2014 in 50% and 95% home ranges for most of the seasons (Table 8).

Table 9. Environmental variables and a prior model set used for estimating the resource selection function (RSF) of buffalos in Dinokeng Game Reserve, 2012-2014.

	HR (%)	GLMM			GLM	
		Wet Season 2012 - 2013	Dry Season 2013	Wet Season 2013 - 2014	Dry Season 2014	Wet Season 2014
Both buffalos	50	7	19	19	-	-
	95	19	17	19	-	-
Male 455	50	-	-	-	8	19
	95	-	-	-	2	7

4.3.1 Features related to predator probability

The buffalos selected areas that had high lion probability of occurrence after release, but as the seasons progressed the ungulates selected areas that had less likelihood of lion occurrence within their 50% and 95% HR (Figure 9).

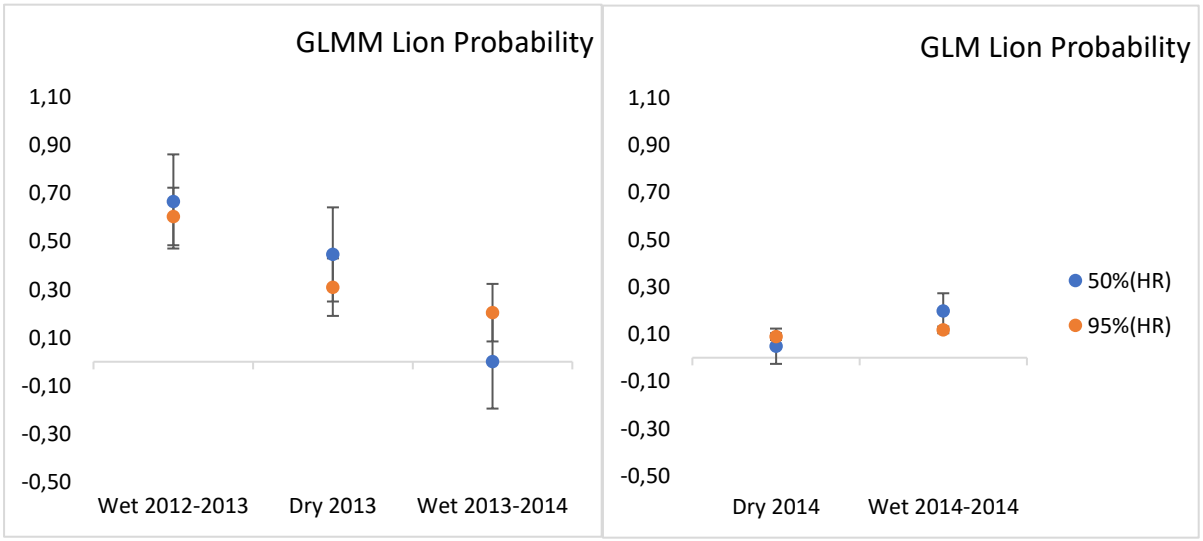


Figure 9. Lion probability of occurrence selection within 50% and 95% home range by both buffalos and Individual buffalo 455 (from February 2014) using GLMM and GLM regression estimates respectively in Dinokeng Game Reserve, 2012-2014 are presented.

4.3.2 Features related to resource availability and accessibility

Buffalos selected areas that were generally close to a water source (rivers and dams) within their 50% and 95% HR throughout the study period, however, during the dry season the buffalo selected areas that were slightly further away from water sources (Figure 10). In terms of vegetation indices, in general, the buffalos selected areas of high vegetation health. However, the quality of vegetation varied seasonally – with the general trend being lower in the wet season than the dry season within the 50% and 95% HR (Figure 10).

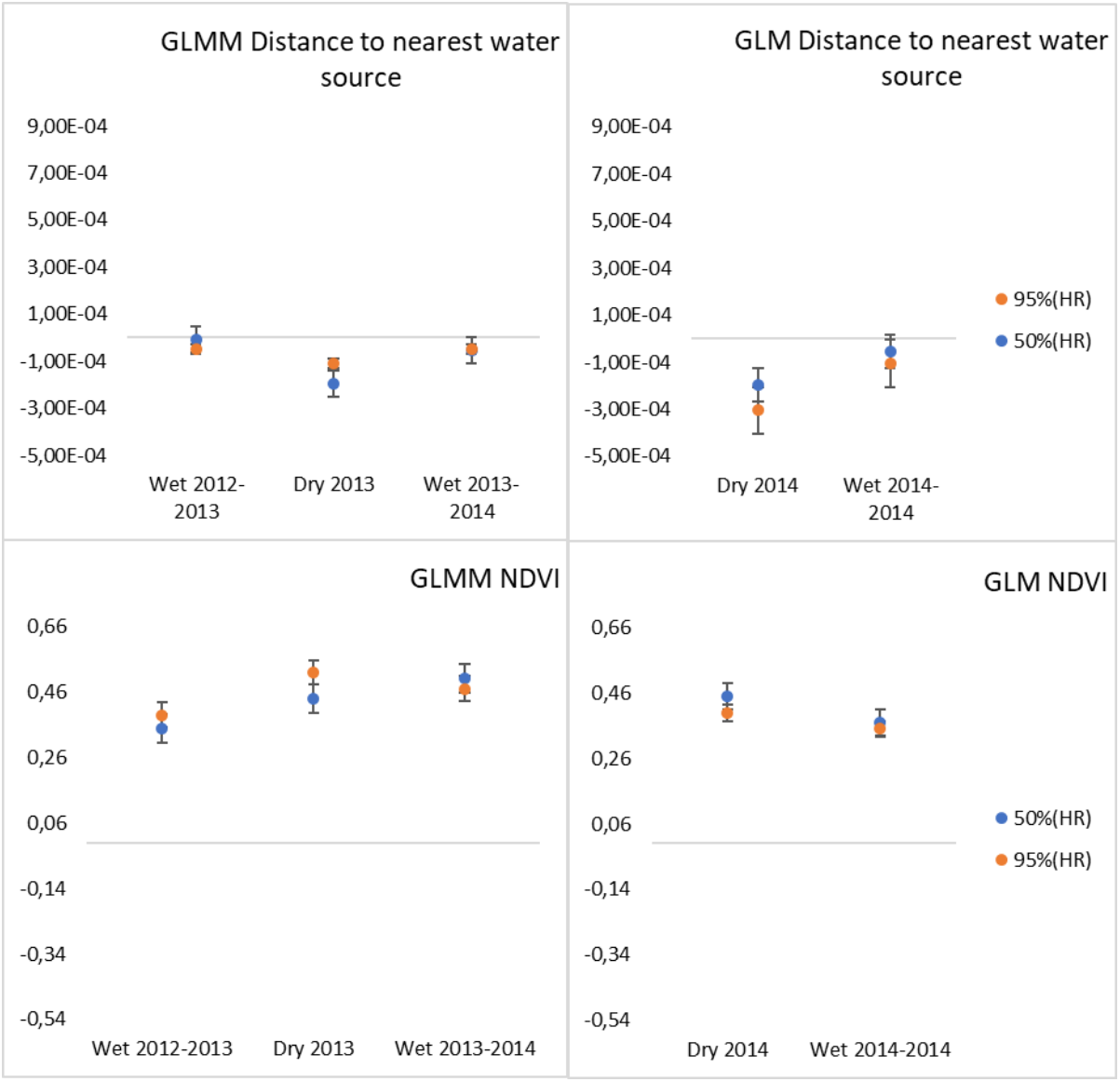


Figure 10. Resource availability and accessibility selection within 50% and 95% home range by both buffalos and Individual buffalo 455 (from February 2014) using GLMM and GLM regression estimates respectively in Dinokeng Game Reserve, 2012-2014 are presented.

4.3.3 Features related to human disturbance

Both buffalos selected areas where road density was high after release. Selection of such areas decreased over the study period from the first dry season onwards for both 50% and 95% HR. In terms of distance to nearest buildings the buffalos selected areas further away from buildings over the entire study period (Figure 11).

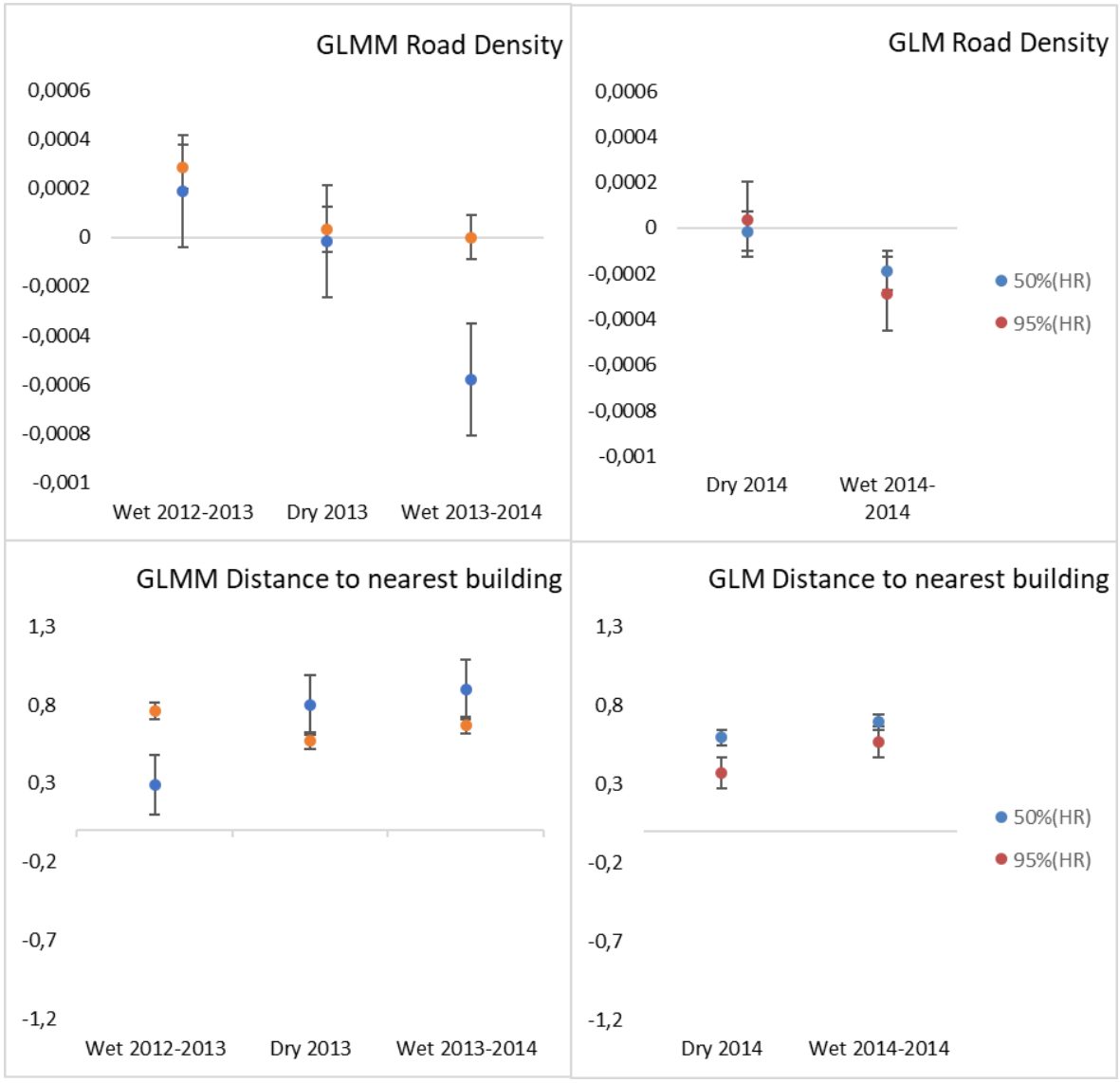


Figure 11. Resource selection based on human disturbance within 50% and 95% home range by both buffalos and Individual buffalo 455 (from February 2014) using GLMM and GLM regression estimates respectively in Dinokeng Game Reserve, 2012-2014 are presented.

Chapter 5 – Discussion

5.1 Home Range Analysis

Results illustrate that home range expansion of the buffalo is a lengthy process, which can last more than a year. However, irrespective of the continuous expansion during the study period, home range sizes of the two-male buffalo remained below half the entire size of the game reserve (<70 km^2). This, therefore, suggests that man-made boundaries such as roads and fencing did not define home range establishment of the two-male buffalo, meaning the ungulates were able to attain essential resources with small defined areas. From a reintroduction perspective, this is a good sign as this is an indication of the buffalos adapting to the new environment. Furthermore, changes in the home range expansion is indicative of change in movement pattern/behavior from large scale exploration to small scale exploration. Cumulative home range of both buffalo reached a long-term stabilization, however, buffalo 427 had a significant decrease from October 2013 to January 2014. Decrease in home range can be a result of predator-prey interactions which is known to affect population dynamics and cascade to environmental changes (Brown *et al*., 1999; Tolon *et al*., 2009; Laundré *et al*., 2010; Coleman and Hill, 2013). Home range overlapping between reintroduced lions and buffalos occurred around the same period (October 2013 – January 2014) when buffalo 427 displayed a decrease in home range. For the most part, overlap was found to be in areas that were close to a water source and further away from built-up areas. For predators, occupying such areas makes more sense as these are particularly areas that prey, such as buffalo are drawn to – given the fact that water availability often attracts prey (Valeix *et al*., 2010; Davidson *et al*., 2013).

Buffalo 427 established its core home range exclusively at its area of release, while buffalo 455 established its core home range outside of its area of release. However, buffalo 455 continued to utilize the area it was first released which is within the 95% home range. Both buffalos, however, utilize the central area of the DGR where they were released, despite their capability

of travelling 5.4 km per hour (Nowak and Walker, 1999). According to Rosenbaum *et al.* (1991) and Lenore (2007) home range establishment and expansion patterns arise from animals trying to optimize their energy expenses, by exploring and utilizing the areas they are more acquainted with and less likely to encounter misadventures unexpectedly, which could result in injuries and decrease in fitness. This, therefore, might result in the type of home range establishment and expansion displayed by the two-male buffalo. As a result, release site location has significant influence on home range establishment and utilization.

There were seasonal differences in home range sizes for both male buffalos, except for the 95% home range size for buffalo 455. These findings coincide with findings of Ryan *et al*. (2006) where buffalo home ranges in the Kruger National Park were smaller during the wet season than dry season. Reasons behind such patterns range from buffalos travelling further in search for food or spending more time on grazing in order to fulfil metabolic needs.

Tracked NDVI values changed seasonally and indicated that there were seasonal differences in vegetation greenness and health. According to Wang and Prince (2003), under normal circumstances, NDVI values would peak in the wet season where precipitation levels are high and drop in the dry season where precipitation levels are low as precipitation is a climatic variable that strongly influences variation in NDVI for given areas. However, in the DGR results suggest the contrary when looking at the correlation between mean NDVI and mean precipitation values. When mean precipitation were high, mean NDVI values were generally low in the wet season (October – April) and vice versa for the dry season. Reason for such results may be influenced by a variety or combination of climatic and environmental variables. Farrar *et al*. (1994), found that as much the correlation between NDVI and precipitation in a study in Botswana was high in a multi-month average, NDVI was highly influenced by soil moisture in the concurrent month. Also, Yang *et al*. (1997) after studying the relationship between temperature and NDVI in Nebraska, USA, discovered that there is a strong

relationship between NDVI and soil temperature and NDVI and accumulated growing degree days (AGDD).

This therefore highlights the importance of investigating multiple climatic variables (precipitation and temperature) and potentially other influencing environmental factors such as soil moisture, geomorphology, and vegetation phenological events.

Features associated with predator proximity (predator home range), resource availability and accessibility (Normalized Difference Vegetation Index [NDVI], and distance to nearest rivers and dams) and human disturbances (road density, and distance to nearest building), all influenced habitat selection of the Dinokeng reintroduced buffalos. Results presented here are similar to other studies of large herbivores (Taolo 2003; Bennitt *et al*., 2014; Tambling *et al.*, 2015; Sianga and Bonyongo 2017). According to Yiu *et al*. (2017) lions in the DGR selected areas that were closer to dams due to the likelihood of prey availability due to water availability throughout the study period. Therefore, sudden decline in habitat home range displayed by buffalo 427 in the wet season, selection of habitats further away from water sources during the dry season and selection of areas with low lion probability of occurrence by both buffalos may suggest predator avoidance.

Buffalos displayed an increasing tendency of selecting areas that had low lion probability of occurrence over the course of the study. Previous studies on African buffalo suggest that behavioral changes are a necessity for prey species to adapt to new environments with varying predators "landscapes of fear" (Brown *et al*., 1999; Laundré *et al*., 2010; Tambling *et al.*, 2015). On the contrary, results from this study disagree with those of Hopcraft *et al*. (2012) which suggested that buffalo distribution is not constrained by predation but by abundance of food.

For features related to resource availability and accessibility (NDVI and distance to water sources) the buffalos showed a general liking for areas close to a water source, however,

seemed to move away during the dry seasons. A general preference for areas close to water is common amongst ungulates as water is a crucial element in their livelihoods (Sinclair, 1977; Prins, 1996; Nowak and Walker, 1999). However, the shift to areas further away from a water source – especially during the dry season is uncommon, and therefore suggests change in behavior, potentially due to predators occupying these areas to potentially increase their probability of predation success (Yiu *et al*., 2017).

As for NDVI the values are fairly high, which is an indication of health vegetation and therefore good foraging grounds. However, on the contrary the high values could be the result of a lot of trees in the reserve and could therefore mean high NDVI values were based on Tree canopy above buffalo grazing ground. Therefore, I could not be able to find a relationship between NDVI and the movement of grazers in Tree areas. Failure to establish a link between NDVI values and movement patterns of buffalo was also indicated in a paper conducted by Ryal *et al*. (2006) where there was insufficient evidence that buffalo herds selected greener areas on a monthly basis and therefore suggesting that perhaps NDVI was not an appropriate surrogate for determining and potentially predicting buffalo movement in the Klaserie Private Nature Reserve. Contrary to this, in a study conducted in tropical island dry landscapes, Chynoweth *et al*. (2015) suggest that the NDVI was a good surrogate in distinguishing habitat and movement patterns of feral goats.

Resource selection of both buffalos in response to human disturbance were similar. The two individuals in general showed tolerance of higher density of roads after release and thereafter seemed to move further away from such areas. In terms of distance to buildings both buffalos showed low tolerance of such areas immediately after release. Such behavior is common amongst animals, whereby animals are likely to avoid human disturbances. Similar behavior was documented in a study conducted by Yan *et al*. (2013), where Eld's deer in Datian Nature Reserve preferred areas at different spatial scales that were far away from human disturbances.

Considering that selection for particular habitats is crucial for purposes of conservation, it is however, difficult to determine which factors are mostly responsible for spatial responses of herbivores (Bleich *et al*., 2010). For instance, the dataset illustrated that the individual buffalo selected areas that were generally close to water in the one season and selecting areas further away in the other. It is not apparent from the results whether selection was primarily based on food quality, proximity to a water source or avoidance of predators. Therefore, suggesting that multifaceted interactions among variables can be crucial in defining the way ungulates move in a reintroduced environment and hence their home range distribution across the DGR (Bleich *et al*., 2010).

Chapter 6 – Conclusion and Recommendations

6.1 Summary

In summary, results from home range analysis showed that there weren't considerable variations in habitat selection and home range size between the two-male buffalo. However, predator presence had considerable influence on habitat selection of the buffalos, specifically buffalo 427 as home range percentage overlap was calculated to be 6.04%. Seasonal variations in NDVI were also apparent, showing the dry season as having considerably high values than the wet season. This seems to be uncommon as the wet season is expected to have higher values. However, a reason for this may lie in the type of satellite imagery used (Medium resolution) and also other influencing factors that may have seasonal impacts on NDVI values. Overall, however, NDVI values for the varies seasons were positive, but these values cannot be used to draw conclusive evidence of the relationship between NDVI and buffalo habitat selection.

Both male buffalos illustrated avoidance of built-up areas which is common amongst animals and also showed an element of habitat adjustment by shifting further away from water sources during the dry season due to lions predominantly occupying those areas. This research serves

as a baseline to the DGR management to consider all biotic and abiotic influences buffalo behavior pertaining to the reintroduction of buffalos for more informed and better decision making. Therefore, the release site of the buffalo, vegetation health, and proximation to water sources and predators need to be considered in order to maximize reintroduction success and minimize prey-predator encounter in early establishment stages which could potentially influence ranging and habitat selection behavior of the buffalos.

6.2 Limitations

The buffalos used were both male, meaning the sex factor of the ungulates could not be taken into consideration. Desire to mate amongst ungulates is known to be a crucial influencing factor in movement pattern and behavior. Due to cost and availability, I could not attain high multi-temporal satellite imagery. Therefore, meaning the accuracy of the satellite images used maybe flawed for the analysis performed. Particularly, in conducting Normalized Vegetation Index (NDVI). Therefore, due to this, the spatial resolution of the satellite imagery used cannot allow for the distinguishing of grass vs tree areas especially when looking at grazers in relatively tree/bush dense bush areas.

6.3 Recommendations and future research

This research utilized medium resolution imagery for mapping and extraction of NDVI values. Future studies could look at high to very high-resolution satellite imagery such as Quick bird and Worldview. When looking at reintroduction of animals, collaring of both sexes and therefore gathering of GPS locations of both sexes would be beneficial as this would also include a different aspect or variable in monitoring movement behavior of reintroduced animals. Furthermore, other climatic variables (such as temperature) and environmental factors (soil moisture, and soil temperature) coupled with medium/high resolution sensors and the current variables and factors considered in this study could potentially yield better results and therefore more conclusive evidence.

Appendices

Topography of the Dinokeng Game Reserve

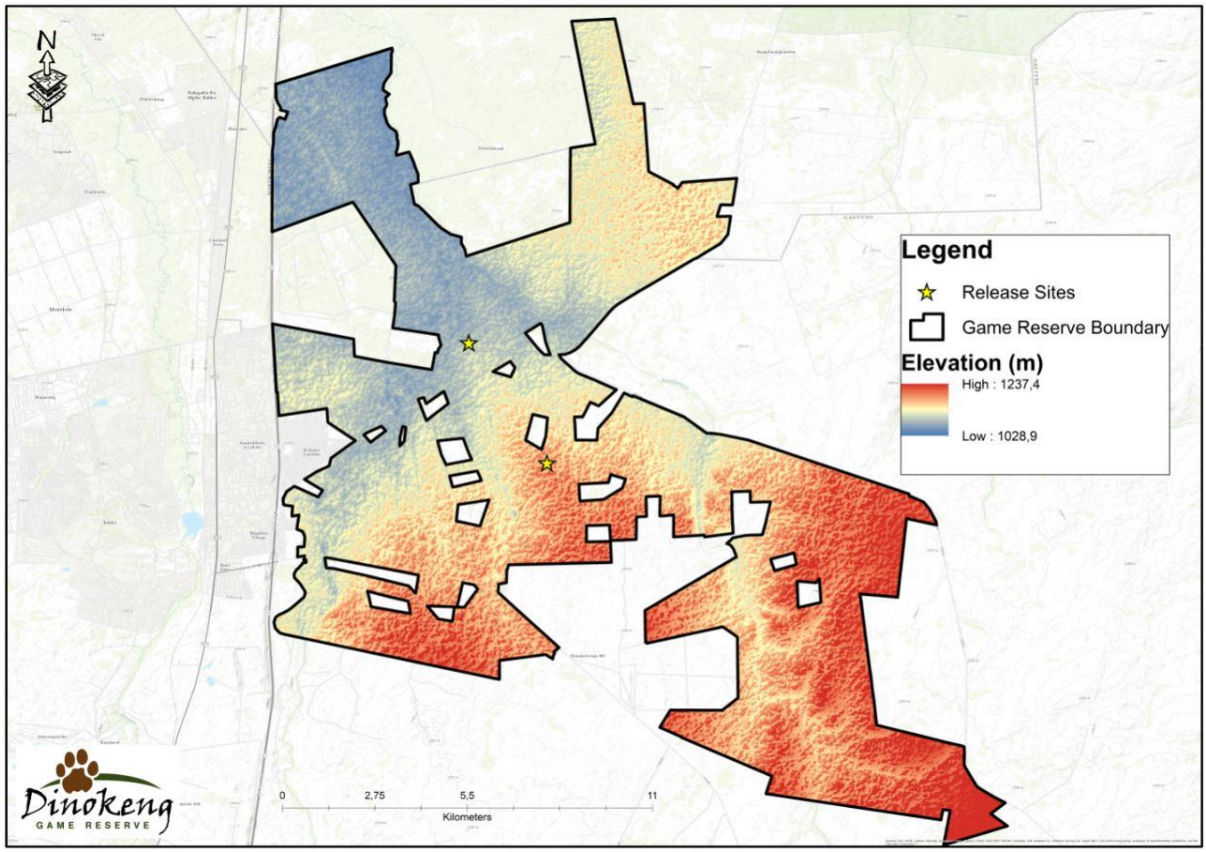


Figure 12. Maps of elevation (m) in the Dinokeng Game Reserve, 2012-2013 derived from ASTER DEM at 30m resolution**.**

Buffalo 427 seasonal home range

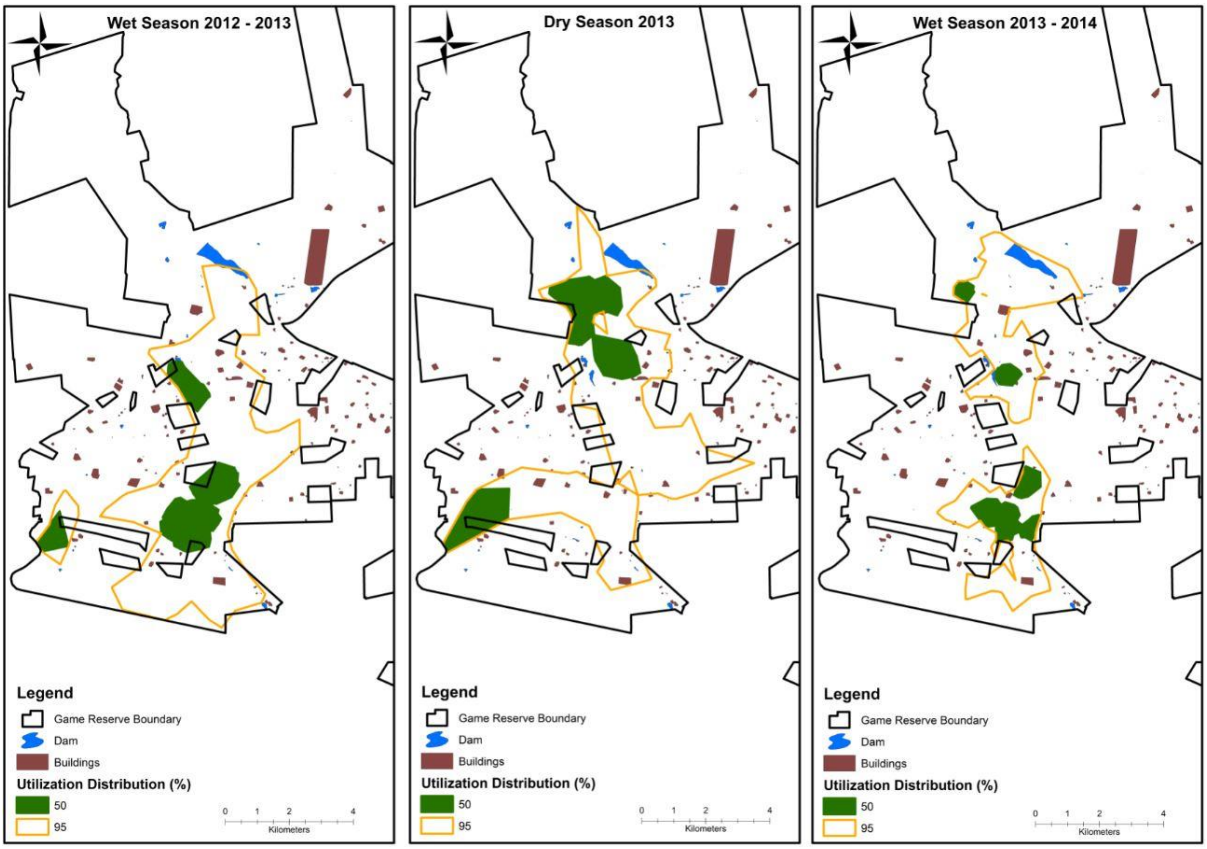


Figure 13. 50% and 95% seasonal home ranges for buffalo 455 in Dinokeng Game Reserve, 2012-2014**.**

Buffalo 455 seasonal home range

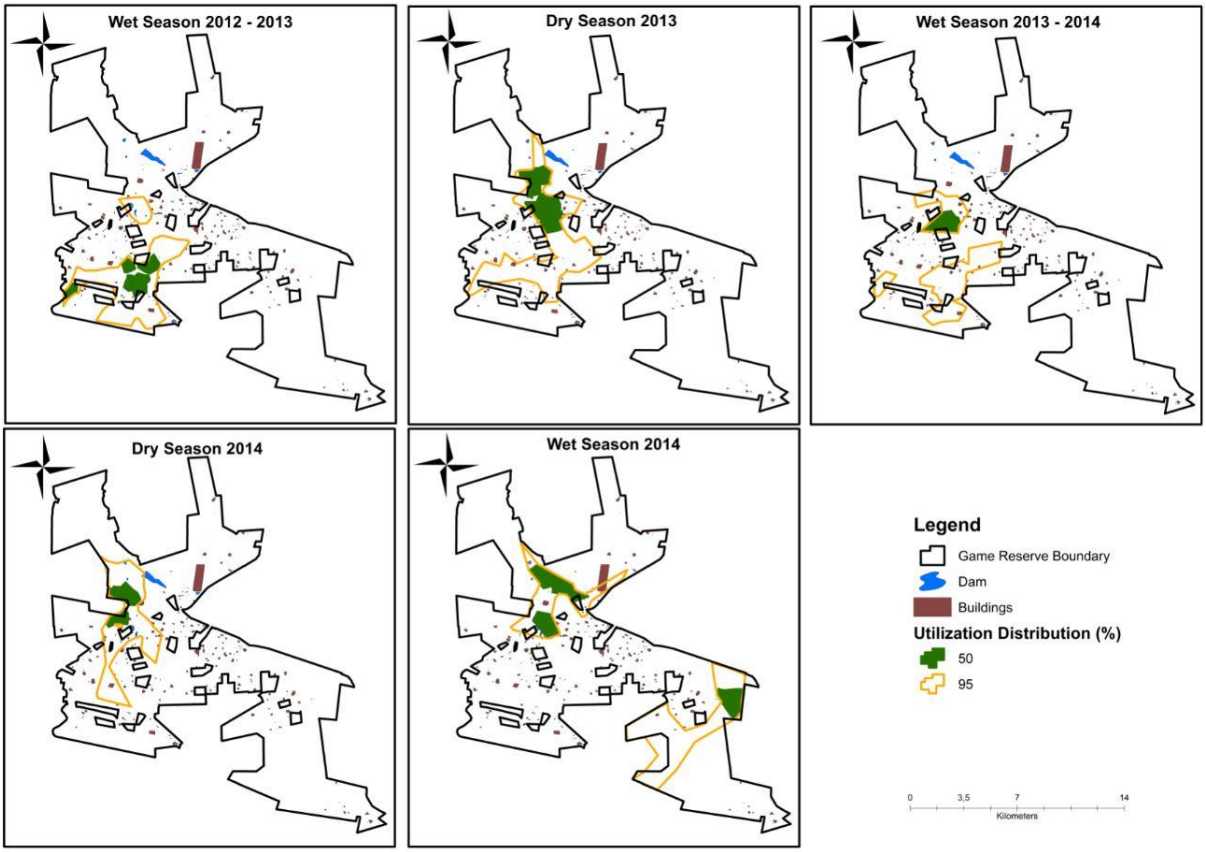


Figure 14. 50% and 95% seasonal home ranges for buffalo 455 in Dinokeng Game Reserve, 2012-2014**.**

Predicted probabilities of lion occurrences

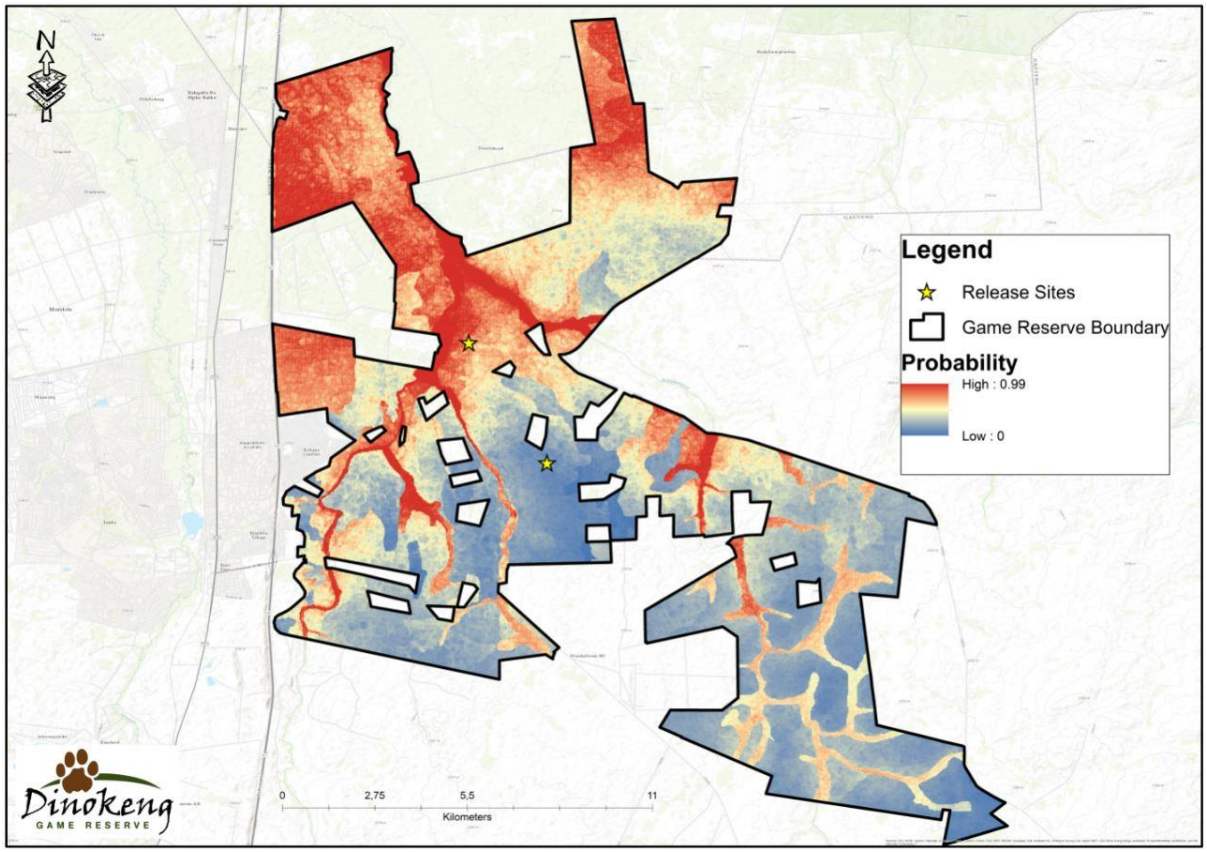
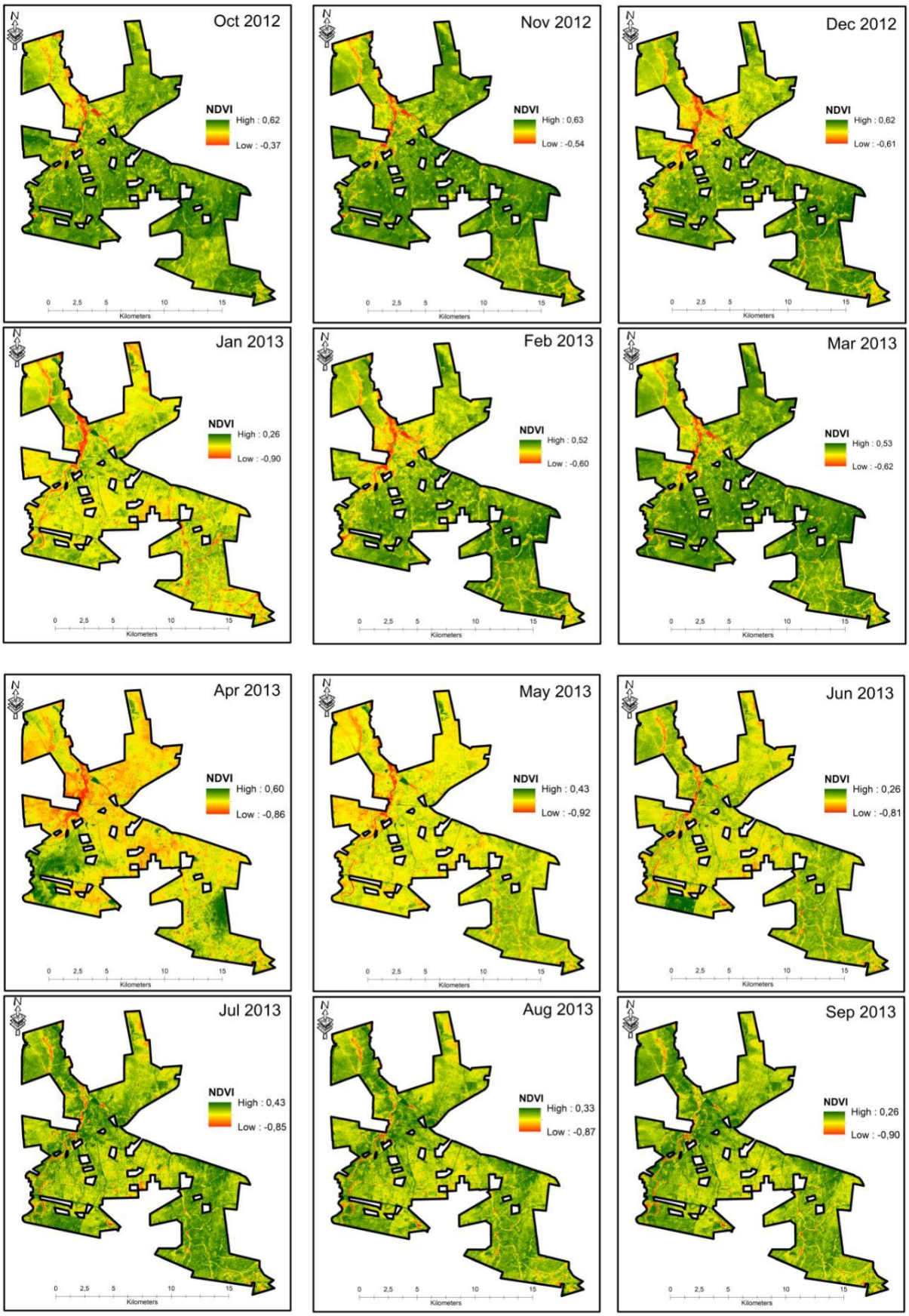
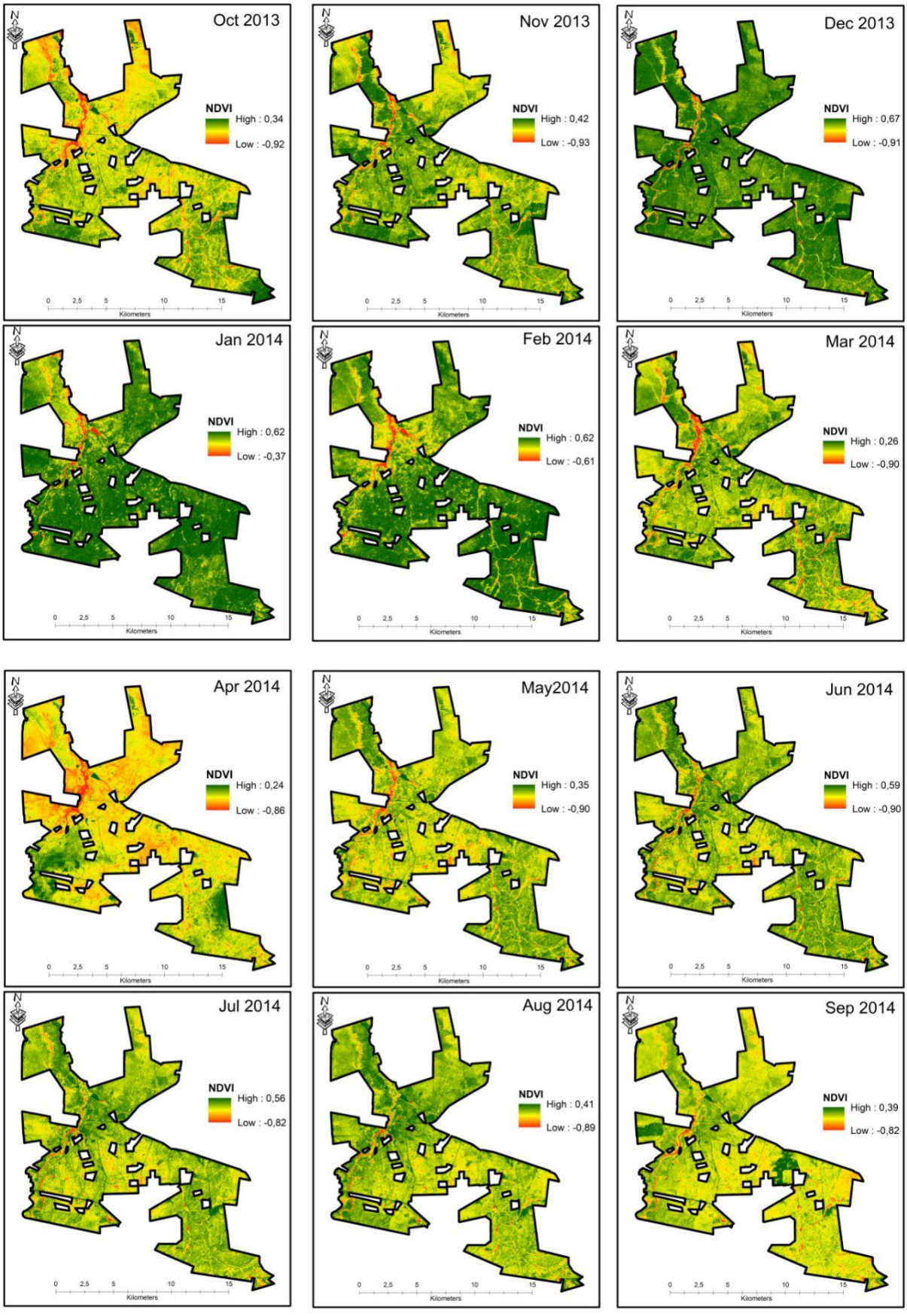


Figure 15. Maps of the predicted probabilities of occurrence of lions in the Dinokeng Game Reserve, 2012-2013**.**

Normalised Difference Vegetation Index




Oct 2013
NDVI
High : 0,34
Low : -0,92
Nov 2013
NDVI
High : 0,42
Low : -0,93
Dec 2013
NDVI
High : 0,67
Low : -0,91
Jan 2014
NDVI
High : 0,62
Low : -0,37
Feb 2014
NDVI
High : 0,62
Low : -0,61
Mar 2014
NDVI
High : 0,26
Low : -0,90
Apr 2014
NDVI
High : 0,24
Low : -0,86
May2014
NDVI
High : 0,35
Low : -0,90
Jun 2014
NDVI
High : 0,59
Low : -0,90
Jul 2014
NDVI
High : 0,56
Low : -0,82
Aug 2014
NDVI
High : 0,41
Low : -0,89
Sep 2014
NDVI
High : 0,39
Low : -0,82
0 2,5 5 10 15
Kilometers

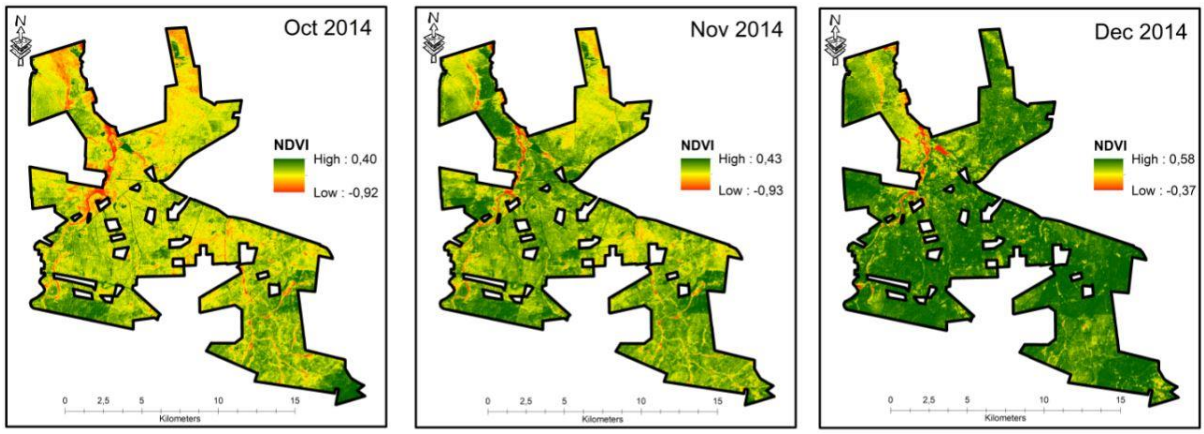


Figure 16. Maps of the Normalized Difference Vegetation Index (NDVI) in the Dinokeng Game Reserve, Oct 2012- Dec 2014**.**

Road Density

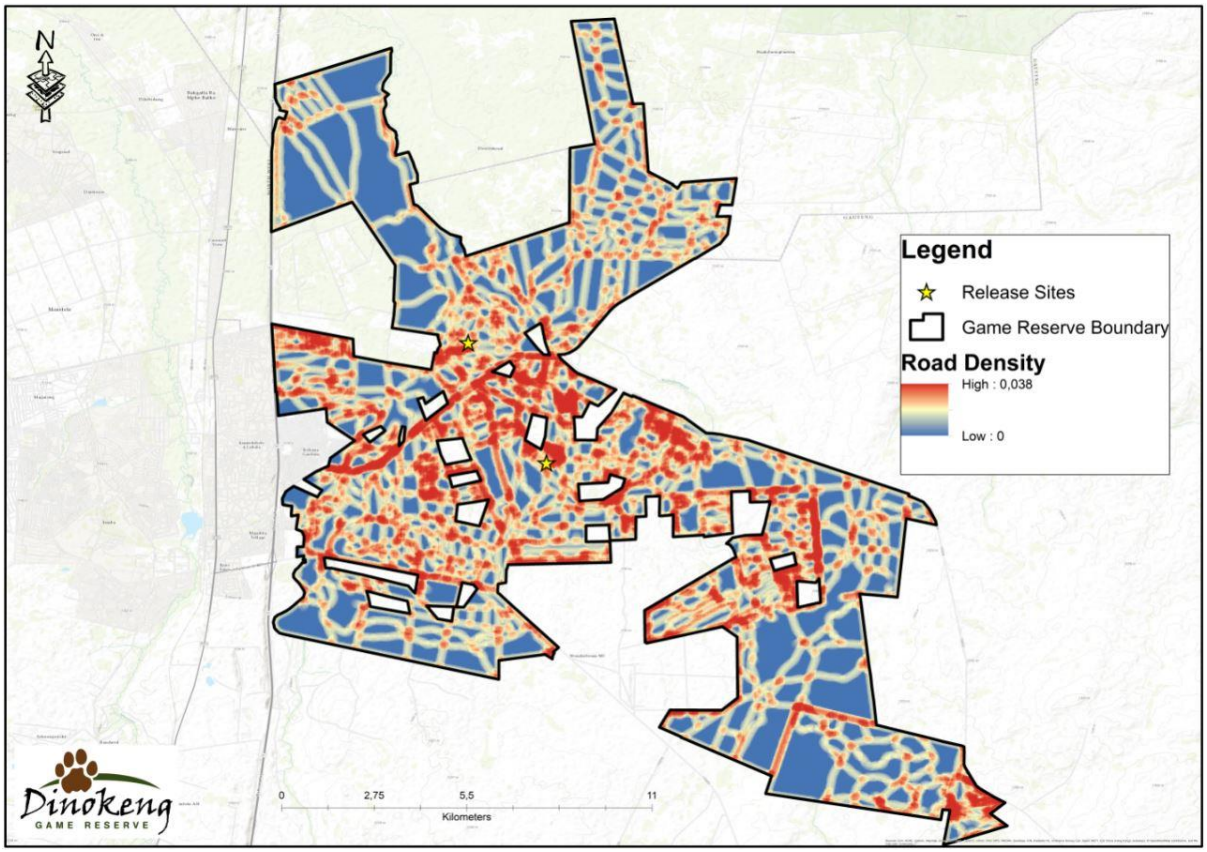


Figure 17. Map of road density (km/km2) in Dinokeng Game Reserve, 2012-2014.

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