MAPPING AND PREDICTING POTENTIAL DISTRIBUTION PATTERNS OF FREE-RANGE LIVESTOCK IN THE RURAL COMMUNAL RANGELANDS OF MGWALANA, EASTERN CAPE, SOUTH AFRICA

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Abstract

Communal rangelands provide habitat to many plants and animals. However, there is evidence that livestock cause range degradation. Range degradation occurs because livestock select grazing based on the availability of resources such as water and forage material, their use of the landscape is non-uniform, consequently causing resource deterioration. Range management is thus necessary because communities depend on range condition for livestock productivity. However, precise quantification of livestock distribution within communal rangelands is lacking.

In developed countries, Global Positioning Systems (GPS) collars have been used to monitor wildlife and domestic livestock in pastures and seem to have worked efficiently. However, in a developing country like South Africa, GPS technology to monitor animal behaviour has been used only for wildlife on privately owned land. The high costs of monitoring livestock herds in large open areas such as communal rangelands have resulted in little or no monitoring of domestic livestock using GPS technology. This study links monitored livestock distribution to physical landscape variables in Mgwalana, and uses the modelled relationship to predict livestock distribution in quaternary catchments, T12A and T35A-E. The research addresses the questions (1) where do livestock spend time in the wet and dry seasons? And (2) how can areas of potential livestock distribution be identified in other catchments where actual distribution is unknown?

Livestock were tracked during the wet and dry seasons using GPS collars. The resulting distribution data is combined with selected physical landscape variables to identify selectivity. The GPS location data and the physical landscape variables are used to predict potential livestock distribution where distribution is unknown in quaternary catchments (T12A and T35A-E). The ArcGIS Predictive Analysis Tool (PAT) was used to extract the selected landscape variable ranges based on the GPS location data and identify areas with the same conditions in the quaternary catchments were subsequently selected. The key findings are that livestock prefer accessible areas with gentle terrain near water sources, avoiding south-facing slopes which receive less solar radiation and tend to be cooler. Livestock are attracted to vegetation in riparian zones.

Rural communal lands are dominated by poverty, and land-based livelihood strategies can potentially contribute to the well-being of the community. Therefore, understanding livestock

distribution can contribute to a rangeland management strategy aimed at improving range condition which could increase livestock productivity and contribute to the livelihoods of local people.

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Declaration

I, QAWEKAZI MKABILE, hereby declare that this thesis is my own original work, that all assistance and sources of information have been properly acknowledged, and that this work has not been presented to any other University for a higher degree.

Student number: G17m9723

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ARC	Agricultural Research Council
GIS	Geographic Information Systems
GPS	Global Positioning Systems
IWR	Institute for Water Research
NDVI	Normalised Difference Vegetation Index
NLEIP	Ntabelanga-Lalini Ecological Infrastructure Project
PAT	Predictive Analysis Tool
WMA	Water Management Area

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"God is within her, she will not fail." Psalm 46:5

Chapter 1: Introduction

1.1 Background and rationale

Pastoralism in Africa

Pastoralism has been practised in Africa for many years (Smith 1984, 1992; Behnke 1985; Manhire *et al.,* 1986; Sealy & Yates 1994; Coppolillo 2000), evidence of the domestication of livestock is as early as 10000BP in northern Africa (Egypt, Sudan, and Niger). As a result of climatic shifts overtime, pastoralism practices moved towards Central Sahara in 4500BP, but was not until about 2400BP that pastoralism was identified in southern Africa (Smith 1992).

Today, the engravings and paintings on rock walls serve as evidence of multiple historic events in relation to livestock. These rock paintings show the interaction of pastoralists and domesticated livestock, the interactions with hunter-gatherers, and later, with the European settlers. Manhire *et al.* (1986), reviewed the distribution patterns of livestock in two areas, the south-western Cape and the Natal Drakensberg. Based on the rock paintings, cattle were confined to the Drakensberg, Lesotho, parts of Natal, the north-eastern Cape and the southern Orange Free State. This study compares the number of domesticated cattle in the northern and southern Natal Drakensberg. Manhire *et al.* (1986) main findings were that more cattle were found in the southern Drakensberg and there was a distinct difference in the horns and in the patterns on the body of the cattle. Rock paintings of the northern cattle showed mostly black cattle (few were white) with twisted horns. However, in the southern Drakensberg, the cattle were painted in dark reds or oranges and black and had patterns that resembled the Sanga group of cattle. The horns are similar to the cattle found in the northern Drakensberg, but some were depicted straight out to the sides (Figure 1). The rock paintings serve not only as evidence of livestock distribution, but also show historic scenes and stresses such as depredation by white settlers which posed a threat in the domestication of livestock (Lewis-Williams *et al.,* 1982).

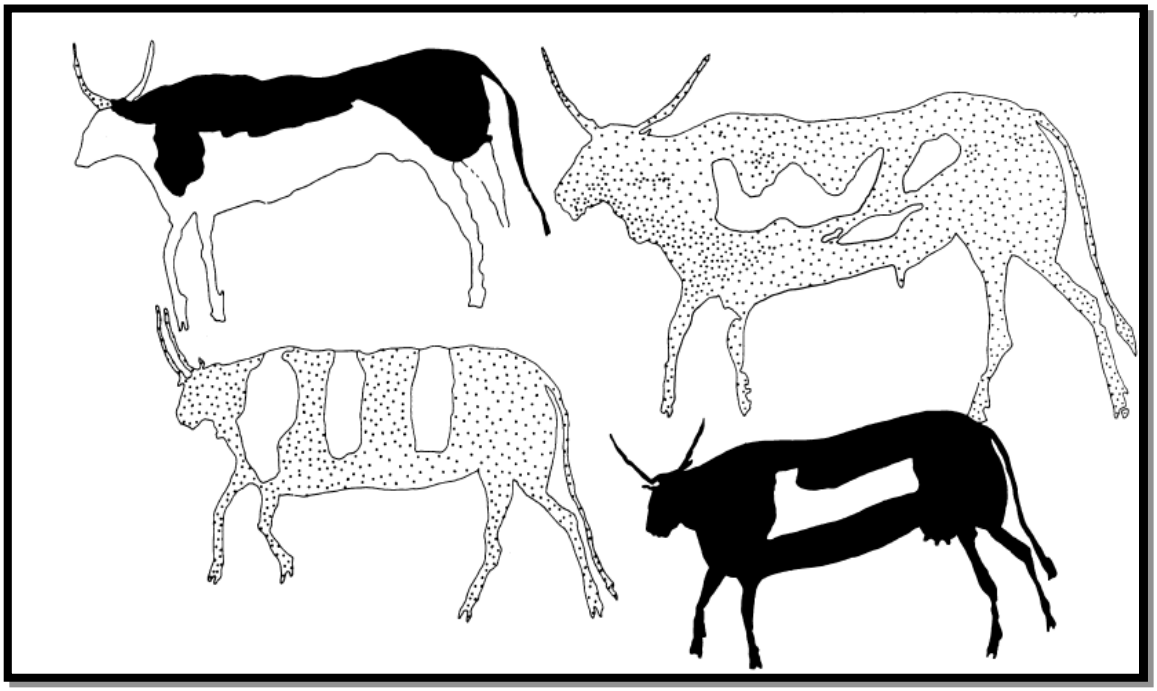

Figure 1: Rock paintings of cattle in the southern Natal Drakensberg, showing the different patterns on the body of cattle and the different horns on the body of cattle and the different horns. Picture adapted from Manhire *et al*., (1986).

Pastoralists have long recognised that livestock distribute themselves for various, multiple reasons, including spatial heterogeneity of resources, temporal variation, and for social reasons such as herding compared to non-herding strategies (Coppolillo 2000). It also been recognised that livestock do not graze uniformly but select a preferred grazing unit on the landscape (Joy Belsky & Blumenthal 1997). This is because livestock search for and choose habitats that provide optimum safety and comfort for them (Kaufmann *et al.,* 2013). Consequently, while the rest of landscape is lightly grazed or not grazed at all, overtime, the preferred unit of the landscape overtime becomes overgrazed, causing degradation (Stephenson *et al.*, 2016). Open grasslands, savannas and shrublands have been identified globally as the main natural habitats that are used for grazing by livestock (Asner *et al.,* 2004).

Rangeland degradation

Land Degradation Assessment in Drylands project (LADA) defines degradation as "the reduction in the capacity of land to provide ecosystem goods and services, over a period of time, for its beneficiaries" (FAO 2011). Rangeland degradation is the deterioration of natural resources (including shrubs, grasses and soil) found within the rangelands. The extent of

degradation in most developing countries is difficult to quantify as the assessments monitoring the conditions of rangelands particularly, are lacking (Bedunah & Angerer 2012).

Generally, livestock prefer grazing in areas that are easily accessible and with the highest quality forage, leaving the rest of the areas under-utilised (Kohler *et al.,* 2006). The selected areas become vulnerable to degradation because when livestock graze, they remove the herbage, trample on the vegetation, deposit dung and urine (Jones *et al.,* 2011). These activities remove vegetation expose the soil and increasing soil erosion, introduce invasive weed, and reduce endemic diversity (Teuber *et al.,* 2013).

Even though the consequences of degradation are difficult to quantify, they can be identified. According to a study by Asner *et al.,* (2004), different types of climate in different regions have different consequences on degradation (primarily due to livestock grazing) (Figure 2). Grazing land in arid regions is typically grasslands and steppe; once the land is exposed to heavy grazing and drought the area becomes prone to desertification that is, a reduction in net primary productivity and vegetation growth and an increase in exposed soils. The grasslands diminish, and resilient desert shrubs dominate. The consequences of rangeland degradation differ in semi-arid regions; once the land is exposed to heavy grazing, fire suppression and drought, the grassland ecosystems are converted to savanna and woodlands, a process called woody encroachment. In humid regions, the forests' poor soils, clear cutting and grazing reduce the trees to grasslands and pastures, resulting in deforestation.

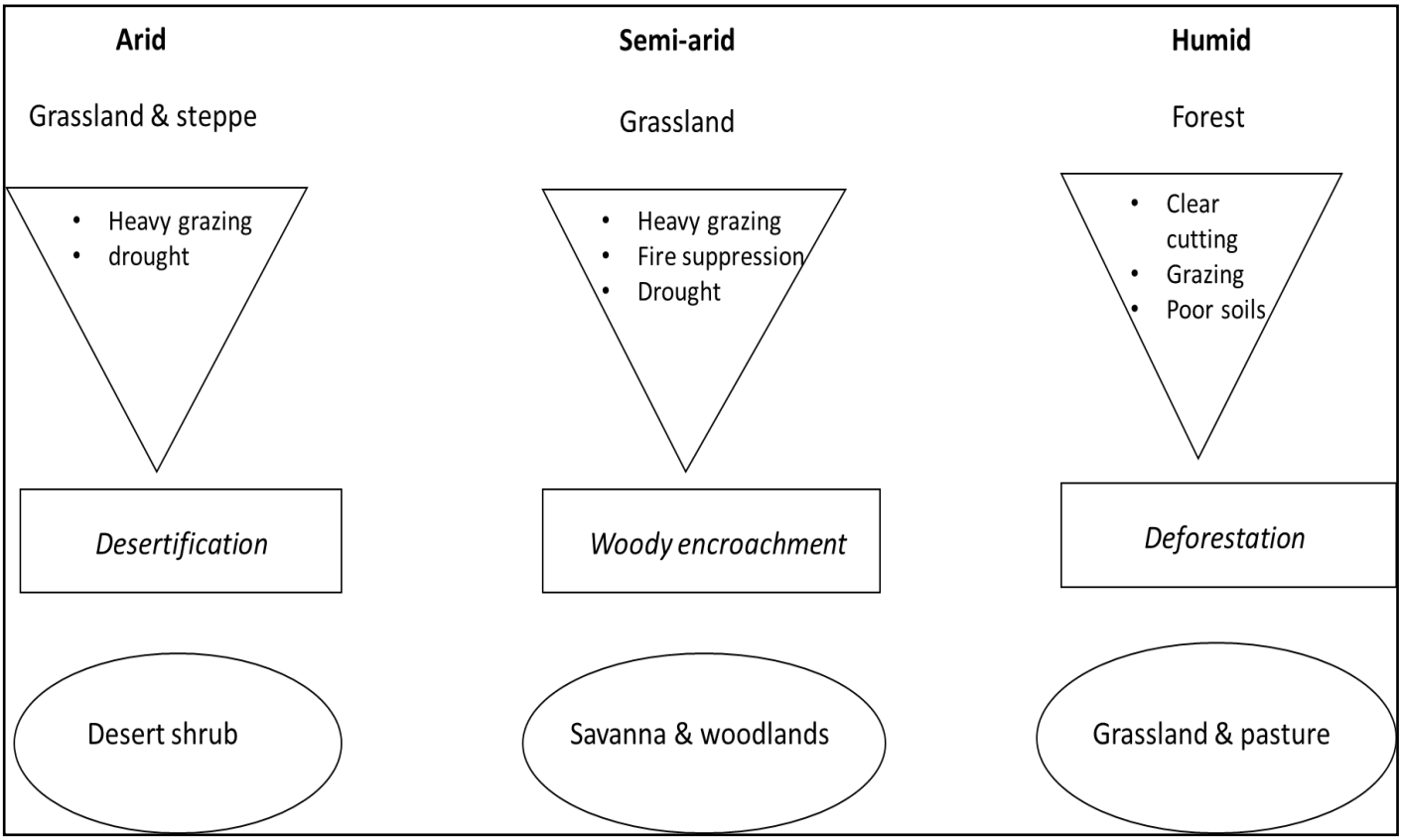

Figure 2: The results of intense grazing practices in different climatic regions (arid, semi-arid and humid). The consequences of intense grazing, drought, soils in poor conditions and clear cutting depend on the type of vegetation found within different climatic regions. Adapted from Asner *et al*., (2004).

Therefore, considering the consequences that are imposed on rangelands due to intense grazing by livestock, it is evident that firstly, the impacts that livestock grazing have vary depending on the ecosystems. Secondly, if livestock distribution is understood, areas of potential distribution (including selected grazing areas) can be identified. This section of the work reviews literature on environmental factors that influence livestock distribution in different agricultural systems internationally and nationally, with the intent to highlight the contrasts and similarity in influential livestock distribution factors in different regions.

The understanding of livestock distribution has been regarded as an important step towards managing agricultural systems (Senft 1989; Verburg *et al.*, 1999; Science *et al.*, 2003; Marty 2005; George *et al.*, 2007; Neumann *et al.*, 2009; Sanderson *et al.*, 2010). In this regard, it is necessary to firstly emphasise that cattle distribution in different scale levels (from continental-scale migration, down to landscape or patch-scale distribution) are influenced by abiotic and biotic factors concurrently. The abiotic (including elevation, slope, water and

aspect) and biotic factors (including vegetation) contribute to natural resource use and grazing distribution of livestock (Sanderson *et al.,* 2010; Verburg and van Keulen, 1999, Coppolillo, 2000). Secondly, agricultural systems vary so variation in agricultural systems means that different livestock management strategies are implemented within these systems, thus, influencing the livestock distribution. For instance, in South Africa, agricultural systems are distinguished either privately owned or communal. Most privately-owned agricultural system implement a rotational grazing strategy. The rotational grazing strategy is the practise of livestock grazing on a section of land for certain season thereafter, once the grass is almost depleted, livestock is moved to another section, giving time for the nearly depleted land to regrow again (Kotzé *et al.,* 2013). However, in communal lands, multiple-owned livestock use rangelands with no restrictions and minimal management (Ainslie *et al.,* 2002). The different livestock management strategies applied within these agricultural systems influences the interaction between livestock and landscape (Bennett & Barrett 2007; Rasch *et al.,* 2017).

Therefore, considering the differences in scale and social context mentioned above. A livestock management strategy can be effective if it includes the identification of natural resources and resource use of an area, identifies areas that are potentially grazing "hotspots" and could cause resource exploitation, lastly identifies and provide factors that influence livestock distribution and shape landscape structures and rangeland ecosystem function. Most of the studies have shown that the factors: the distance from water, slope, forage material, elevation and shade with temporal variation determine the distribution of livestock (Cook 1966; Senft 1989; Howery *et al.,* 1998; Pringle & Landsberg 2004; George *et al.,* 2007; Raizman *et al.,* 2013; Schoenbaum *et al.,* 2017). The way in which these factors influence livestock distribution differentiate in different climatic regions.

The biotic and abiotic factors which influence livestock distribution

Water

Livestock use rangelands unevenly; the main driver of this unevenness is primarily the distance and the availability of water (Andrew 1988). Access to water is an important factor for livestock because water maintains body condition and meets their lactation demands, which can be very high in summer (Kaufmann *et al.,* 2013). Although water is important, animals do not want to spend a lot of energy walking to water sources, therefore the horizontal and vertical distance travelled on a daily basis to reach water sources is important

is the reason livestock generally prefer grazing near the water sources (Coppolillo 2000). Ganskopp (2001) moved salt bars and water point sources around within an arid-land pasture in Oregon. The main aim was to manipulate cattle distribution and to assess if there would be a response from the cattle when the location of the salt and water points were changed. Interestingly, the cattle did not respond to the change in location of the salt bar, but expectedly changed their grazing and resting activities to be close to near the new location of the water sources.

Arid and semi-arid regions are water restricted, and, as a result, shade and more nutritious forage for livestock are found near the riparian zones (Clark 1998) where livestock spend a large amount of time thus causing uneven grazing distribution (Agouridis *et al.,* 2005). Selection of these areas by livestock is an ecological concern as riparian zones are biologically rich and easily damaged, particularly in semi-arid and arid regions (Bizzi *et al.,* 2016). For example, the Murray-Darling Basin in Australia is a dryland river basin where, the spatial and temporal variations of flow are extreme and unpredictable. It has been exposed to human disturbances, including agricultural and grazing practices since the European settlement. The livestock have based their grazing activities within the riparian zones and the adjacent rangelands for many years; the grazing has resulted in the removal of native grasses such as the tall spike rush, exposing the soil and increasing weed colonisation (Robertson & Rowling 2000). In contrast, the distribution of livestock may differ in humid and high rainfall areas where water is not a limiting factor and livestock are not restricted to near the riparian zones for water, forage material and shade (Clark 1998).

Elevation

Livestock prefer low-lying areas and avoid steep mountainous areas, because livestock prefer, using minimal energy costs to optimise nutrient intake and water (Kie & Boroski 1996). Access to drinking water is important for livestock, and the distance to water sources strongly influences the distribution of livestock; however, cattle avoid water points in mountainous areas and prefer water in gentler terrain. Kaufmann *et al.* (2013) conducted a study in the mountainous Montane rangelands south west of Alberta, confirming that cattle strongly preferred lowland grasslands, and spent little time in the forested areas and the mountainous watersheds. In another study conducted in Oregon, cows did not graze in elevations of 260 feet (79 m) above the water points, with the vertical distance being more important than the horizontal distance to water (George *et al.,* 2007).

Slope

Slopes and soils

Landscapes have different slope gradients that influence the dominant hydrological properties which, in turn, impact the soil and vegetation (van Tol *et al.*, 2010). This concept of the landscape clarifies the influence that slopes have on moisture and vegetation of landscapes. When an area receives rainfall, infiltration occurs mostly in the upper regions of a hilltop, because dense vegetation and the gentleness of the slope facilitate the infiltration process. The soils in upper slopes are typically permeable and promote vertical flow. If the subsurface is impermeable, the water flows horizontally resulting in a seepage. However, if the underlying layer is permeable then vertical water drainage continues. At the bottom of the slope, the soils are recharged by overflow (recharge flowing on the surface from the crest) and by subsurface flow (a result of an impermeable layer). The moisture at the footslope promotes vegetation growth (Figure 3).

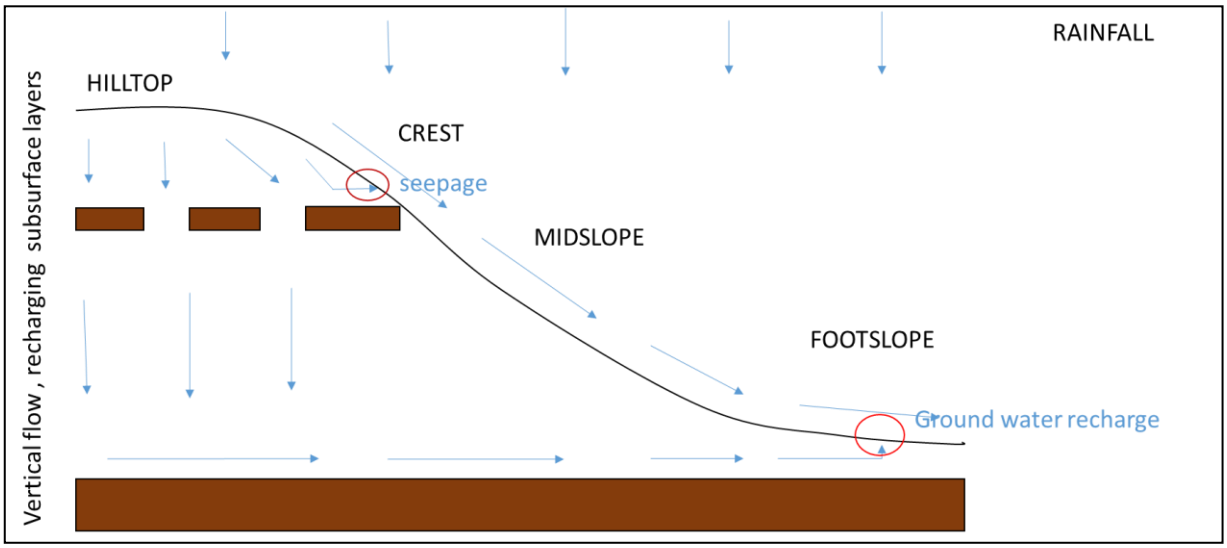

Figure 3: Hillslope major recharges vary depending on the position of slope (hilltop, crest, mid-slope and foot slope). Adapted from Van Tol et al., (2010).

Slopes and livestock

Slopes influence soils and vegetation due to hydrological processes occurring on landscapes, and the soil and vegetation, in turn, influence the distribution of livestock as they select grazing based on palatability. As mentioned, livestock prefer flat, more accessible areas than areas with steeper slope gradients (Neumann *et al.*, 2009; Kaufmann *et al.*, 2013). In a study

conducted in the foothills of Nevada in Madera County, Carlifornia, Tate *et al.* (2003) note a combination of both slope and aspect as physical landscape variables that impact the distribution of livestock. The study monitored faecal deposits of livestock in riparian areas because they pose a threat to the quality of water (faecal pathogens potentially end up in supply of drinking water for humans). The researchers observed there were more faecal deposits on the south-facing slopes than on the north-facing slopes, and that faecal deposits decreased for every 10% increase in slope. In areas that were naturally steep cattle preferred steeper slopes facing south than steeper slopes facing north (Tate *et al.,* 2003). The results are consistent with George *et al.* (2007) and Kaufmann *et al.* (2013) who observe that slope and distance to water have a strong effect on livestock distribution; in a typical landscape where there is a mixture of gentle and steep terrains, cattle preferred gentler slopes of 10% and less. As slope and the distance to water increased, grazing often decreased.

Aspect

Aspect influences the moisture of the soils, thus affecting the spatial distribution characteristics of vegetation (Shoshany 2002; Yimer *et al.,* 2006). In the northern hemisphere, the south-facing slopes are usually dry, as they receive more solar radiation. In turn, this affects soil temperatures and processes, including vegetation composition. Slopes that receive greater solar radiation (due to topographic aspect) tend to maintain greater specie richness (Bennie *et al.,* 2006). By contrast, the north-facing slopes receive less solar radiation, soils are usually moist and there is less evapotranspiration resulting in greater relative percentage cover, biomass and volume (Sternberg & Shoshany 2001; Armesto & Martinez 2004). The combination of elevation, aspect and slope influence solar energy and water regimes of a landscape. This affects the temperature and moisture of landscapes and results in variation of vegetation composition, structure and distribution (Yimer *et al.,* 2006). Most importantly, these microclimatic conditions influence spatial patterns and disturbances such as livestock grazing (Swanson *et al.,* 1988).

Amezaga *et al.* (2004) assessed the effect of grazing intensity, slope and aspect on plant community structure and soil characteristics of the mountainous pastures in Gorbeia Natural Park, northern Spain. The livestock herds grazed freely within the rangelands, and distribution was not affected by human-animal interactions. Their results show that north-facing and steeper slopes (10%-30%) had low grazing intensity, suggesting that livestock avoided these areas. Gong *et al.,* (2008) witnessed a similar pattern in the hilly grasslands of

Xilin River Basin, Mongolia. Livestock avoided north-facing slopes which exhibited higher productivity and specie composition than the south-facing slopes. The south-facing slopes showed signs of degradation and lower productivity.

Seasons and forage material

Temporal variations influence vegetation, wet seasons are typically characterised by rainfall and sunny days which promote vegetation productivity, while dry seasons are dominated by low rainfall and cold (in some climatic regions, frosty) days. In arid and semi-arid regions (particularly developing countries), such as South Africa, dry seasons are a concern because the communal rangelands on which livestock owners depend for grazing are dry (Rasch *et al.,* 2017). The reduced amount of forage material available causes starvation and has detrimental health impacts to the livestock, this occurs predominantly in rural areas, where most community members are poor and cannot afford additional feed to support animal health (Shackleton *et al.,* 2010).

The amount of rainfall occurring in a season determines the herbaceous biomass available on rangelands. In a study conducted in Llwarne and Dordrecht in the Eastern Cape Province, Fynn and O'Connor (2000) compared the effect of stocking rate and seasonal rainfall on rangeland dynamics in a ten-year period. Rainfall had a strong effect on the seasonal peak of herbaceous biomass in both areas. However, grazing days had a negative effect as they reduced the peak biomass; this had a greater impact in rangelands classified as in poor condition. Unsurprisingly, drought periods also had negative effects on the vegetation and reduced the peak biomass in Llwarne and Dordrecht, such is not surprising considering that the study area is in a semi-arid area.

As explained livestock grazing varies seasonally and is primarily based on the vegetation quality and quantity near water sources. On account of the relatively higher availability of vegetation in the wet season, livestock have more forage material on the landscape. However, during the dry season, forage material is limited as the landscape is dry although certain parts have abundant vegetation biomass. The areas that are still 'green' and attractive to livestock are usually riparian areas and permanent wetlands. Metzger *et al.* (2005) compared plant species diversity and vegetation structure in two areas situated next to each other in the semi-arid Serengeti ecosystem. The Serengeti National Park hosts a huge number of migrating wildebeest, gazelle and zebra during the wet season where livestock grazing is not allowed. The Ngorongoro Conservation Area hosts pastoralists who use the area for their livestock

throughout the wet and the dry seasons. The study revealed no difference in plant species diversity or species community composition between the two areas suggesting the resilience of systems that have long evolutionary grazing history. However, during the wet season in both areas, animals were attracted to areas that had higher grass cover and productivity, these areas were spatially distributed over the landscape, thus influencing grazing distribution. In the dry season, when water is limited, the grazing distribution is more restricted in areas close to the water.

Common biotic and abiotic factors influence the distribution of livestock. The literature highlights livestock preference for areas that are near drinking water, they avoid steep landscape and areas in high elevation. Microclimatic factors including aspect influence the forage material (plant biomass, diversity and richness) available for livestock. However, the extent to which these factors influence livestock distribution varies in different climatic regions.

Global Positioning System (GPS) telemetry development and history

Global Positioning Systems (GPS) technology has been used by pastoralists to monitor livestock distribution in pastures for many years (Turner *et al.,* 2000; Ganskopp 2001; Putfarken *et al.,* 2008; Handcock *et al.,* 2009; Butt 2010; Roberts *et al.,* 2010; Perotto-Baldivieso *et al.,* 2012; Raizman *et al.,* 2013; Jordan *et al.,* 2016). Before the development of GPS technology, animal distribution data was collected using direct observations and interpreted through mapping. The limitations to the observation approach are that (1) the animal of interest must first be located and then continuously followed; (2) this close tracking through observation by humans disturb the animals' natural patterns of movement (Rutter 2007). Monitoring livestock using direct observations is time consuming and can fatigue the observer leading to errors in the dataset (Turner *et al.,* 2000).

GPS telemetry benefits and limitations

In the early 1960's, radio-tracking collars were developed, providing more reliable ways of locating animals without disturbing their natural movement pattern and have been commonly used to track both domestic animals and wildlife (Swain *et al.,* 2011). The use of GPS collars for monitoring the movement of animals in order to understand behaviour and pasture utilisation has provided researchers with more efficient and accurate data than direct observation methods (Handcock *et al.,* 2009). Turner *et al.* (2000) used GPS collars to gather information on grazing cattle in a paddock. Benefits include large datasets of accurate

locations, 24 hours a day, in large areas and under any weather conditions (Cain *et al.*, 2005). The GPS data can be manipulated using software such as GIS to analyse patterns and develop distribution models. The imported spatial movement data is imported into GIS (ArcMap) to visually map the distribution and behaviour of livestock in relation to landscape features including fences, forage availability and composition, shade, water sources.

Though GPS technology has been an advantageous method in animal studies, it has disadvantages which include issues of accuracy and autocorrelation. Researchers have interrogated such issues in attempts to improve GPS technology in animal studies. The issue of GPS accuracy is based on whether the GPS collars record accurate location data relative to true position. In attempt to address GPS accuracy, Agouridis *et al.* (2004) tested the accuracy of horizontal-position data collected using GPS collars (comparison in static and dynamic environments) and found that tree cover had a negative impact on the performance of GPS collars; the collars produced more errors when under trees than in open fields, a similar result was evident with fences: GPS locations were more accurate in open fields than near fences. Furthermore, the dynamic testing underestimates the horizontal accuracy of collars. In summary, GPS collars are potentially problematic in terms of accuracy, thus additional visual observations can be useful.

Perotto-Baldivieso *et al.* (2012) conducted a study in two locations in the Uvalde County in south Texas. The first location was in west Uvalde County and the second location was a pasture located in the central parts of the Uvalde County. The main aim of the study was to analyse the extent of correlation between position fixes to determine the minimum time intervals while, at the same time, ensuring data independence. They compared the impacts of time intervals in livestock and wildlife distribution studies. By tracking free-range cattle in different locations with five-minute intervals between position fixes. They collected data for 21 days and selected a random six-day dataset. The selected dataset was subsampled to 10, 20, 30, 60, 90, 120, 150, 180, 240, 300, 360 and 420 minutes. The results showed a correlation between the distances when time intervals were < 90minutes and <120 minutes in both locations respectively. The core outcome is that the goals of the study need to be known and understood before choosing an appropriate data collection time interval when monitoring temporal and spatial distribution of free-range cows. Animal movement studies should be done in fine scales to identify topography, vegetation distribution and human infrastructure. Using minimal time intervals while increasing data independency gives appropriate results

because when the time intervals are long, they underestimate the distances and lose information on animal behaviour.

For collecting large quantities of GPS location data with minimal human labour or with visual observations which disturb animal movement patterns, GPS technology remains preeminent in animal tracking technology. However, the limitations such as accuracy and autocorrelation need to be given attention, particularly in a study of this kind, which monitors free-range cattle that have an option to select any available resources in the landscape. Attention should also be given to landscape features, such as forest canopies and fences, as studies have shown that these factors interfere with the accuracy of GPS location points. The issue of correlation is challenging, as it is based on the study aims, therefore, if the study aims to monitor resource selectivity, then GPS intervals need to be minimal so that important information regarding selectivity cannot be missed.

Opportunity of tracking domestic animals using GPS technology in South Africa

Monitoring livestock movement and behaviour provides information related to spatial and temporal distribution patterns (Rutter 2007). Such information can reduce the environmental impacts caused by livestock through the development of optimal pasture management strategies (Handcock *et al.,* 2009). Researchers in developed countries such as the United States of America, Canada and Australia have examined the use and efficiency of GPS collars to demonstrate livestock distribution and the multiple environmental variables that influence it from patch scale (restricted pastures) to free-range livestock that have open access to any part of the landscape (George *et al.,* 2004; Ungar *et al.,* 2005; Tomkins & O'Reagain 2007; Handcock *et al.,* 2009; Kawamura & Akiyama 2010; Jordan *et al.,* 2016). However, the use of GPS collars in monitoring domestic animals is not as common in developing countries (Cagnacci *et al.,* 2010). The lack of availability of GPS technology is usually due to funding, as it is expensive to have enough units to track every animal. Therefore, for an experiment the researcher tracks a small number of animals per experiment or selects one animal within a herd (usually when tracking domestic livestock such as cattle) (Raizman *et al.,* 2013). Originally, GPS fitting was usually done in large animals such as elephants, because of the weight of the trackers (Swain *et al.,* 2011).

Tracking wildlife in South African game reserves is not new and the use of GPS collars to track animals has provided researchers with information about animal behaviour and resource/habitat selectivity. The information thus obtained contributes to effective natural

resource management. In a study conducted in Sabi Sand Reserve and the Kruger National Park, Thomas *et al.* (2008) tracked an elephant for five years using GPS satellite tracking. The purpose of the study was to incorporate elephant movement patterns in effective elephant management policies. From the GPS location data, they gathered that the elephant had strong seasonal habitat selection patterns and that it spent time close to rivers and artificial water points. In another study Fayrer-Hosken *et al.* (2000) used GPS collars to track female elephants that were injected with immune-contraceptives in the Kruger National Park. The overall aim of the study was to control elephant populations as an alternative to culling. The GPS collar location data showed that injected females did not separate themselves from their families, proving that the immune-contraceptives caused no abnormalities in behaviour. Swanepoel *et al.* (2010) tested the efficiency of GPS collars on leopards in a study conducted in the Waterberg Mountains in the Limpopo province. The study reported on factors that affected the failure of GPS fixes in five GPS collars fitted on leopards: GPS failures were identified when leopards were lying on the ground and when the females were confined in dens. The rate of GPS failures was within the ranges of what had been reported on similar species in other studies.

Evidence from the literature gathered above shows that the use of GPS collars in wildlife has provided effective and provides sufficient location data to understand animal temporal and spatial distribution within South Africa. However, the use of GPS collar technology in tracking domestic animals is not as common. Some studies such as Samuels *et al.* (2007) have used hand-held GPS technology to monitor grazing patterns of herded livestock in communal rangelands of Namaqualand during drought. They witnessed no changes in the spatial distribution patterns during or after the drought, possibly because of the abundance in water points in that area. Another interesting finding was that, during the drought, livestock did not travel further for forage as expected, perhaps because livestock were too weak to travel longer distances. In another study Moyo *et al.*(2013) looked at the seasonal habitat use and movement patterns of cattle in communal rangelands of the Eastern Cape. They hypothesised that forage patterns would change in different seasons and cattle would graze near the riparian zones during the dry season. A GPS hand-held device was used to obtain the location of the cattle. The results of the GPS location data showed that cattle preferred areas near the riparian zones, as expected. Although the use of hand-held GPS devices has shown success in data collection, such studies require labour; data acquisition may disturb the

natural patterns of livestock and using hand-held devices seems to have been carried out only at specific times of day while GPS collars collect GPS location 24 hrs a day.

Livestock distribution patterns in South Africa

South Africa is a semi-arid country and the availability of water plays a crucial role in maintaining ecosystems (Snyman & Du Preez 2005; de Winnaar *et al.,* 2007) and generally, livestock in these regions are attracted to water sources (Masubelele *et al.,* 2015). Temporal variations caused by seasons change forage material and water availability thus influencing the distribution of livestock in rangelands (O'Farrell *et al.,* 2007; Mapiye *et al.,* 2009a). In dry seasons or drought, water becomes a limiting factor and grazing patterns in communal rangelands shift to confined areas such as riparian zones as they retain with forage material and water. Over years, pastoralists have adapted to seasonal variability and use strategies like moving livestock up mountains to access water (Hendricks *et al.,* 2005; Samuels *et al.,* 2007; Haarmeyer *et al.,* 2010). O'Farrell *et al.,* (2007) conducted a survey in Nieuwouldtville on the Bokkeveld plateau on ecological services provided by the ecosystem which promotes livestock production. Depending on the dry and wet season, livestock are herded to productive grasslands for forage to ensure optimal grazing and access to water throughout the year. Surveys identified that the farmers implemented a seasonal grazing strategy that moved livestock between different vegetation types. Also, the farmers identified ecological goods and services that sustain livestock production, including water, nutritional grazing forage, shade and shelter, and seasonal regeneration of vegetation. Mapiye *et al.* (2009a) examined seasonal dynamics in the sweet and sour velds in the Eastern Cape. The study was conducted in communal rangelands to explore the potential and efficiency of cattle productions to improve community livelihoods. The researchers found that seasonal variations were the key factors in cattle management and that the wet or dry season influenced the forage quality and quantity. In another study aimed to explore the opportunity to improve the Nguni cattle production in smallholder farming systems in the Eastern Cape. Mapiye *et al.* (2009b) found that sufficient feed was a restriction to the production of the Nguni cattle within the study area. In winter particularly, cattle were exposed to insufficient palatable biomass and this affected their body condition.

Seasonality and water clearly play an important role in the distribution of livestock, while variables such as slope and elevation seem to have a lesser impact on livestock distribution in South African agricultural systems. Anderson and Hoffman (2007) observed a shift in

grazing intensity from lowland to upland rangelands in Namaqualand in the Northern Cape Province. This suggested that livestock grazed intensely in lowland rangelands and avoided the rocky upland rangelands which were difficult to access. Hendricks *et al.* (2005) witnessed a similar pattern in the Richtersveld National Park: terrain restricted access by herded livestock to parts of the rangelands, but watering points were the main drivers of livestock distribution. However, there seems to be a lack of information in the literature on the influence of slope, aspect and elevation. These variables should be considered because, with the combination of GPS location data, they can provide a holistic explanation of livestock distribution patterns. However, realistically, this is not possible particularly if a researcher is working in a large catchment when it becomes time consuming and expensive. Therefore, predictive modelling of livestock distribution using occurrence datasets is a possible way of identifying potential livestock distribution from one catchment to the other.

Livestock distribution predictive modelling

Animals select resources on the landscape, whether for grazing or drinking water. The selection of resources is an important component to conservationists as it can provide helpful information on landscape management (Kaufmann *et al.*, 2013). It is often assumed that, if animals are present in a specific area disproportional to the rest of the landscape, there is selectivity (Lele & Keim, 2006). The predictive modelling of animal distribution is based on their resource selectivity which can be determined through successive animal locations (Manly *et al.,* 2006). In such cases, predictive modelling is the quantification of the relationship between species and the environment. This type of modelling is based on the hypothesis of environmental factors controlling or influencing the distribution of species (Guisan & Zimmermann, 2000).

Predicting livestock distribution requires precise quantification of behaviour and the contributing environmental variables which can be accomplished by using GPS collars to track livestock locations and provide accurate distribution data (Senft 1989). Geographic Information Systems (GIS) enables the researcher to define environmental variables: relating GPS locations to environmental factors enables the researcher to identify areas where the same animal presence conditions exist, and to assume that these are the areas of potential distribution.

Researchers, however, have used different methods to predict the distribution of livestock based on resource use and habitat selection. Butt (2010) used GPS collars to track livestock in

the Narok District in Kenya, where the location data were related to the availability of vegetation biomass in the study area. The NDVI, a robust indicator of available biomass was used. Butt (2010) found that cattle mobility differs between seasons due to change in vegetation biomass. During the dry season, livestock were confined to grazing in smaller spaces, due to the low vegetation availability, however during the wet season, livestock distribution spread out as there was relatively more forage material available. Pringle and Landsberg (2004) predicted the distribution of livestock grazing pressure in rangelands in Western Australia. Their concern was the cumulative grazing pressure by livestock which threatened rangeland biodiversity. Since water is important for livestock, and grazing occurs near water points, they predicted livestock distribution using the distance to water as the variable to predict livestock distribution. However, this model is limited because it only includes water related grazing gradients and disregards other environmental variables such as slope, forage material, elevation and aspect which some studies have shown to influence livestock distribution. Ungar *et al.* (2005) used GPS collars to monitor and predict free-range cattle activity in rangelands in two different countries (Israel and USA). The researchers used regression models and discriminant analysis to predict animal activity. In both analyses they discovered that the activities were correctly classified by the models and GPs collars were reasonably accurate for inferring free-range cattle activities.

The success of relating GPS location data to influential environmental variables when studying free-range livestock in the above studies suggest that. a similar methodology could be implemented within the communal rangelands of South Africa as an appropriate range management tool to reduce degradation driven by livestock.

1.2 Motivation of the study

The Eastern Cape Province includes land that was formerly the rural Transkei during the apartheid era, the so-called "African homelands". These rural communal lands which were and still are occupied by predominately Xhosa speakers (Hebinck *et al.,* 2011). The apartheid system imposed massive inequalities of income and access to services for black South Africans and the homelands had maximum concentrations of humans and animals in one place (Westaway 2012). The congestions in the homelands, meant that degradation was a threat, though it was believed that the cause of the degradation was due to the poor farming practice of native African men (Letsoalo & Rogerson 1982).

In an attempt to avoid political instability and, at the same time, reduce the environmental impacts and rehabilitate the land, the government developed the betterment planning (de Wet 1989). Betterment planning, Proclamation 31 of 1939, declared the homelands throughout South Africa as betterment areas. The core of betterment planning was to introduce better crops, methods of production and livestock strains by using fences to divide the land into rangelands for livestock grazing, arable land for crop production and residential land using fences (Letsoalo & Rogerson 1982; Minkley & Westaway 2005 Bennett *et al.,* 2010). Rotational grazing was practised as livestock were shifted between rangelands in different seasons. During the dry season, livestock were moved to arable land after harvesting seasons as it provided forage (Kotzé *et al.,* 2013). The government rangers ensured that communities abided by the rules so, even though the land was a common resource, it was state controlled.

Since the 19th century, the Transkei countryside has been, and is still, home to most of the poorest communities in the Eastern Cape (D'Haese & Van Huylenbroeck 2005; Mapiye *et al.,* 2009b). After 1994 a breakdown of institutions and infrastructure (including fences that were constructed during betterment planning) transformed the use of communal grazing land. The post-apartheid government has attempted many interventions to recompense such as the introduction of Nguni cattle in these rural areas; however, these agricultural systems have lacked continuity (Perret *et al.,* 2000). These socio-cultural traits have profoundly affected the rural communities in the Eastern Cape today; it is one of the poorest provinces in South Africa with the majority of its population classified as poor and has the highest unemployment rate 35.6% in the country (Statistics South Africa, 2018).

To most people livestock ownership and staple crop production is an important land-based strategy to maintain and improve livelihoods within rural communities (Shackleton *et al.,*

2001). Livestock is the central agricultural asset to the people: it serves as a source of income, provides manure and is culturally important (Cousins 1999). This dependence on natural resources, even though the areas are subject to rangeland degradation, at least provides basic living requirements (Ainslie *et al.,* 2002). Most parts of the Eastern Cape Province are classified as grasslands with some savanna and thicket biomes in the southern parts (Lubke *et al.,* 1986). The rangelands are sweetveld, meaning the grasses, dwarf shrubs and trees are palatable to domestic livestock (Palmer & Ainslie 2006). Unfortunately, different forms of degradation have been evident. This was long ago identified by Hardin (1968) who classified communal systems as endangered because of a lack of collective, sustainable management of natural resources sustainably; a phenomenon he identified as the "tragedy of the commons".

Van Breda Weaver (1991) identified traces of erosion in the Roxeni, Amatole, Middledrift and Yellowwoods areas in the former Ciskei. Vetter (2007) also witnessed an increase in soil erosion in the Hershel district. Another form of degradation is the reduction of productivity and vegetation composition and cover. The issue of reduced rangeland productivity is not an issue confined to the Eastern Cape; it is a national issue. Wessels *et al.* (2004) identified the reduced rangeland productivity in the northern parts of South Africa by using remote sensing tools to assess degradation impacts: the main findings were that high grazing impacts were a major contributor to decreasing range productivity. Kakembo (2001) examined trends in vegetation degradation in relation to land tenure, rainfall and changes in population in the Peddie District, Eastern Cape. The study shows that though rainfall changes vegetation types, land tenure practices such as the betterment process, decreased the cover of riparian and woody vegetation and opened the land to invasive plants.

Livestock-driven range degradation

Common resources are natural resources available in a certain area, to which community members have equal rights without any restrictions (Edwards & Steins, 1999). Rangelands in Mgwalana are common resources and are of importance as they provide food for livestock (Cousins, 1999). Free-range livestock currently have access to available resources with minimal management, but this access raises concerns about resource use and management of rangelands because livestock are selective, and the selected areas are vulnerable to degradation (Kaufmann *et al.,* 2013).

Mgwalana is one of the rural areas in the Eastern Cape Province in South Africa where communal rangelands have been utilised by livestock for many years (Ainslie *et al.,* 2002).

Though rangelands support multiple uses, such as cattle grazing, biodiversity, wildlife habitat, watershed protection (Kaufmann *et al.,* 2013). They are regarded as unproductive because of land degradation (Bennett *et al.* 2012). The land degradation is caused by extensive agriculture and livestock farming documented in past reports (Perret *et al.,* 2000; Palmer & Ainslie, 2007).

Livestock farming is practised to reap benefits from them. Small-scale livestock production is more common in rural Mgwalana, as the community is predominantly poor. For the households that own livestock, the benefits are both cultural and financial. The cultural benefit is using the livestock as a sacrifice in rituals, and as a source of *lobola* (bride price). Financially, owners benefit by selling some of the livestock for cash when in need. Another source of income is from selling animal skin and wool (Shackleton *et al.,* 2001). The livestock move around within rangelands in search of resources, such as food, water and shelter from wind (Rutter, 2007). Their grazing distribution is influenced by external factors such as water availability and forage material, and internal factors such as spatial memory, which guides them to grazing material and water (Ganskopp & Bohnert 2009; Saizen *et al.*, 2010). On a daily basis, they decide where to graze, ruminate, rest and drink, influenced interchangeably by abiotic and biotic factors (Ganskopp & Bohnert 2009). In these rural communal lands, where poverty dominates, land-based livelihood strategies can potentially contribute to the overall well-being of people (Perret *et al.,* 2000; Shackleton *et al.,* 2001).

The communal rural areas usually have herders or family members to herd the livestock to the surrounding grasslands in the morning, so that the livestock can begin grazing, resting and drinking. In the evening, the livestock are herded back to the households where they are kraaled overnight (O'Farrell *et al.,* 2007). However, there has been a breakdown in herding practice in many homesteads (Samuels *et al.,* 2016). Largely due to the stricter enforcement of schooling rules, and the high cost of employing herders in low income households. When cultivated lands are fenced, which is un-usual in many communal areas, livestock are also allowed into the cultivated land in winter to feed on stock residues. Because Mgwalana is a semi-arid environment, which it is vulnerable to degradation and loss of biodiversity by heavy grazing (Haarmeyer *et al.,* 2010). If poorly managed, grazing will continue to negatively affect biodiversity in the rangelands (Marty, 2005). Furthermore, because, the land within the communal systems belongs to the local community and no form of grazing strategy is implemented, it is a challenge to manage livestock holistically. In the past,

continuous grazing systems and strategies that enhance the provision of ecosystem goods and services have not been consistent (O'Farrell *et al.,* 2007).

Interventions need to include social and ecological dynamics that influence livestock-rangeland interaction. Commercial farmers who farm livestock for financial income use different techniques to manage livestock from those practiced on communal land. The most common strategy used by commercial farmers on privately owned land is rotational grazing which involves livestock grazing on a certain portion of land for a season. After grazing on that portion of land, they are moved to another part of the land when the season changes. This allows the land already grazed on to regrow (Muchenje *et al.,* 2008).

The generalised information on cattle distribution is open to many contextual variations that are likely to influence actual livestock distribution, grazing patterns, and therefore rangeland condition (Neumann *et al.,* 2009). For example, temporal variations based on wet and dry seasons and spatial variations such as the effect of a system with herders and one without herders, the presence or absence of croplands, the location of water and the preferred grazing species will all impact grazing patterns and land degradation (O'Farrell *et al.,* 2007; Tate *et al.,* 2003). Therefore, if an area is designated for landscape restoration, local contextual understanding of livestock spatial distribution and movement patterns is valuable (Kaufmann *et al.,* 2013). Successes reported in rangeland science and management have occurred in developed countries, but in many developing countries where rangelands are critically important to the livelihoods of community members, severe rangeland degradation and/or conflicts over rangeland use create significant social, economic, and environmental problems (Hankins *et al.,* 2004; Vayssières *et al.,* 2011; Farrié *et al.,* 2015; Martin, 2015). This study contributes to the identification of areas that livestock select for grazing which are prone to range degradation based on the extent of usage. If the disproportional use is ignored, ecological services can decline. However, with appropriate management, grazing as a form of disturbance could maintain the structure, function and diversity of the grasslands in the area.

Knowledge of spatial distribution is essential for any assessment of environmental impacts caused by livestock on grasslands, for example, soil erosion caused by overgrazing, as well for monitoring land change over time (George *et al.,* 2007; Neumann *et al.,* 2009). Incorporating livestock distribution and its drivers into models permits local people to recognise other potential areas within the rural area that their livestock could use in different seasons (Tate *et al.,* 2003). Lastly, this study could serve as a baseline of information in

ecological reports to raise awareness about livestock needs and management for livestock farmers, community members and policy makers (George *et al.* 2007). At the same time, such information could contribute to initiatives such as the restoration of grasslands and management of the grasslands against undesirable effects (Pykälä 2003).

1.3 Aims and objectives

Aims

This study aims to link monitored livestock distribution to physical landscape variables in Mgwalana, and to use the modelled relationship to predict livestock distribution in quaternary catchment T12A and T35A-E.

Objectives

I. To identify and map livestock distribution in the rangelands of Mgwalana using GPS location data collected during the wet and dry season.
II. To relate influential physical landscape variables (slope, aspect, elevation and vegetation) to livestock distribution in order to identify resource selectivity.
III. To use a desktop method that will combine the measured physical landscape variables and the GPS location data to predict areas of potential livestock distribution in Mgwalana, T12 A and T35A-E.

1.4 Specific research questions

To achieve the above-mentioned objectives, the following specific research questions were addressed:

(a) Where do livestock spend time and which areas receive grazing attention in different seasons?

(b) How can areas of potential livestock distribution be identified in other catchments where actual distribution is unknown?

1.5 Thesis structure

The thesis is made up of six chapters: Chapter 1 provides a general introduction and the background on livestock distribution internationally and in South Africa. It examines the factors that affect distribution and outlines the motivation for and the aim and objectives of the study. Chapter 2 describes the study area in detail and provides social and ecological background. Chapter 3 describes the methodology and includes the data collection and data analysis used in the study. Chapter 4 details the results from the relating livestock GPS location data with the selected physical landscape variables. It includes results from the predicted potential livestock distribution in the greater extent of Mgwalana as well as in quaternary catchments T12A and T35A-E as a proof of concept. Chapter 5 presents the discussion of the results from the assessment of livestock distribution patterns and the efficiency of predictive modelling of potential livestock distribution. The thesis ends with an assessment of the research contribution, limitations and the future research direction.

Chapter 2: Contextual Analysis

2.1 Study area

The first part of the aim is *to link monitored livestock distribution to physical landscape variables in Mgwalana*. The study was conducted in the north-eastern part of the Eastern Cape in a rural area called Mgwalana located 14 km from the small town Cala (31˚31’32.22”S, 27˚47’33.26”E). The second component of the aim is to *use the modelled relationship (*from data collected in Mgwalana*) to predict livestock distribution in two quaternary catchments,* namely *T12A and T35A-E.*

The Tsitsa River catchment in quaternary catchment T35A-E are situated within the Mzimvubu River catchment, which is in one of the least developed and poorest regions in the country. The Department of Water and Sanitation together with the Department of Environmental Affairs-Natural Resource Management (DEA-NRM) are planning to build dams with the aim of providing domestic water supply, irrigation and generating hydropower for the surrounding communities to improve livelihoods. The Tsitsa River catchment lies in communal areas of the former Transkei homelands. It is characterised by grassland plateaus, indigenous and alien invasive forests, and livestock farming on both private and communal land (Bannatyne *et al.,* 2017). The Tsitsa River catchment has highly erodible duplex soils which have resulted in a network of deep gullies. Livestock grazing, particularly on slopes, and frequent burning has resulted in soil loss and high levels of suspended sediment deposits in the rivers (Bannatyne *et al.,* 2017; Gwapedza *et al.,* 2018).

Quaternary catchments T12A and T35A-E are located within the Mzimvubu-Tsitsikamma Water Management Area (WMA) (Department of Water & Sanitation, 2015) (Figure 4). In South Africa, the WMAs are subdivided into catchments, with quaternary catchments being the fourth-order catchments in the classification system (Department of Water & Sanitation, 2015). Mgwalana is in quaternary catchment T12A and the predictive modelling is extended into the rest of quaternary catchments T12A and in T35A-E (Figure 5).

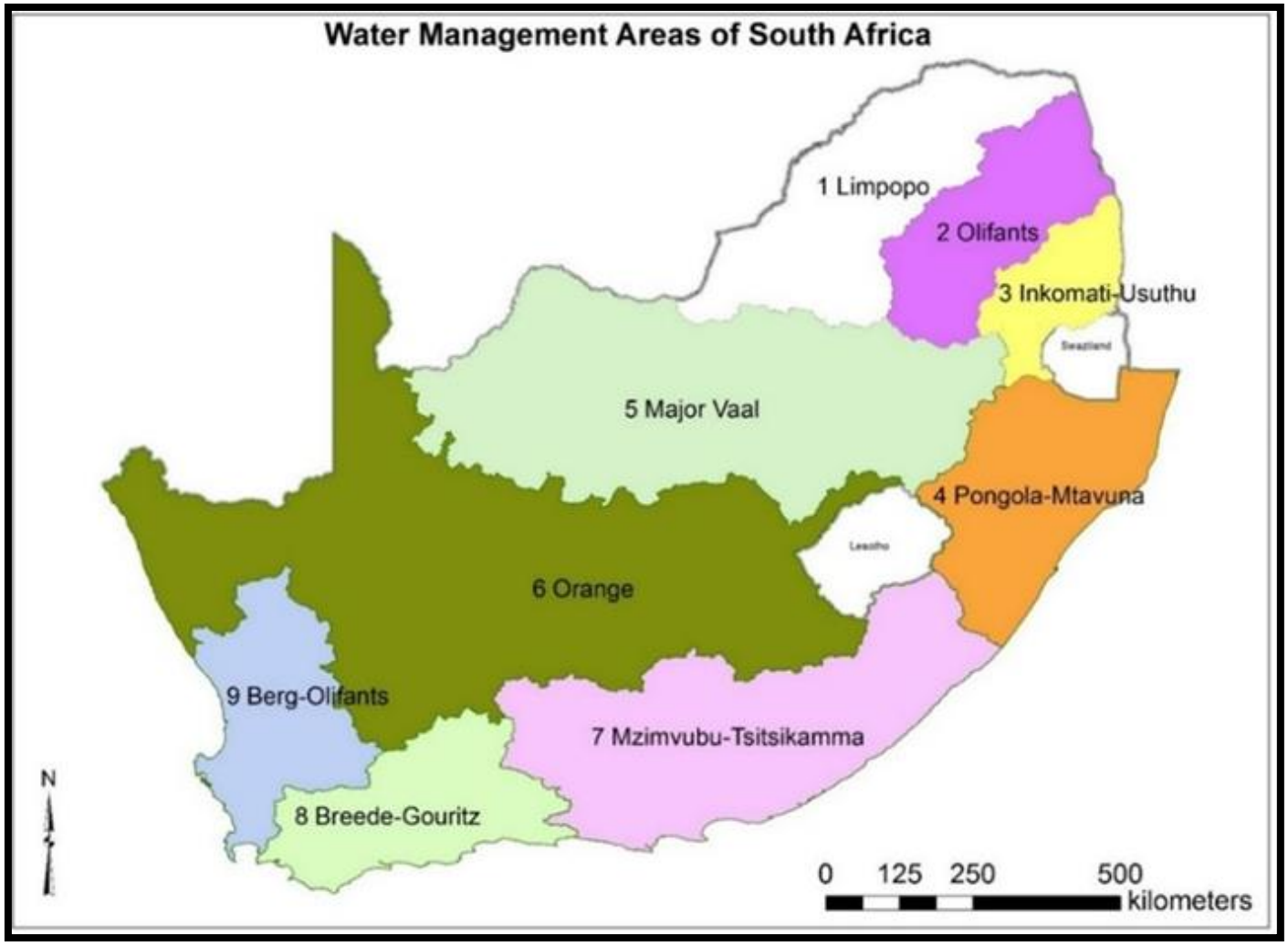

Figure 4: The study area is within the Mzimvubu-Tsitsikamma Water Management Area (WMA).

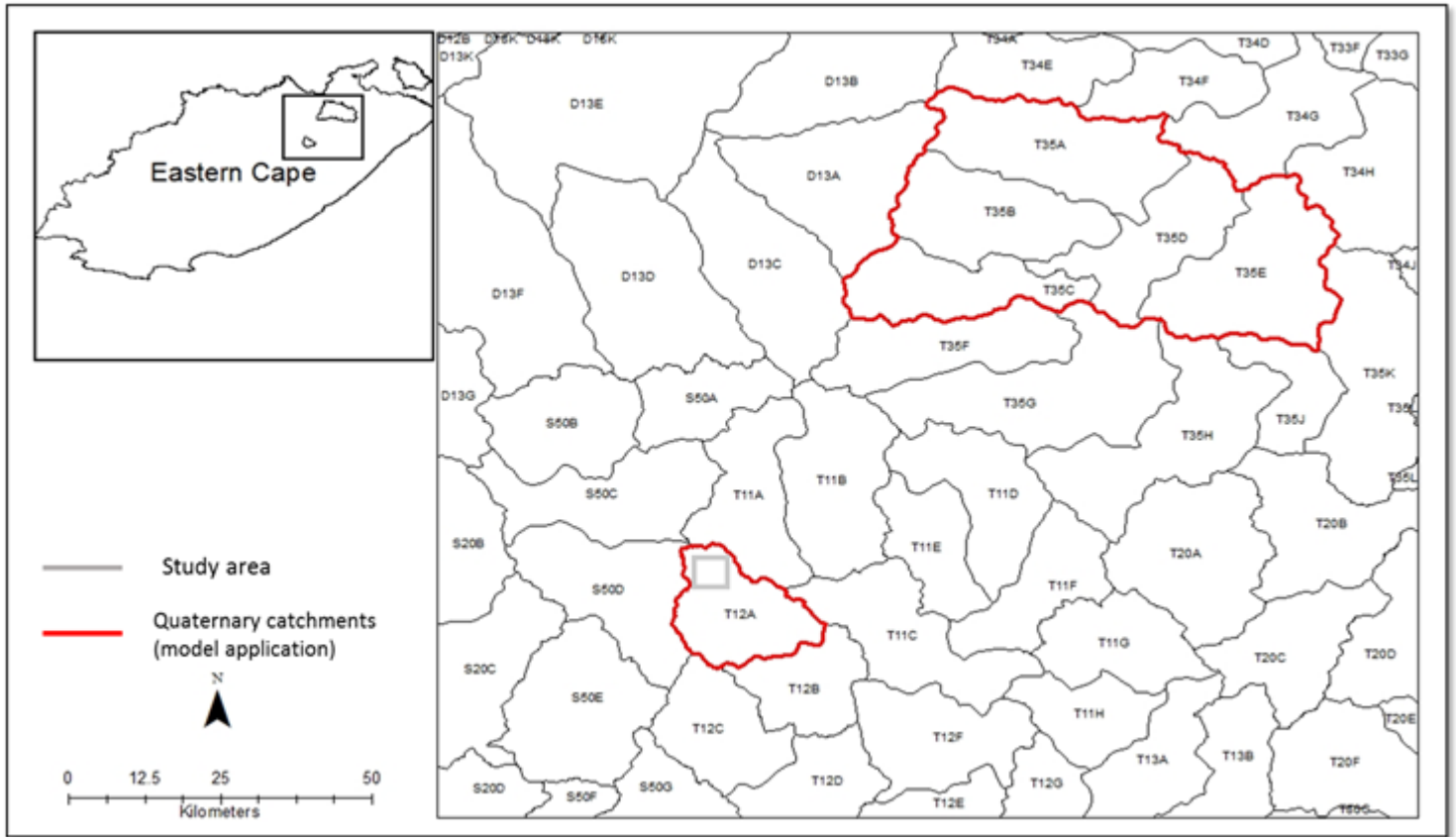

Figure 5: The study area (grey) is within quaternary catchment T12A (red), the predictive modelling of livestock distribution lies within T12A and T35E (red).

The Mgwalana rural area (where GPS data were collected) is divided into three sections which are named **A**, **B** and **C** in Figure 6. The area forms part of the former homelands of Transkei and consists predominantly of traditional villages surrounded by communal rangelands (Palmer & Bennet, 2013). The local people are financially disadvantaged, but they own livestock for a variety of reasons including income generation (selling some of the livestock) and for cultural purposes (Bank & Minkley, 2005; Palmer & Bennet, 2013). The livestock use the surrounding rangelands for food, water, and shelter (Cousins, 1999).

Figure 6: The Mgwalana rural area, image from Google Earth showing the different homestead and the nearby rangelands.

2.2 Historical perspective and social context

Brief history and background

During the apartheid era, the Eastern Cape was separated into the Transkei and Ciskei homelands to which native Africans were moved (Figure 7). The homelands were surrounded by communal rangelands accessible to all community members.

The rural area of Mgwalana is part of the former Transkei and was part of the areas where the Betterment planning was implemented with the purpose of introducing common resource management because homelands were becoming overcrowded and degraded. To improve land use, the lands was divided and fenced off into arable land, rangelands and residential lands (Figure 8).

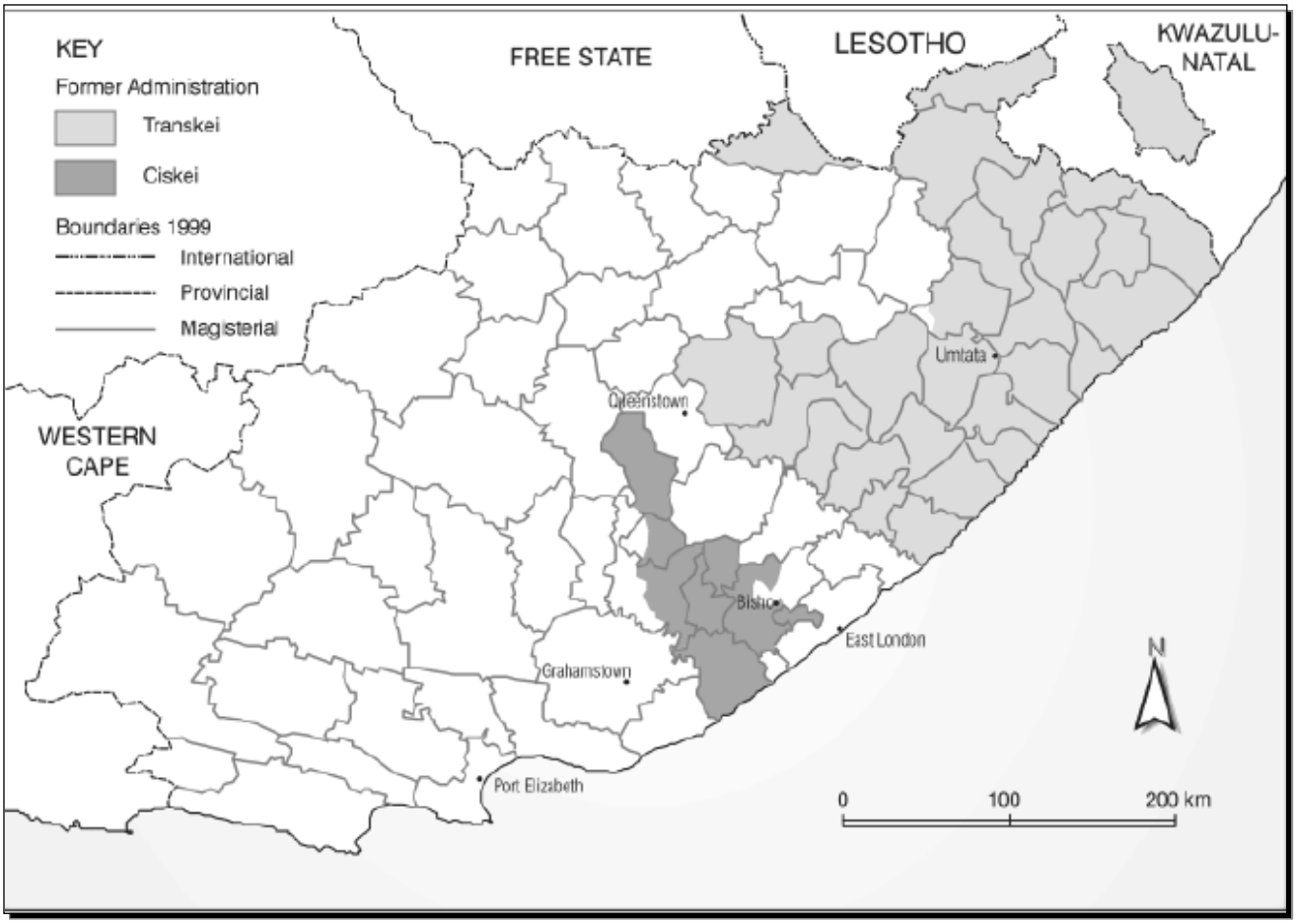

Figure 7: The former administrations during the apartheid era, the Ciskei in the southern parts of the province and the Transkei in the north eastern parts of the Eastern Cape Province.

Figure 8: Abandoned arable land on the northern parts of Mgwalana which is invaded by wattle.

Where rotational grazing was implemented, focusing on resting a camp while livestock rotationally grazed in other camps. During the dry season the arable land would be open for livestock to graze in as additional forage. The betterment process was discontinued in the early 1970s and the South African Bantu Trust was introduced. This system worked differently as the control of the rangelands were now rested with individuals in the communities. The land reform programme was introduced to such areas post-1994 to give access to land for residential and productive purposes; however, not much has changed except the collapse of management of grazing land (Ainslee, 2002). Grazing strategies such as rotational grazing was implemented during the apartheid period but currently, those strategies have been impossible to maintain because fences have been cut by tribal authorities and there are no longer rangers who enforce rules and regulations. The reality of democratic South Africa is that there is minimal support from the government to support livestock production.

The rural area of Mgwalana is one of many rural areas in the Eastern Cape where most of the community members now depend on social grants, piece work and a subsistence income based on selling their livestock (cattle, sheep and goats). The communal livestock systems contribute little to the economy of the Eastern Cape (sales and markets) but they serve as a source of short-term income (Cousins 1999; Shackleton *et al.,* 2001; Nowers *et al.,* 2017). Cattle have had cultural significance for decades culturally, a man's status and financial security has been based on the number of cattle he owns. Thus, cattle have importance beyond subsistence purposes or a market-based strategy to boost the provinces economy (Bembridge, 1987).

Livestock (housekeeping, maintenance)

Livestock ownership was and is still important to rural the people of Mgwalana. However, there is concern when it comes to the health and safety of the livestock. These concerns include issues with land administration, drought, diseases, water access, theft and shortage of land (Ainslee, 2002). These are issues that put livestock systems at risk and compel people to reduce the number of livestock they have, or even not have livestock at all.

To avoid stock theft, livestock owners adopt a very common practice in communal systems of the former Ciskei and Transkei: they kraal their animals at night. Every morning, the livestock is herded out to begin its daily activities, which include grazing in the nearby rangelands until sunset, when they are kraaled again for the evening. The rangelands are currently under no sort of rangeland management but are open to access by all local community members.

2.3 Ecology

2.3.1 Communal rangeland

The communal rangelands used by livestock are near the homesteads and provide natural resources in the form of shrubs, wattle forests (an invasive alien), open grasslands, rivers and wetlands. These resources are accessible to the livestock and the local community members at large.

Invasive wattle has formed forest patches in the northern sections of the rangelands. Although the livestock benefit from the wattle forests which serve as windbreaks, the forests pose as a threat in that they make livestock vulnerable to stock theft. The Community Work

Programme, which is part of the Expanded Public Works Programme, works with local communities in clearing invasive wattle. The programme is not only ecologically beneficial but also creates jobs and contributes to livelihood sustainability (http://www.epwp.gov.za/). (Figure 9) shows the stages of wattle clearance in August 2013, based on Google Earth imagery: the wattle had not been cleared. Three years later, a part of the forest in the north western parts had been cleared (yellow line) and on the north eastern parts (broken yellow line). In 2017 (March and July) the wattle in the north western area (had been cut off) had regrown, but the wattle forest in the eastern parts had undergone further clearing.

During the dry season, (August 2013 and July 2017) fires are often common. If these fires are not controlled, they can become disastrous and damage the homesteads and even kill livestock, particularly the calves. However, once the burnt grass receives rainfall new grass sprouts and livestock are attracted to it.

A river tributary flows from the west to the east and is joined by the Tsomo River catchment tributary that flows north to south (Figure 10). The river plays an important role as it provides water for the livestock throughout the year. Terrestrial wetlands which remain saturated with water and the plants remain green throughout the year (Walters *et al.*, 2006), are found near the rivers (blue arrows) and on the hillsides of the mountains. Some parts of these rangelands are on relatively elevated slopes where hillslope seep wetlands are mostly found (Walters *et al.*, 2006). These wetlands form as a result of an impermeable layer below the surface that redirects the flow from vertical to a lateral so, the discharge seeps and appears on the surface of the ground (Van Tol *et al.*, 2010).

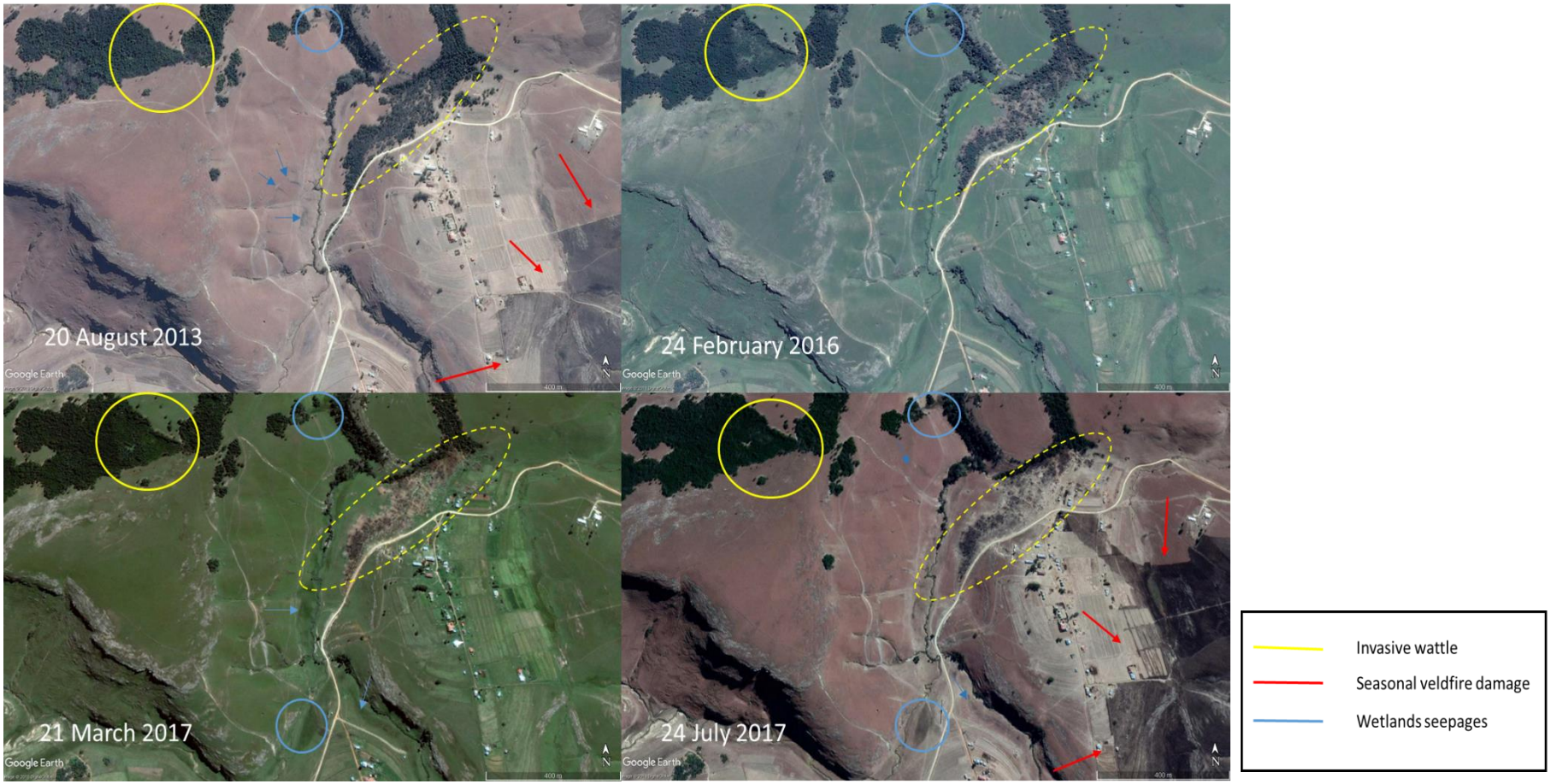

Figure 9: The study area (Mgwalana rural area) in August 2013, February 2016, March 2017 and July 2017. The images show the area in different seasons and shows the changes in land cover over the years (images from Google Earth).

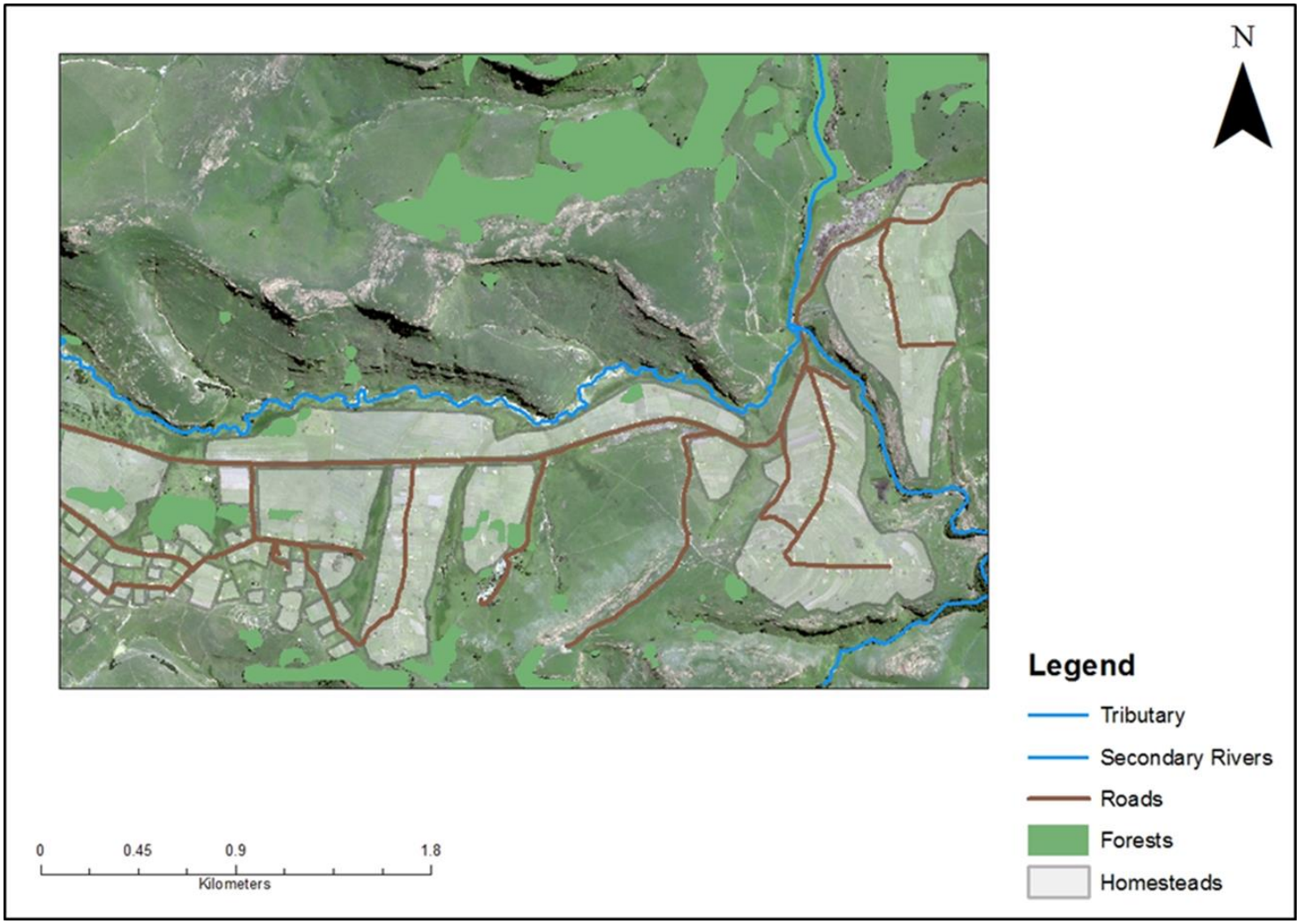

Figure 10: The main tributaries that flow through Mgwalana are a source of water to livestock. The wattle and the indigenous forests are used for multiple purposes by the community and livestock. The community uses woods for making fire and building kraals.

2.3.2 Geology

Quaternary catchment T12A is characterised by Molteno, Tarkastad and the Karoo dolerite formation, these formations are from the Karoo supergroup. (Lithology: Arenite, mudstone and dolerite) (Visser, 1984). Quaternary catchment T35A-E is characterised by Molteno, Tarkastad and the Karoo dolerite (Lithology: Arenite, Mudstone and dolerite) (Figure 11).

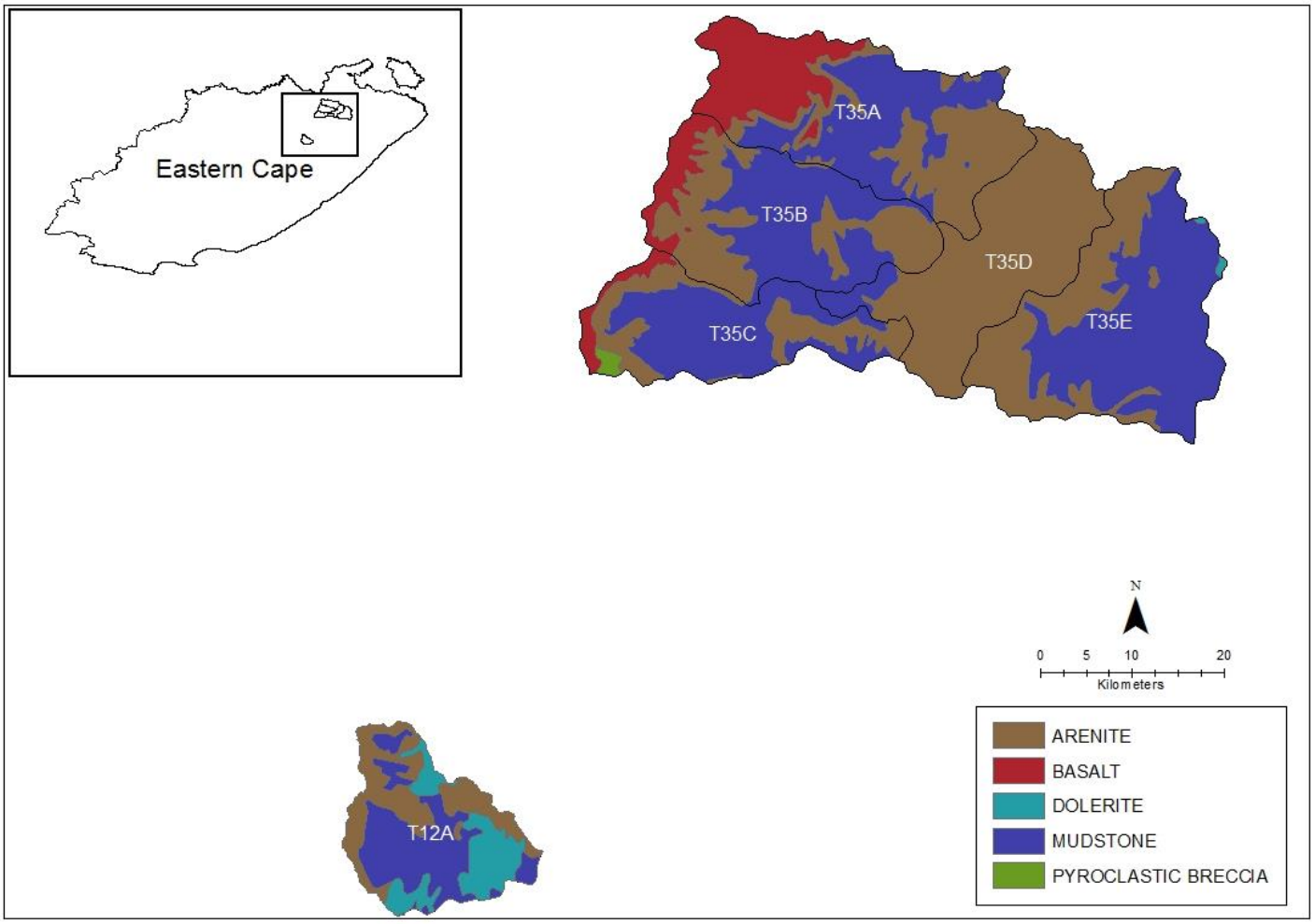

Figure 11: The geology of quaternary catchment T12A and T35 E.

2.3.3 Vegetation

The study area falls into the Southern Drakensberg Highland Grassland bioregion (Mucina *et al.,* 2006). Where the vegetation is classified as the Tsomo Grassland, which is chiefly grassland, forest patches of indigenous trees, and some patches of invasive wattle trees (Mucina *et al.,* 2006). Quaternary catchment T12A is characterised by Drakensberg Foothill Moist Grassland, Southern Mistbelt Forest and the Tsomo Grassland. Quaternary catchment T35A-E is characterised by the Drakensberg Foothill Moist Grassland, East Griqualand Grassland, Eastern Valley Bushveld, Mthatha Moist Grassland, and Southern Mistbelt Forest (Figure 12).

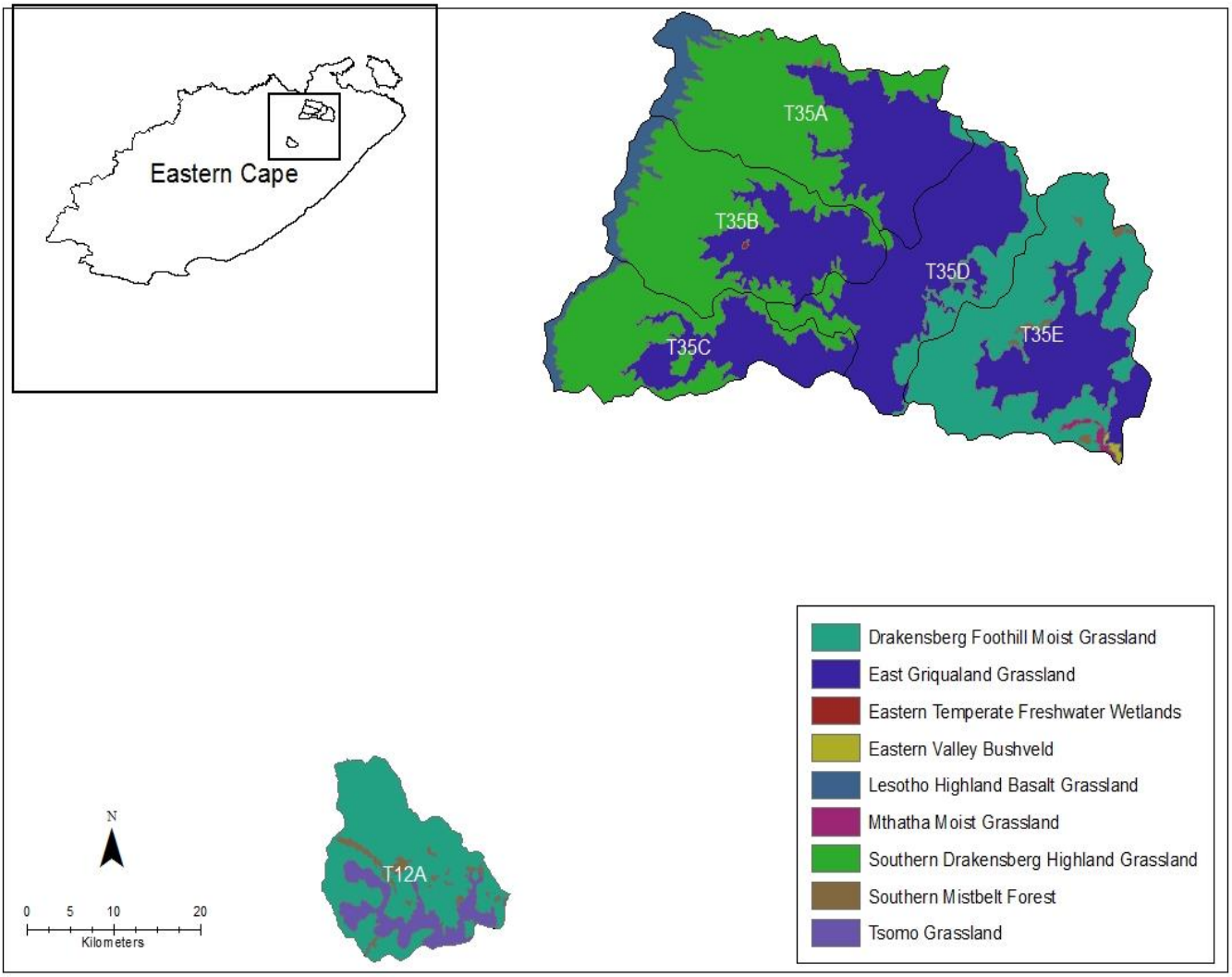

Figure 12: The vegetation for quaternary catchments T12A and T35A-E.

2.3.4 Precipitation and temperatures

The Mgwalana rural area experiences wet summers and dry winters, with low mean annual precipitation of 606 mm (Schulze, 1997). In February, the area has its highest mean temperature and the lowest mean temperature in July (below 5˚C) (Figure 13). The area experiences a mean of 28 annual frost days, mostly in winter. Quaternary catchment T35A-E is generally characterised by seasonal rainfall and temperatures, with most of the rainfall occurring during summer and the winters mostly dry (Gwapedza *et al.*, 2018).

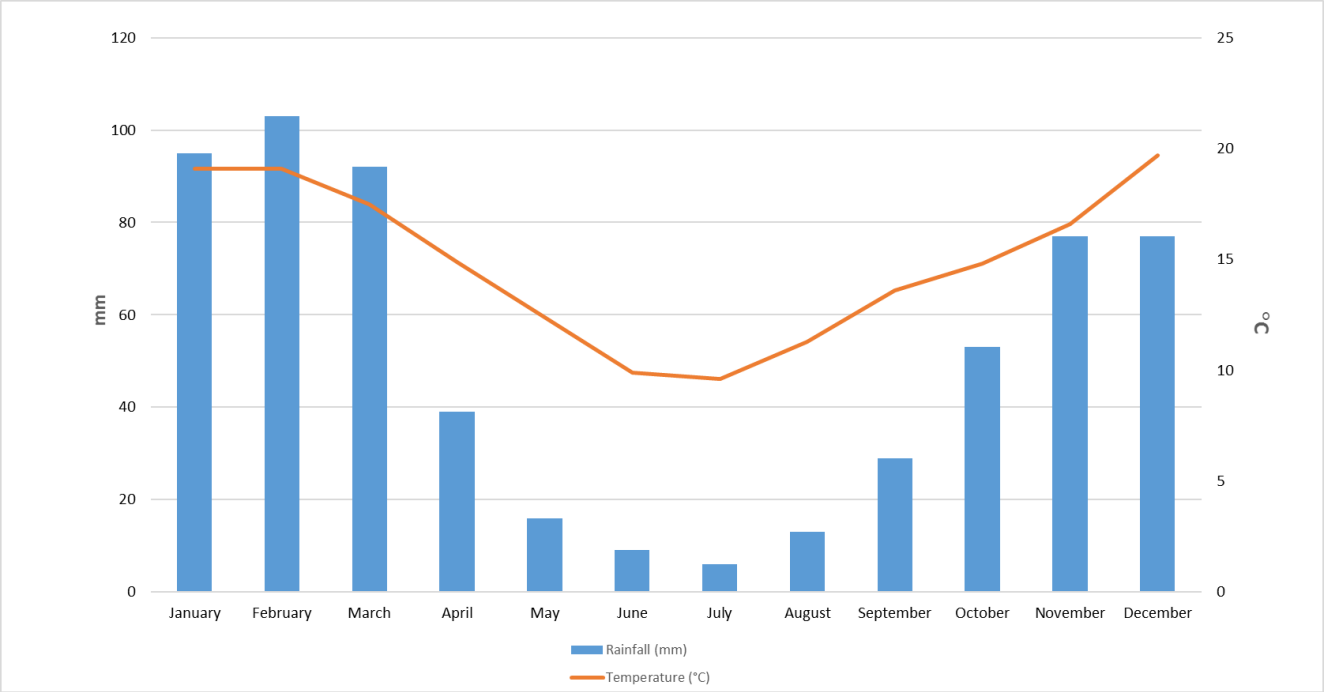

Figure 13: The monthly median temperatures and the mean monthly precipitation for Mgwalana. The temperatures and rainfall are at their highest in the months of November to March. The temperatures and rainfall decrease in April, June and July and start increasing again in August to October.

Chapter 3: Methodology

3.1 Livestock distribution

GPS collars were chosen as a data collection tool as being the most effective way to gather location data of livestock in Mgwalana. The ability to collect large amounts of accurate location data, 24 hours a day, in large areas and in all weather conditions were among the advantages of using GPS collars (Cain *et al.* 2005). The ability to produce information about areas where data had not been collected and in areas where it was difficult to gather animal movement data made this method of data collection less challenging.

The GPS points were integrated with relevant surface landscape maps to analyse distribution patterns in different seasons, a method that has been widely used (Lele & Keim, 2006). For the purpose of this study, satellite imagery was processed in ArcGIS to develop selected layers that represent physical landscape variables. These satellite images represent physical landscape variables of slope, aspect, topographical wetness and vegetation greenness which were selected because they potenitally influence livestock distribution. The predictive modelling of areas of potential distribution was conducted in quaternary catchment T12A (where Mgwalana rural area is located) and in the Tsitsa River catchment in T35A-E.

3.1.1 Analytical framework

The analytical framework below (Figure 14) illustrates the steps taken in the study to address the study aim: to link monitored livestock distribution to physical landscape variables in Mgwalana, and to use the modelled relationship to predict livestock distribution in other areas. The details of the framework are provided in the next section.

Before the study was conducted, the researchers engaged with the local community members to build trust and an understanding of the study we were conducting, and to satisfy ethical and traditional values related to livestock handling. Animals (cattle) from different households were selected by the researcher with the permission from each homestead to fit them with GPS collars. At the beginning of the summer season (2016) the GPS collars were fitted and were collected at the end of the season. The same field methodology was used during the winter (2017). Thereafter, the data from the GPS collars was prepared and analysed. The result of the analysis was the determination of animal selectivity based on the physical landscape variables, and this relationship was demonstrated using histograms showing the frequency distribution based on the variables.

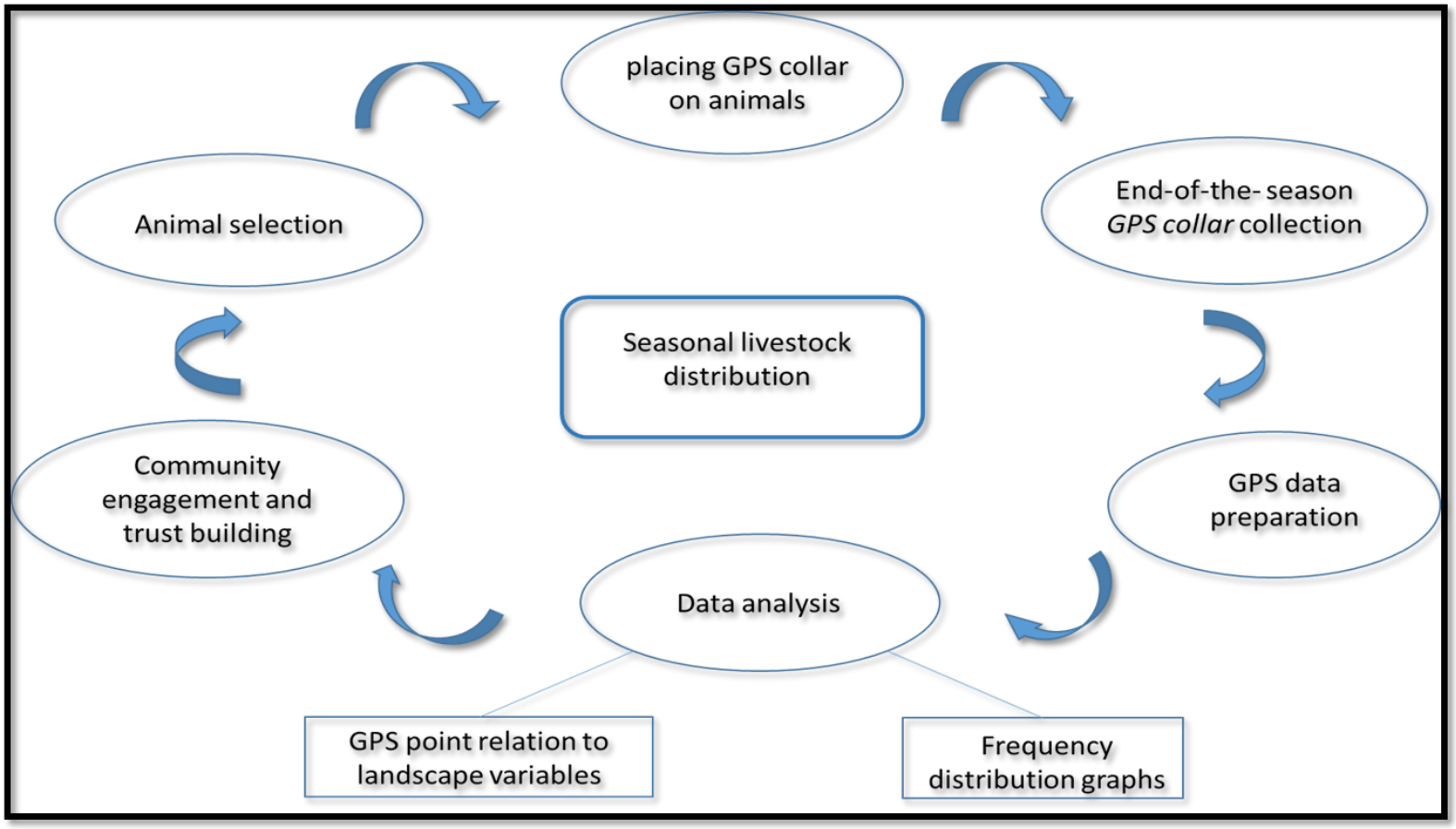

Figure 14: The analytical framework used to relate the GPS point location with physical landscape variables in both summer 2016 and winter 2017. The stages start with building community trust, the selection of animals, fitting the GPS collars at the beginning of each season and then collecting collars at the end of the season. The whole dataset was then cleaned up and prepared for analysis producing frequency distribution graphs and livestock selectivity based on physical landscape variables.

3.1.2 Data collection and preparation

Data collection

Community engagement and ethical clearance

The study was part of the ongoing Ntabelanga Lalini Ecological Infrastructure Project (NLEIP) of which the Agricultural Research Council (ARC) team and the Institute for Water Research (IWR) are part of. The NLEIP is based in quaternary catchments T35A-E, however due to the lack of trust from the community members, the GPS collars could not be fitted in quaternary catchment T35A-E but could be fitted on animals in Mgwalana which is situated in quaternary T12A. The ARC team had been working in the Mgwalana rural area, so the local community members were familiar with the researchers. Prior to conducting the study, the team obtained ethical approval from the Rhodes University Research Ethics Committee (Appendix 1). This step was necessary because it ensured that the community members understood the nature of the project and the researchers gauged the community's cultural norms and the sensitivity associated with livestock.

Selection of animals

For the summer season data collection, from November 2016 to February 2017, 14 cows were selected from different livestock-owning homesteads in the Mgwalana rural area. The cows were Bos indicus, Brahman and semi-Brahman; aged between one to five years (calves were not included in the study). The selected cows freely utilised the surrounding rangelands and were not kraaled during the day.

The winter season data was collected from July 2017 to September 2017, with 14 cows selected from different homesteads in the same area. The same fieldwork methodology and procedures were used as in the summer season data collection. The cattle breed was also the same (Bos Indicus, Brahman and semi-Brahman) and the cows ranged in ages between one to five years.

Fitting GPS collars on the selected animals

With the assistance of the local herders (Ndade and Anele), the selected cattle were taken to the communal dipping area, in the centre of the Mgwalana rural area (Figure 15). The cattle

were lined up and the GPS collars were fitted to the neck of each cow, after which the cows were set free to begin their daily activities (Figure 16).

Figure 15: The communal dipping area used to gather and control cattle as the GPS collars were fitted to their necks.

Figure 16: A local herder Ndade, assisting with handling the cattle and placing the GPS collars on the necks of the animals.

The GPS chip recorders information

The GPS collar consisted of a chip recorder with battery which was put in a plastic pocket and then sealed with silicon to protect the equipment from moisture or easy access. Finally, the pocket was screwed into the belt of the collars (Figure 17). These collars were fitted to the necks of the cattle for a period of three months for each season (summer and winter).

The CatLog Gen2 chip recorder is 4.4 cm x2.7 cm x1.3 cm in size and weighs 22 g. It is equipped with a ceramic patch antenna (GPS antenna) with control status elements, a magnetic switch (to switch it on and off), micro USB interface (used for charging and communicating with the computer), status light (green) and charge light (red).

To communicate with the device (chip), an interface serial communication cable and micro USB adapter can be connected to a computer USB port. The CatLog Gen2 device driver and control centre needs to be downloaded on to the computer for connecting and downloading data from the chip to a computer.

The battery has runtime of 2160 hours which is equivalent to three months. The battery can take a certain fixed number of points for a certain period. Therefore, it is important to keep this limitation in mind when using GPS trackers because it could affect the data collection process (Rutter, 2007).

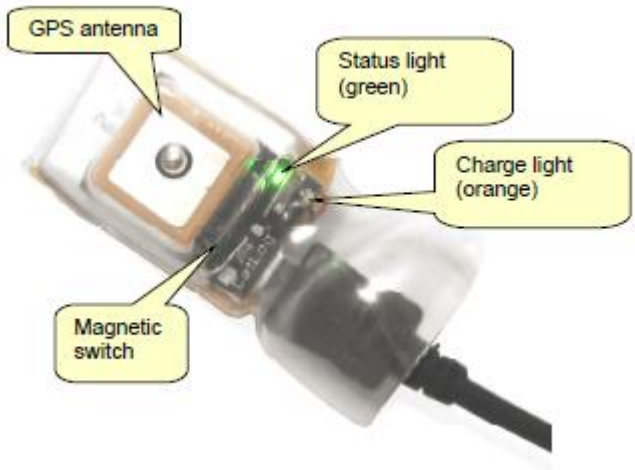

Figure 17: The GPS chip recorder, with its antenna, magnetic switch and light ports.

Another important aspect of using the GPS was to consider appropriate sampling intervals for the GPS position data. Usually this depends on the type of animal being studied; for instance,

the time interval for wildlife animals could be longer than for domestic livestock, because GPS trackers are usually left for a longer period in wild animals and retrieval is more difficult and challenging than it is with domestic animals (Rutters, 2007). For this study, the GPS recorder was set to capture GPS location on five-minute intervals, if there was no satellite position available, the recorder attempted capturing the data after a 10 second delay. The recorder captured the animal's location, time and date, atmospheric temperature and speed.

The GPS recorder features based on the Catlog manual provided with GPS chips are:

- Small size of chip recorder
- Interface for data exchange and charging USB port
- GPS chipset: Sirf 3
- Battery capacity: 2160 hours
- Accuracy: 5-10m, depending on signal strength (position jitter is expected in low satellite signals reception conditions)
- Position logging interval time: 1s-60 minutes
- Storage capacity: up to 50 000 waypoints
- Operation temperature: -10 to +50 degrees Celsius
- Export data format: GPX, CSV (Excel)
- Recorded data: time, date, position (latitude and longitude coordinates) and speed (cattle movement)

Data preparation

GPS Point dataset preparation

At the end of each seasonal data collection, the GPS collars were removed from the cows and data downloaded for analysis. This process started with the GPS chips removed from the belts, and data transfer from the chip to a computer device. The first step in data analysis was data cleaning, as the logging by the GPS tracker device was started several hours prior to being fitted on the animal. Once all the poor-quality data points (from when the GPS collars were in a vehicle to the Mgwalana rural area) were removed, the data was subjected to time

and geo-location transformations. The geo-location data on the CatLog device is collected in a pseudo-projection (geographic projection: latitude and longitude in DD.dd). It is not possible to calculate area and distance measures correctly in this projection, and thus the data was converted into Universal Transverse Mercator (UTM) projection. This preliminary sorting (cleaning) of the data undertaken using an R script. An output file in a CSV format was produced, which was read into Excel. Each GPS chip contained the cow's position and speed, the CSV file for each cow was renamed ARC followed by a number (e.g. ARC01). Finally, the dataset was cleaned in R-statistics for further analysis using an R script (Appendix 2). The process of cleaning and preparing the dataset was based on the steps below:

- Raw data was loaded in CSV format or TAB files.
- Missing values were removed and the latitudes and longitudes that the study area falls into were selected.
- High speed values (while the GPS was in a moving car) were removed.
- Time-zones were converted from Greenwich Meridian Time (GMT) to Central African Time (CAT). This step was important because livestock do not feed continuously throughout the day and night, and GPS since data were recorded at five-minute intervals, and thus assumptions had to be made about when animals were feeding/grazing. In communal grazing systems in South Africa, animals are kraaled every night. They are released from the homestead at approximately 6 am and returned at approximately 6 pm in summer. In this study, this interval for day versus night was applied to both summer and winter datasets. Data used in further analysis were sorted into day (6 am-6 pm) and night (6 pm to 6 am).

Further analysis of the spatial patterns of livestock distribution were carried out using the T-locoh package in R (Lyons, 2014). This analysis provides a range of outputs that include Google Earth compatible *kml* files (which enable the display of livestock grazing patterns and distribution), isopleths (which represent the frequently grazed spots in percentages over the veld grazed by livestock). This spatial data can be entered into GIS software to identify the grazing patterns and movement of cattle.

Training and Testing datasets

The dataset was split into *training (75%)* and *testing (25%)* datasets with every fourth data point entered into the testing dataset. The training dataset was used to define the ranges at which GPS location points are found within the raster layers (physical landscape variables). Based on the presence of livestock within these ranges, the ArcGIS predictive analysis tool (PAT) predicts areas with the same conditions as areas of potential presence.

Preparation of response surfaces

The response surfaces (which represent physical landscape variables) were used with GPS point location datasets to determine the areas that were selected by the cattle in the different seasons (summer and winter) and the areas that were accessible to livestock. Therefore, with the GPS point location dataset and the response surfaces we were able to quantify the selectivity of livestock to specific physical landscape variables.

Satellite imagery information

The satellite imagery used to create response surfaces that represent the physical landscape variables was requested and downloaded (Table 1) from the websites below. Landsat 8 bands were used to create NDVI, WorldView-2 was used to digitize land use in the study area, and finally, the Shuttle Radar Topography Mission was used to generate slope, aspect, elevation and the Topographical Wetness Index (TWI).

Table 1: Three satellite imagery datasets used in the study: Landsat 8, Worldview 2 and SRTM.

Dataset name	**Data type**	**Year**	**Source**	**Use**
Landsat-8 Aerial Imagery at 30 m resolution	Satellite imagery	2017	United States Geological Survey (USGS)	The imagery was used to create the NDVI.
WorldView-2 Spatial resolution at 1m	Colour digital photograph	2017	Digital globe	Used to digitise the land use including the homesteads, rivers, forests

				and roads.
SRTM DEM at 30m resolution	Digital Elevation Model (DEM)	2014 (publication date)	USGS	Used to define the elevation and to generate the slope and aspect layers

Land use created in ArcGIS using the digitizing process

To assist in the analysis and interpretation of livestock distribution, land cover was mapped by manual image interpretation using on-screen digitising tools available in ArcGIS. The study area was mapped into different landscape units using the colour digital photograph from WorldView-2. These landscape units were water points, rivers, roads, forests, homesteads and agricultural land which were useful because the distribution of the resources on the landscape influences the distribution of livestock. Because the distribution of resources varies in different landscape therefore, attention was given to the specific distribution in the area.

Water sources are the primary focal points around which daily feeding and resting activities are based, therefore the rivers of the study area were digitised (Ganskopp & Bohnert, 2009). The distance from rivers is also important to livestock because animals avoid spending energy travelling to water sources. Physical barriers such as roads were digitised, because they restrict animal grazing, although livestock are attracted to the roadside where the grass is green and palatable due to the elevated runoff from the bare road surface. The forests and invasive alien plantations in the area were digitized because they form windbreaks for livestock when it is cold and windy.

The digitised land cover layer was used with the land cover layer to identify cultivated fields, plantations, bare soil, the villages, grasslands and the shrubs, the rivers, roads and forests in the area (Figure 18).

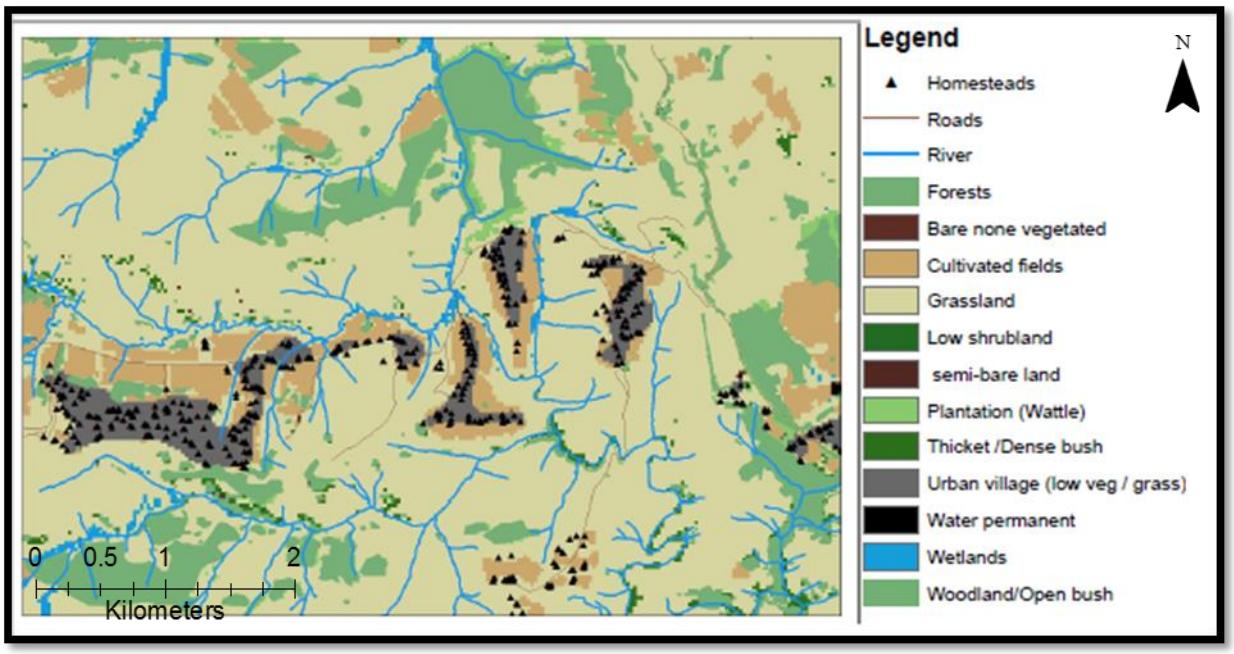

Figure 18: The land cover combined with the digitised land use map.

Projection of GPS point data and response surfaces

The Landsat bands, SRTM and the Worldview colour image were in World Geodetic System (WGS). These datasets were converted to a UTM coordinate system for analysis in ArcMap. The data re-projection process was done after the dataset was loaded into ArcMap using the instructions below:

Arc Toolbox>Data Management Tool>Projections and Transformations> Project

Normalised Difference Vegetation Index (NDVI)

The Landsat-8 satellite imagery (Table 2) was selected as it was the most recent cloud-free imagery available for the study area and was available free of charge. An image from 23 December 2016 was selected for the summer data, as that coincided with the time that the livestock GPS collar data were being collected. For the winter season, an image from 17 July

2017 image was selected, because it also coincided with the time that the livestock GPS collars were on the animals.

The Landsat-8 bands 5 and 4 were used to calculate an image of the NDVI. NDVI indicates actively growing green plant material on the landscape. It was used with the understanding that when there is high reflectivity of green material, NDVI values of dense vegetation are most likely to be high (closer to 1) and they are close to zero over bare soil or water (Carlson *et al.*, 1994).

The limitation of using NDVI is that it does not provide all the natural and physical quantity properties, but only correlates with vegetation canopy, cover and biomass. Fortunately, for the purpose of the study biomass information is critical for this study because it indicates potential forage material for livestock (Carlson & Ripley 1997).

Table 2: The Landsat-8 information including the number of bands, wavelengths and the dataset resolution, source https://landsat.usgs.gov/what-are-band-designations-landsat-satellites.

Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS)	Bands	Wavelength (micrometers)	Resolution (meters)
	Band 1 - Ultra Blue (coastal/aerosol)	0.435 - 0.451	30
	Band 2 - Blue	0.452 - 0.512	30
	Band 3 - Green	0.533 - 0.590	30
	Band 4 - Red	0.636 - 0.673	30
	Band 5 - Near Infrared (NIR)	0.851 - 0.879	30
	Band 6 - Shortwave Infrared (SWIR) 1	1.566 - 1.651	30
	Band 7 - Shortwave Infrared (SWIR) 2	2.107 - 2.294	30
	Band 8 - Panchromatic	0.503 - 0.676	15
	Band 9 - Cirrus	1.363 - 1.384	30
	Band 10 - Thermal Infrared (TIRS) 1	10.60 - 11.19	100 * (30)
	Band 11 - Thermal Infrared (TIRS) 2	11.50 - 12.51	100 * (30)

To calculate the NDVI the following formula was used:

$$NDVI=\frac{NIR-RED}{NIR+RED}$$

Near infrared radiation (NIR) has a reflectance between 0.851-0.879mm and the red is between 0.636-0.673mm 650nm.

The NDVI was created in ArcGIS® version 10.3.1 with band 5 and band 4 of Landsat-8. By using the instructions:

ArcToolbox> Spatial Analyst Tools> Raster Calculator

With the formula relevant for Landsat 8:

$NDVI=\frac{band\ 5-band\ 4}{band\ 5+band\ 4}$

Elevation

Shuttle Radar Topography Mission (SRTM) 1 Arc-Second Global

Shuttle Radar Topography Mission (SRTM) is a sensor system that collects and provides 30 m resolution digital elevation models (DEM) (https://lta.cr.usgs.gov/SRTM1Arc). Table 3 below presents the specifications of the SRTM (DEM) products (Table 3). The SRTM DEM was used to provide the elevation values for Mgwalana; elevation was selected because it influences livestock distribution. The SRTM DEM was imported into ArcGIS where:

- The SRTM DEM was re-projected from WGS84 to Universal Transverse Mercator (UTM).
- The SRTM DEM was clipped to fit into Mgwalana.
- The final product after this processing was used to produce aspect slope and the TWI.

Table 3: SRTM DEM product specifications, source: https://lta.cr.usgs.gov/SRTM1Arc.

Product Specifications	
Projection	Geographic
Horizontal Datum	WGS84
Vertical Datum	EGM96 (Earth Gravitational Model 1996)
Vertical Units	Metres
Spatial Resolution	1 arc-second for global coverage (~30 metres)

	3 arc-seconds for global coverage (~90 metres)
Raster Size	1-degree tiles
C-band Wavelength	5.6cm

Slope and Aspect

In ArcGIS the slope and aspect were generated using the SRTM DEM with the instructions below:

ArcToolbox> Spatial Analyst Tools> Surface

The slope and aspect raster layers were kept at the same resolution as the SRTM DEM (30 metres). The slope surface provided slope (in degrees) from minimum to maximum slope values in intervals of five degrees. The aspect surface provided the aspect (1-360°) in degrees where north=0-22.5° and 337.5-360° east=67.5-112.5°, west=247.5-292.5° and south=157-202.5° of Mgwalana.

Topographical Wetness Index (TWI)

The Topographic Wetness Index is defined as: $\ln(a/\tan\beta)$ where a is the local upslope area draining through a certain point per unit contour length, and $\tan\beta$ is the local slope (Buchanan *et al.,* 2014). The TWI is commonly used to quantify topographic control of hydrological processes (Sørensen *et al.,* 2006). In this study the TWI was prepared at the same spatial resolution as the SRTM DEM and was used to identify areas that were linked to wetness associated with topographic position. Because these areas are most likely to have green grass which will attract livestock. The TWI was also used to identify water points such as rivers in the study area.

Using the raster calculator in ArcGIS Tool box, the algorithm derived from Sørensen, Zinko and Seibert (2006), Buchanan *et al.,* (2014) below was inserted to calculate the TWI. The algorithm uses the slope (in degrees) and the flow accumulation (both layers are derived using the surface creation option in ArcGIS Tool box). Flow accumulation is calculated based

on the weight of raster cells that flow into each downslope cell. The flow accumulation layer is created using the flow direction raster layer.

```
TWI= Con("SlopeDegrees" > 0,Ln(("FlowA1" + 1) * 90 / Tan(3.141592 * "SlopeDegrees" / 180)),Ln(("FlowA1" + 1) * 90 / Tan(3.141592 * 0.00565 / 180)))
```

Data analysis

The aim of the data analysis was to relate GPS point locations to physical landscape variables in order to identify livestock selectivity based on the physical landscape variables. The ArcGIS extract tool was used to extract the values of physical landscape variables at each GPS point. This process was done by using these commands:

ArcToolbox> Spatial Analyst Tools> Extraction> Extract Multi Values to Points

The extraction process resulted in a file in a table format which was converted to csv format. This was imported into Microsoft Excel for preliminary data exploration including the preparation of frequency distribution and the generation of histograms for each variable.

Frequency distributions

Binned frequency histograms are a traditional method used for displaying data (Sircombe, 2004), and for this study, the binned frequency histograms were used to demonstrate the relation between GPS point locations for the selected physical landscape variables. The continuous variables were grouped to create ranges. Binned frequency histograms provided an important step in demonstrating that livestock do select specific grazing areas.

Using Microsoft Excel, the frequency formula was used to generate the frequency of GPS points occurring on landscape variable ranges, e.g. the frequency of livestock in the NDVI range 0.4-0.6. This relationship was plotted in histograms, where the Y-axis showed the frequency of livestock GPS points on a specific landscape variable, and the X-axis, the bin arrays with different intervals. The intervals differ with each landscape variable showing livestock selectivity based on the existence of GPS points in different values of the physical landscape variables.

3.2 Predictive modelling for livestock distribution

3.2.1 Analytical framework

The response surfaces that represent physical landscape variables and GPS point datasets were used to predict the potential distribution of livestock in summer and in winter at three different scales using the same method. The response surfaces (1) slope (2) aspect (3) NDVI (4) TWI were selected as predictors of potential livestock distribution in areas where the livestock distribution is unknown. In this predictive modelling stage, elevation was excluded as a predictive layer because elevation varies in the different catchments and this could cause errors with the potential predicted distribution in the output file. The four response surfaces and the livestock GPS location were loaded into the ArcGIS PAT (ESRI, 2014).

ArcGIS PAT uses point datasets combined with raster layer datasets to generate suitability models based on the input datasets. In this study, the livestock GPS location and the response surfaces that represent the physical landscape variables were used. The results of the analysis done using the Predictive Analysis tool provided visualisations of how different physical landscape variables influence the presence of livestock (further details of how the analysis was done will be explained in the section below).

ArcGIS PAT consists of a *Query generator* which allows the user to select and load the relevant dataset, in this case, the summer and winter GPS point locations with the five response surfaces. Thereafter, the *Query expression editor* appears, which allows the user to select the method on which the predictions should be based; for this study, the methods were based on standard deviation. The result is an output file for the two seasons with the identified areas of potential distribution ranked from highest to the lowest as detailed in the next section (Figure 19).

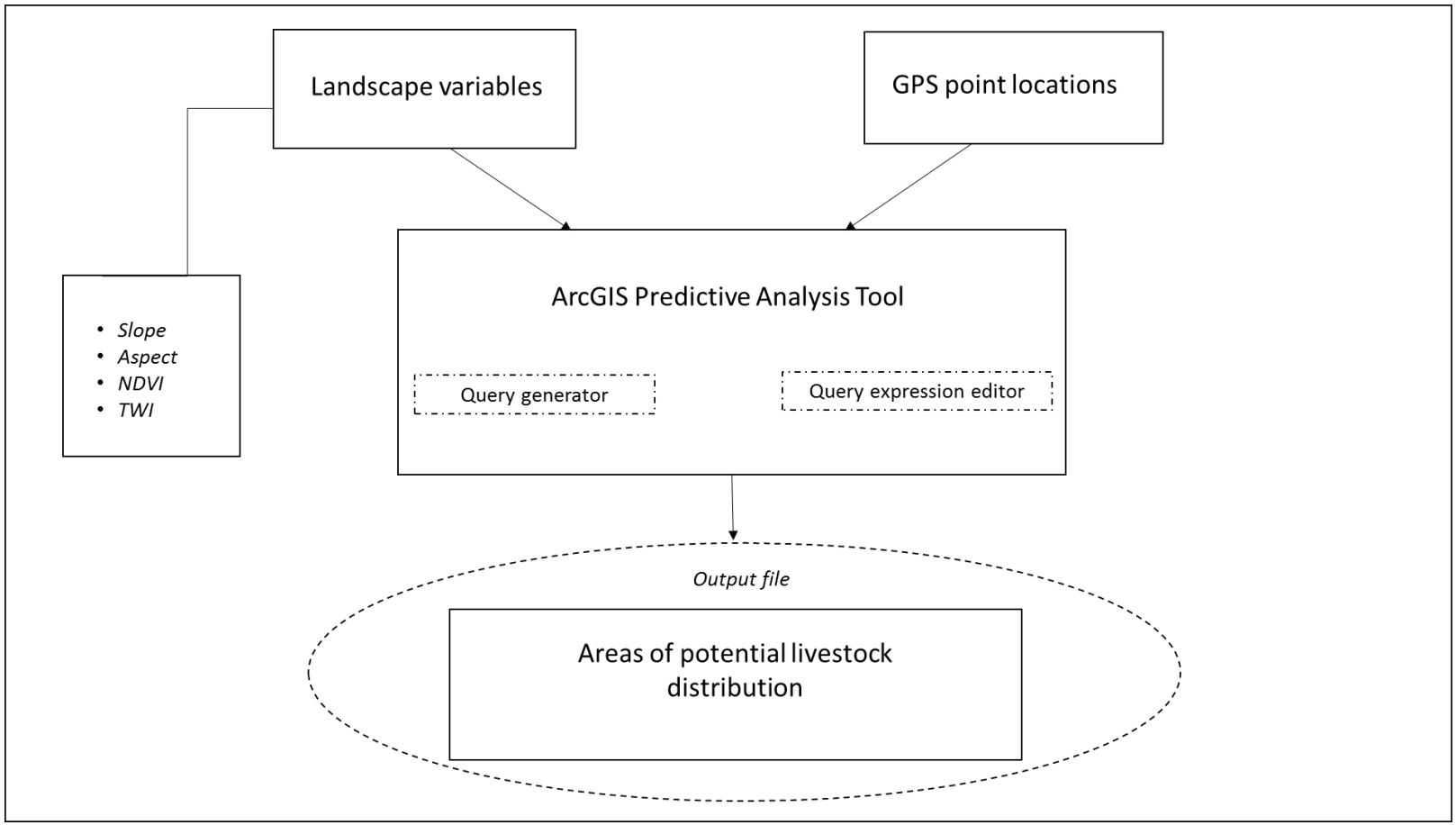

Figure 19: The Predictive Analysis tool (PA tool) is uses raster layers (physical landscape variables) namely slope, aspect, vegetation greenness and water sources (rivers) with the GPS location points to produce a map with areas of livestock potential distribution in both summer 2016 and winter 2017. The tool uses the query generator to extrapolate these points and uses the query expression editor to show ranges of physical landscape variables that are selected by livestock.

3.2.2 Data preparation and analysis for predictive modelling

Data preparation

The predictive modelling of potential livestock distribution was conducted at three different locations: (1) local scale within the study area and immediate surroundings where livestock positions were recorded, (2) quaternary catchment scale for the catchment (T12A) within which livestock locations were recorded, and (3) regional scale within several quaternary catchments (T35A-E) outside of the region where the position data were collected. The data from the GPS point location were used to predict the potential distribution in all three geographic areas in order to validate the model locally and to assess the transportability of the predictive model outside the immediate study area. The relevant datasets were downloaded following the same procedure as the dataset used to determine the livestock distribution in Mgwalana.

Table 4: The dates for Landsat 8 satellite images.

Area	**Summer**	**Winter**
Mgwalana	23 December 2016	19 July 2017
Quaternary catchments T12A	02 February 2017	28 July 2017
Quaternary catchments T35A-E	12 January 2015	28 July 2017

After downloading the dataset, the following steps were conducted for analysis:

1. The different Landsat bands for all the different catchments were combined into one layer; DEM were also combined into one layer using the mosaic tool in ArcGIS. Thus, the Landsat images were merged into a single layer rather than different images of the different locations.
2. Landsat-8 bands were used to calculate NDVI in all three catchments during the summer and winter seasons.
3. SRTM DEM was used to derive slope, aspect and TWI at all three scales.
4. After the calculations of NDVI, elevation, slope aspect and TWI were clipped to fit into the catchments.
5. In the following step, the resultant layers were loaded into the ArcGIS PAT with the GPS point locations.

Data analysis

ArcGIS predictive analysis tool

PAT is an analytic method which enables adaptable analysis within a certain geographic interface (ESRI 2014); the tool was used to visually map outputs of the suitability of the physical landscape variables that influence the distribution of livestock. The areas of potential livestock distribution were identified through suitability modelling using the seasonal livestock distribution data that were used to identify intervals at which the different raster surfaces occur. The tool detects the specific spatial intervals from the raster surfaces based on the existing livestock distribution collected seasonally (Attaway *et al.,* 2016).

The GPS collar dataset (point data) represents the presence of livestock in a geographic area, and these data were used to identify and define parameters for the suitability model. For example, the minimum and maximum values of the intervals of elevation identified from the GPS point distribution data were used to predict potential distribution. A similar process was applied to the different input data layers. By using the *Query Factor Input Table*, the *ArcGIS PAT* generates a *predictive analysis query* by using a set of input data points (GPS collar dataset) and all the raster datasets (the predictive response surface layers).

The predictive analysis uses the equation below:

$Z = (X\ (n\text{=number of point data}):Y_1\text{-}Y_4))$

Z= the final resultant layer from running the model

X= livestock distribution data collected seasonally

Where n is the number of GPS point data and Y_n is the number of different raster response surfaces

In the PAT add-in, the *Query generator* was selected, which opened a pop-up (Appendix 3), the *Analysis Input* option, and the GPS presence data was selected. In the *Factors* option the following were selected as factors that would predict livestock distribution: (1) Elevation, (2) Slope, (3) Aspect (4) Vegetation greenness (5) Surface wetness. The *Query generator*, then analyses the input, producing a table which enables one to select how much of the data should be displayed. The *Query-expression editor* displays all the minimum and maximum threshold intervals from the raster layers that were selected and then the model was run.

Chapter 4: Results

The study aimed to link monitored livestock distribution to physical landscape variables in Mgwalana, and to use the modelled relationship to predict potential livestock distribution in the quaternary catchments T12A and T35A-E. The purpose of this study was to obtain accurate animal location using GPS technology. Using GIS, the GPS location data was combined with selected response surfaces created to represent physical landscape variables and so relate the location with resources on the landscape.

The costs and feasibility of using GPS collars in larger catchments are high; therefore, using GPS location data from a smaller catchment to predict the potential livestock distribution was more feasible. PAT within GIS was used to visually map areas of potential distribution based on the physical landscape variables conditions that were selected by livestock (GPS location data). Similar studies have been conducted using different statistical methods to predict livestock distribution patterns in other areas (Pringle & Landsberg 2004; Chapman *et al.*, 2007; Handcock *et al.*, 2009; Homburger *et al.*, 2015). However, the use of Predictive Analysis Tool has not yet been explored in livestock studies in the Eastern Cape Province. The results presented in this chapter address the aim by the three objectives outlined in Chapter 1.3.

4.1.1 Livestock distribution

This section addresses objective (I): to identify and map livestock distribution in the rangelands of Mgwalana using GPS location data collected during the wet and dry seasons and objective (II): to relate influential physical landscape variables (slope, aspect, elevation, vegetation and water) to livestock distribution in order to identify resource selectivity.

Elevation

During the summer of 2016, livestock spent ~43% of their time in the riparian areas of the nearby rivers where the elevation is between 1300-1320 m (Figure 20). The second most favoured range of elevations was the grasslands, with an elevation between 1320-1340 m, where livestock spent ~28% of the time was between 1320-1340 m. As the elevation increased the presence of livestock decreased, thus areas with elevation 1360-1440 were seldom visited and elevations greater than 1440 m were never visited. In winter 2017, livestock spent most of the time (~41%) in areas with elevation between 1320-1340 m. The second most favoured elevation range was between 1300-1320 m, where livestock spent

~39% of the time. As in summer 2016, livestock presence generally decreased as the elevation increased, which is why in areas with elevation greater than 1440 m, livestock were never found. It also appears that during summer 2016, cattle visited relatively high elevations more often than in winter 2017. Livestock GPS locations mapped on a DEM layer to show the elevation of the Mgwalana rural area (Figure 21), indicate the livestock spent most time was on relatively low elevations near the rivers in both seasons (Figure 22).

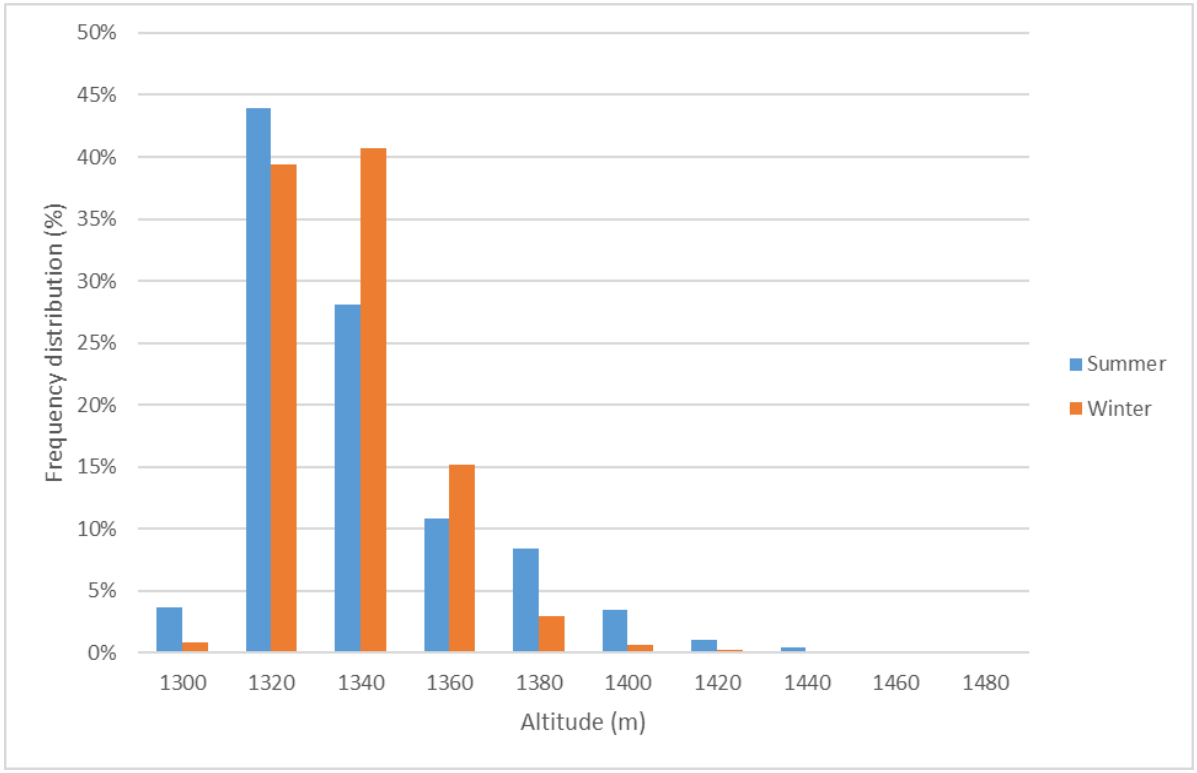

Figure 21: In the study area, the livestock were present within the range of 1300-1440m in both summer 2016 and winter 2017. Generally, livestock spend less time at increased elevations in both summer 2016 and winter 2017.

Summer 2016

Winter 2017

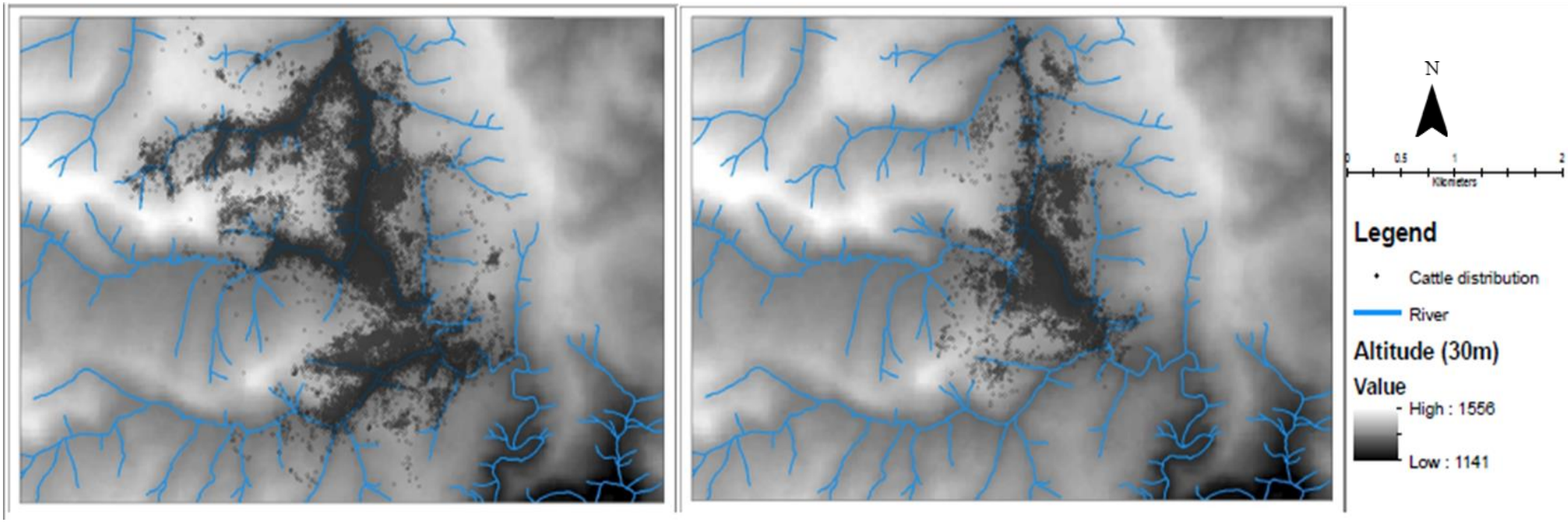

Figure 22: The livestock distribution data gathered using the GPS collars were mapped onto the elevation (m) raster layer for both summer 2016 and winter 2017.

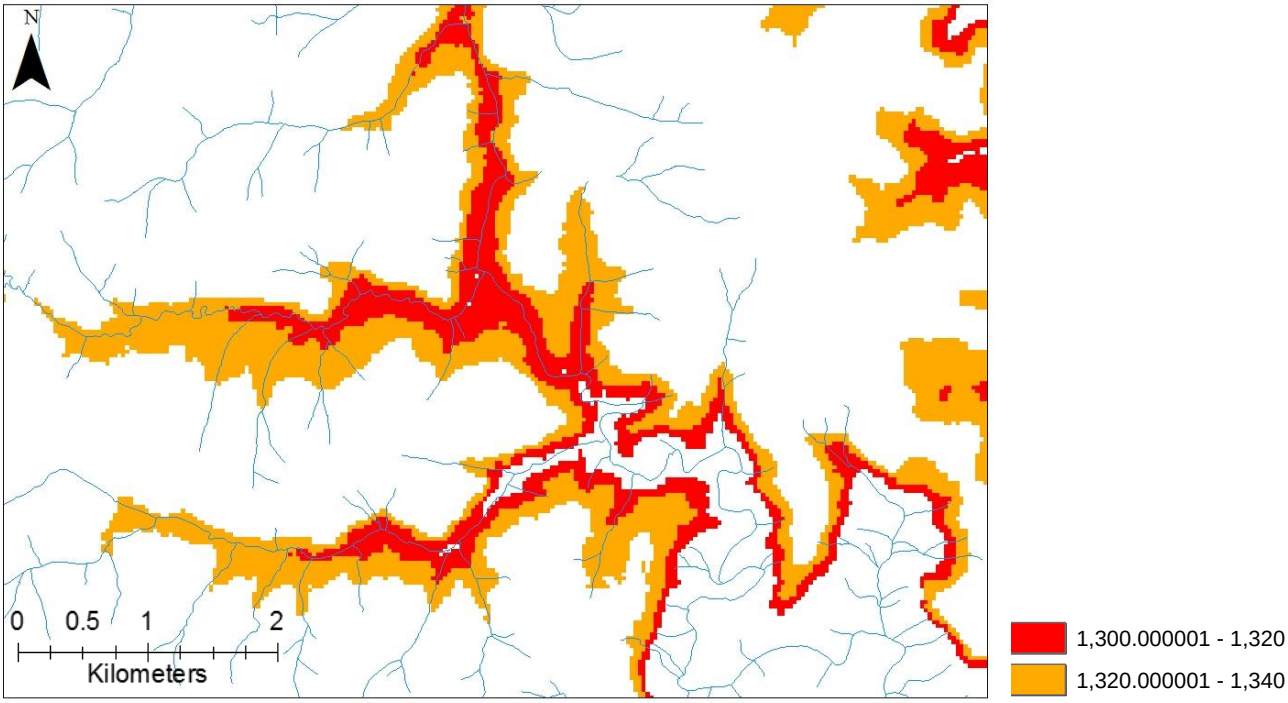

Figure 23: The areas on the landscape with the elevation that livestock mostly spent time in during summer 2016 and winter 2017, these areas include the riparian zones and grasslands that are near the rivers.

Slope

During summer 2016, livestock spent most of the time (49%) on slopes between 0°to 6° (Figure 23), some time on slopes between 6°-12°, but seldom grazed on slopes greater than 12°. Similar to the results for livestock distribution on elevation, the distribution of livestock decreased as the slope increased such that livestock were found in slopes greater than 30° only ~1% of the time (Figure 24). During winter 2017, livestock spent most of the time (~47%) on slopes of between 6°-12°, followed by 39% of the time between slopes of 0°-6°. This pattern was similar to the findings of George *et al.*, (2007) who tracked cattle using GPS, and observed that time spent on the slopes dropped by 50% with an increase of 5° on slope steepness.

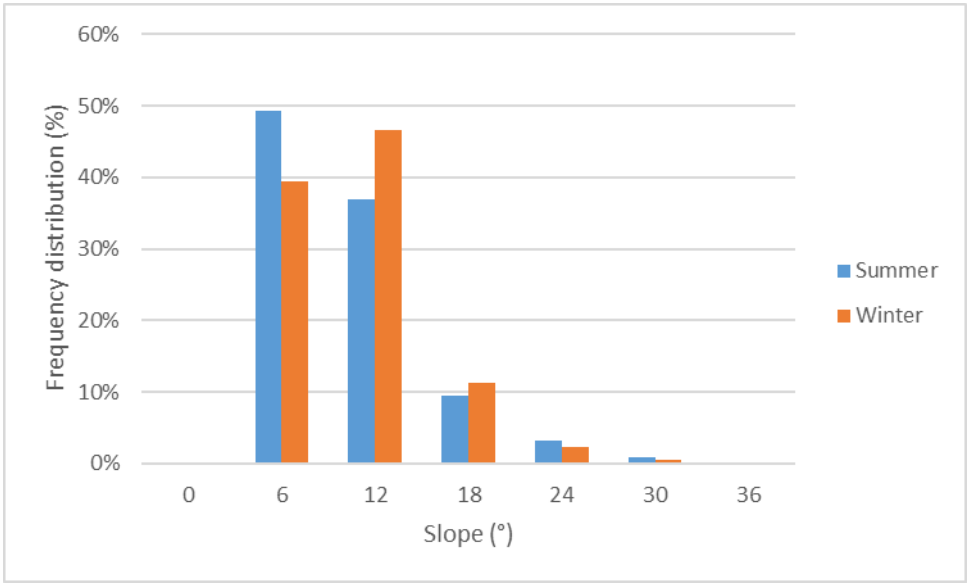

Figure 24: Livestock were mostly found between 6°-12°, a slope covering most of the study area. A few livestock were found between 18°-24°, the fewest on slopes greater than 30°, and on slopes greater than 36°. This pattern was similar in both seasons.

Summer 2016 **Winter 2017**

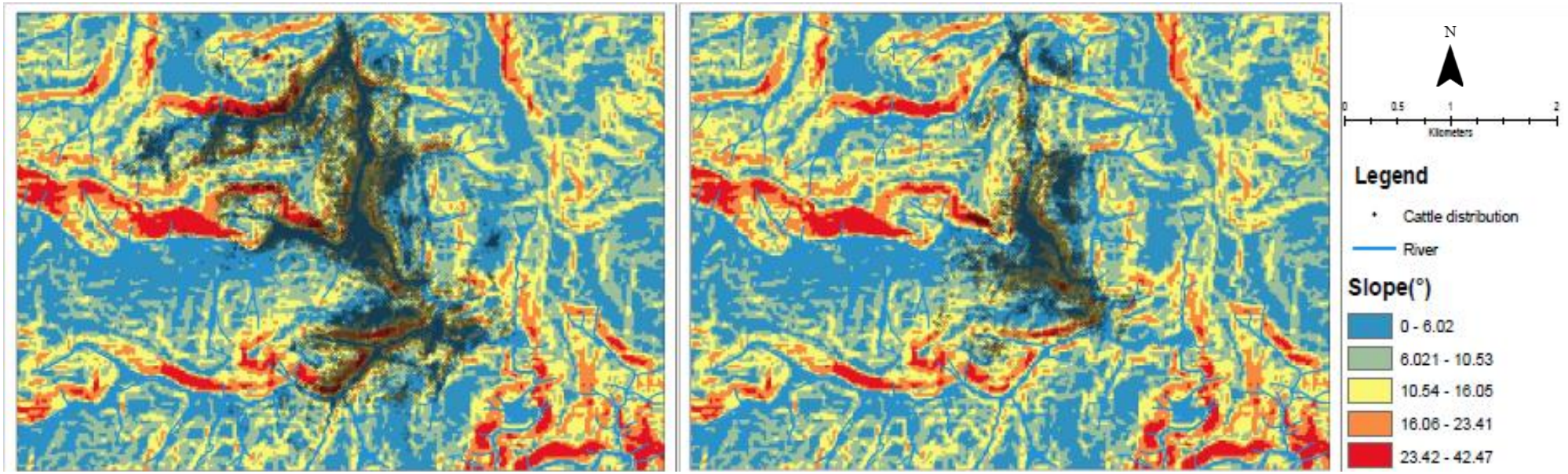

Figure 25: The livestock distribution data gathered using the GPS collars were mapped onto the slope (°) raster layer for both summer 2016 and winter 2017.

Aspect

During summer 2016, livestock spent most of the time (~17%) on the north-east facing slopes, ~15 % of the time on east-facing slopes, and ~14% of the time on north-facing slopes (Figure 25). Livestock spend less time (4% to 7%) in the south-facing, south-east and southwest-facing slopes. In winter 2017, a similar pattern was observed; livestock spent most of their time on north-eastern slopes (~26%), and ~17 % of the time on east-facing and on north-facing slopes. Similar to summer 2016, the south-facing, south-east and south-west slopes were least preferred in winter 2017, as livestock spent ~4% to 7% of the time in these areas. The aspect layer was mapped with the GPS points to visually demonstrate the distribution of livestock in Mgwalana and to show the distribution based on aspect as an influential landscape variable (Figure 26).

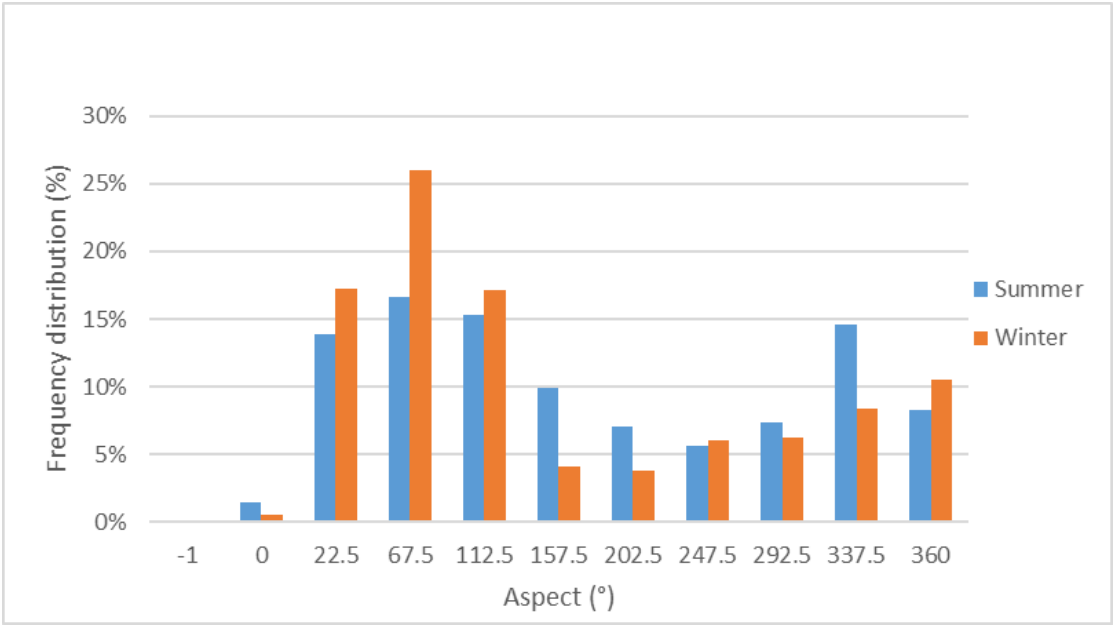

Figure 26: Frequency distribution of livestock on the aspect values in Mgwalana. Generally, livestock seem to be less affected by aspect than by slope and elevation. Even though livestock use the north-facing slopes in both seasons, the pattern is not as marked, nor is the livestock as selective when compared to other physical landscape variables.

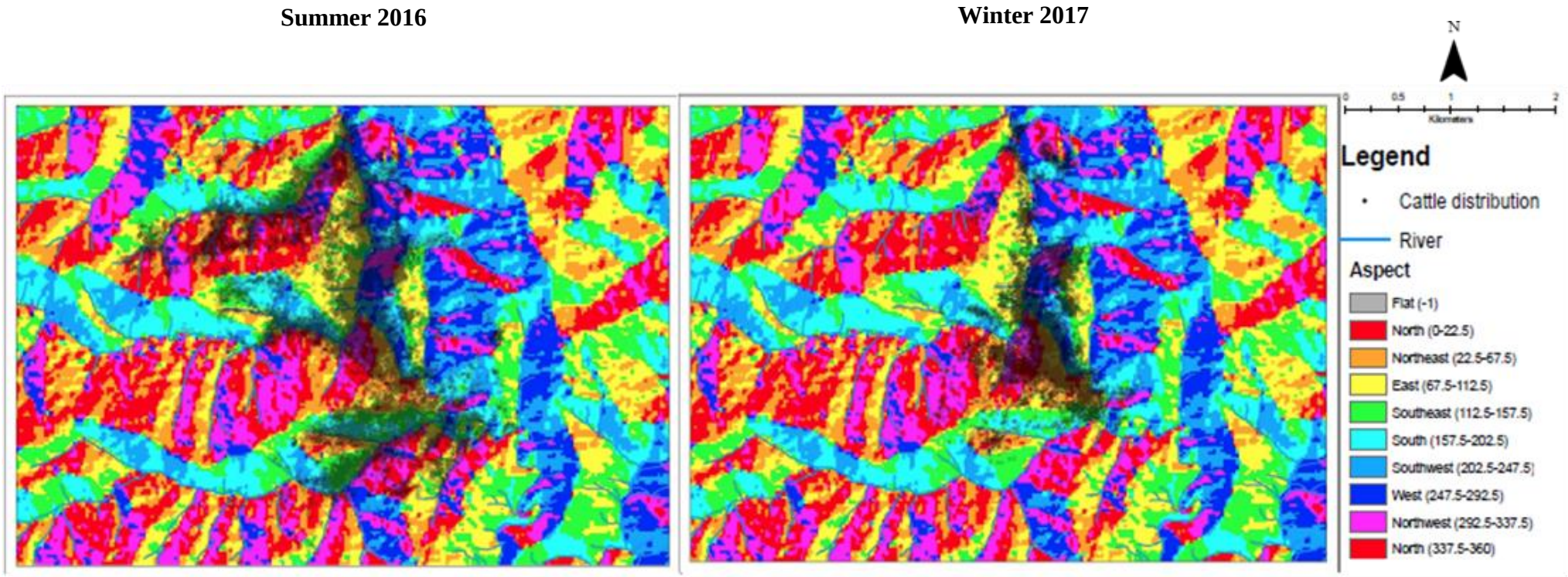

Figure 27: The livestock distribution data gathered using the GPS collars were mapped onto the aspect (°) raster layer for both summer 2016 and winter 2017.

Water

The TWI represents wetness on the surface of the landscape and is defined as: ln(a/tanβ), where a is the local upslope area draining through a certain point per unit contour length, and tanβ is the local slope (Buchanan *et al.*, 2014). TWI is commonly used to quantify topographic control of hydrological processes (Sørensen *et al.*, 2006). The values of TWI represent wetness on the surface of the landscape from least to most with the low values such as TWI of 3 being less wet than to high TWI values such as 21.

In summer 2016 livestock spent most of the time (~76%) on TWI intervals of 6-9, with the second favourable TWI values being 9-12, where livestock spent some time (~18%). Livestock were seldom found in TWI of less than 6 and or greater than TWI of 12 (Figure 27). During winter 2017, livestock spent most time (~82%) on the TWI interval 6-9, seldom spent time (~13%) in TWI interval 9-12 and were never observed in TWI values less than 6 and greater than 18. The GPS location points were mapped with the TWI of Mgwalana to visually show the distribution of livestock in relation to surface on the landscape (Figure 28). Thereafter, based on the intervals defined in (Figure 29) the TWI of Mgwalana was reclassified to relate the TWI to what was on the landscape (Figure).

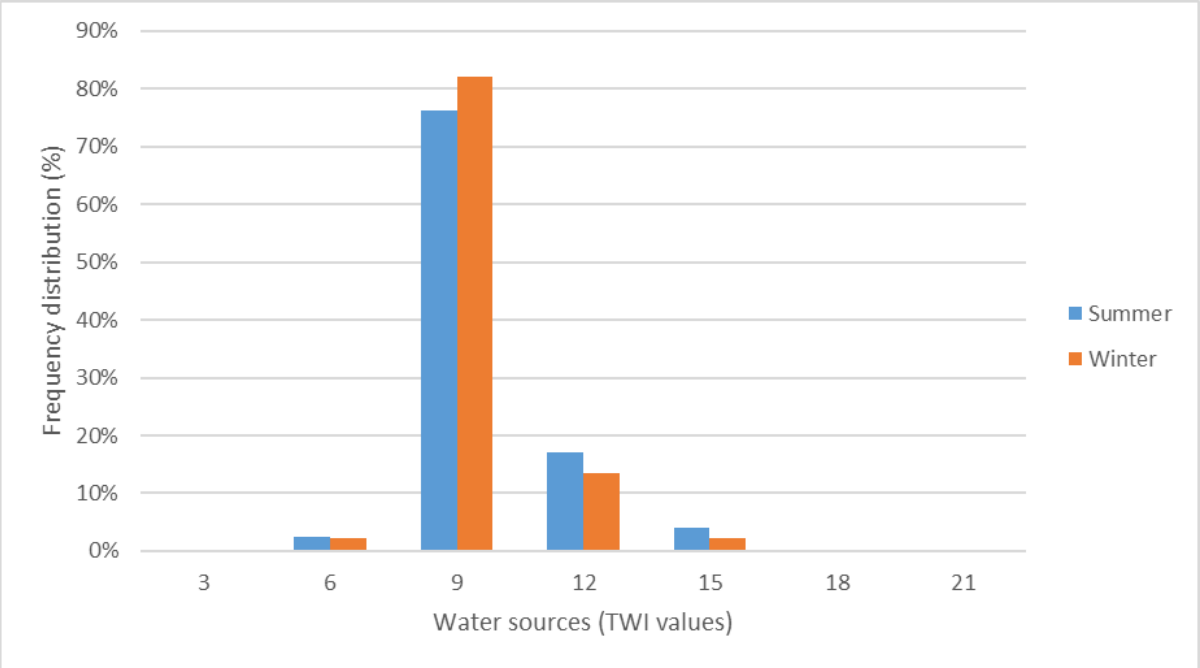

Figure 28: Livestock were mostly found in areas with TWI of between 6- 9 in both summer 2016 and winter 2017. These areas are near the river channel. The livestock were sometimes found between TWI of 9- 12 in both seasons but were never found in areas of TWI greater than 18.

Summer 2016

Winter 2017

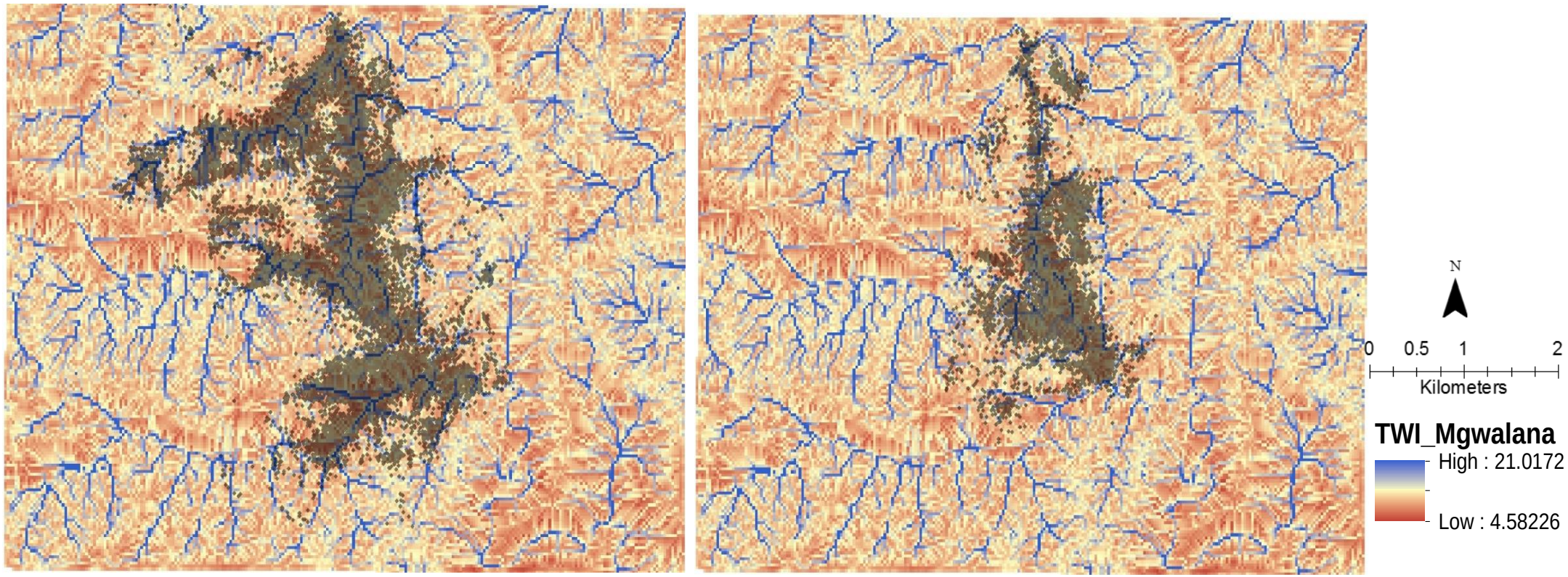

Figure 29: Livestock distribution data gathered using the GPS collars were mapped onto the Topographical Wetness Index (TWI) raster layer for both summer

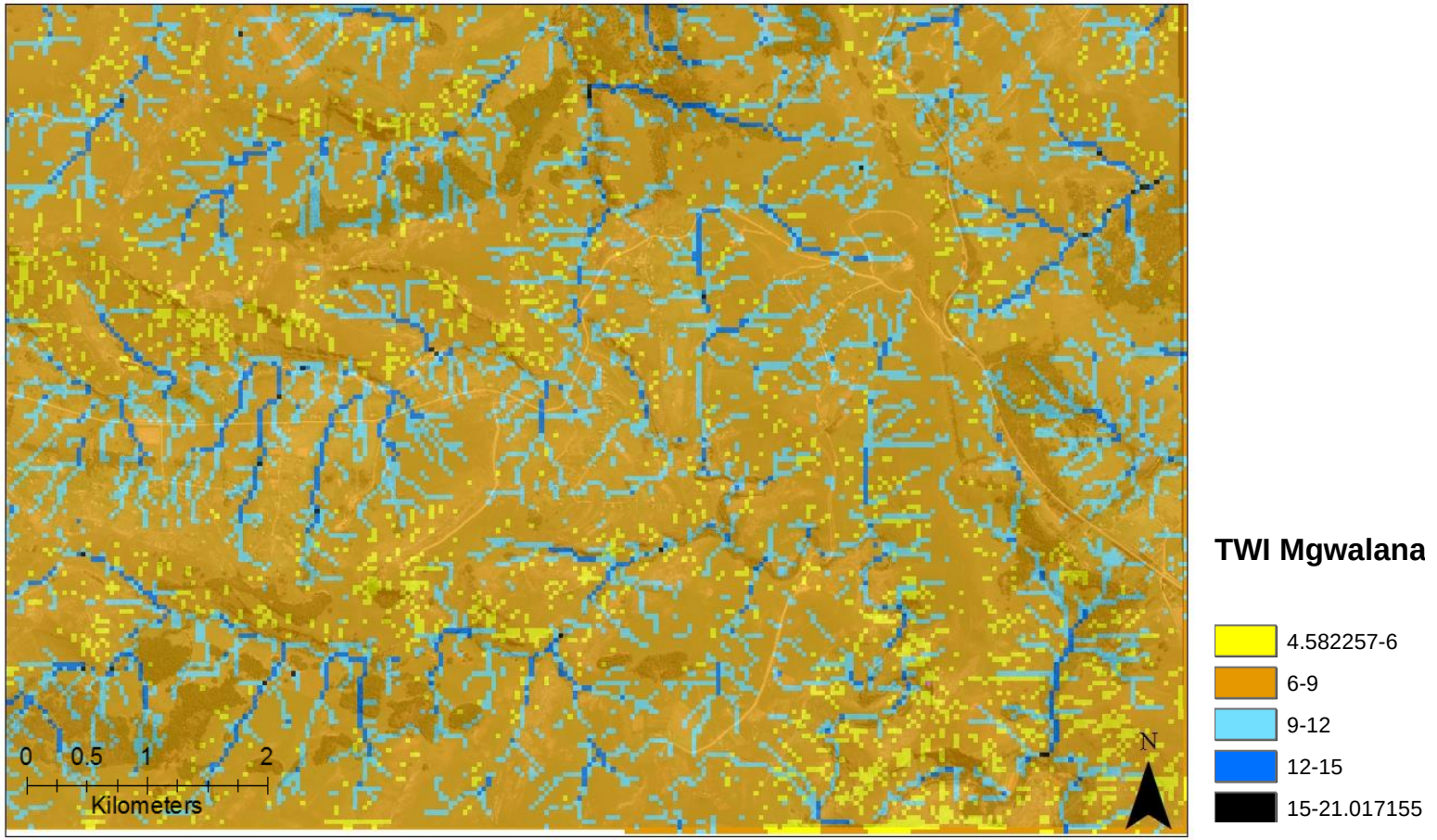

Figure 30: The TWI of Mgwalana, 4.582257-6 were mostly found in south-west facing slopes and on the south eastern parts of the areas while 9-15 were identified as rivers and wetlands and greater than 15 were depressions on the landscape since their slopes were relatively lower than the surroundings.

Vegetation

Vegetation greenness indicates the presence of plants whether its forests, shrubs or grass. It is expected that in the rainy season (which is usually summer in Eastern Cape), there is more vegetation greenness as opposed to the dry season, which is usually in winter. Not so surprisingly, these typical conditions were identified using the NDVI calculated from the landsat-8 band 4 and 5.

In summer 2016, livestock spent most of their time (~20%) in NDVI of 0.18-0.22, however as the NDVI increased the time spent diminished, as NDVI intervals of 0.30-0.32 show less than 2% presence of livestock (Figure 30). The highest NDVI were usually the forests, therefore livestock generally avoid spending much time in these areas (Figure 31). During winter 2017, livestock spent most of the time (~37%) in areas with NDVI of 0.16-0.18. The second most favoured area was on NDVI between 0.14-0.16 where livestock spent some time (~24%), followed by NDVI of between 0.18-0.20 where livestock spent ~21% of the time. Livestock seldom spent time on NDVI greater than 0.22, or on NDVI values less than 0.14. The results also show that during winter 2017, livestock selected grazing on NDVI values between 0.16-0.18 more often this selectivity was not as evident in summer 2016.

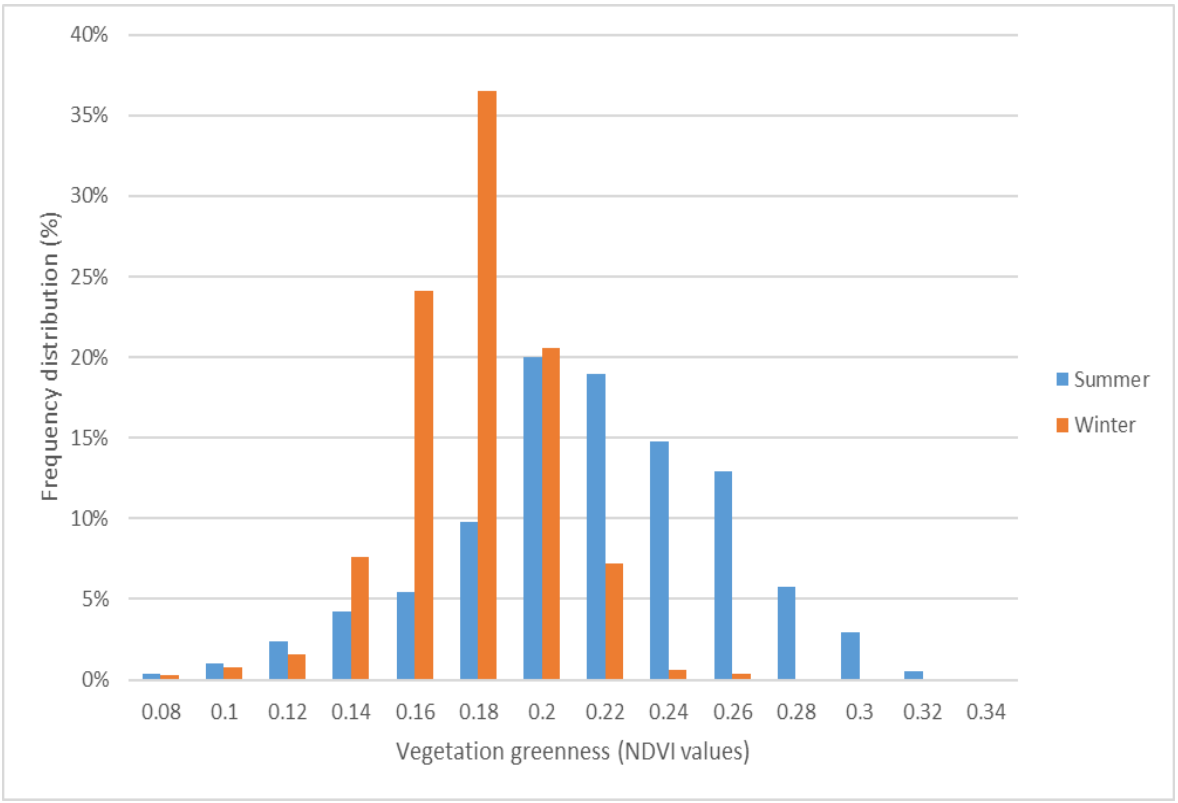

Figure 31: During summer 2016, livestock were generally found most often between 0.18-0.22. During winter 2017 livestock spent most of the time on vegetation with NDVI values between 0.16 and 0.18; they were sometimes found between 0.14-0.16 and 0.18-0.20.

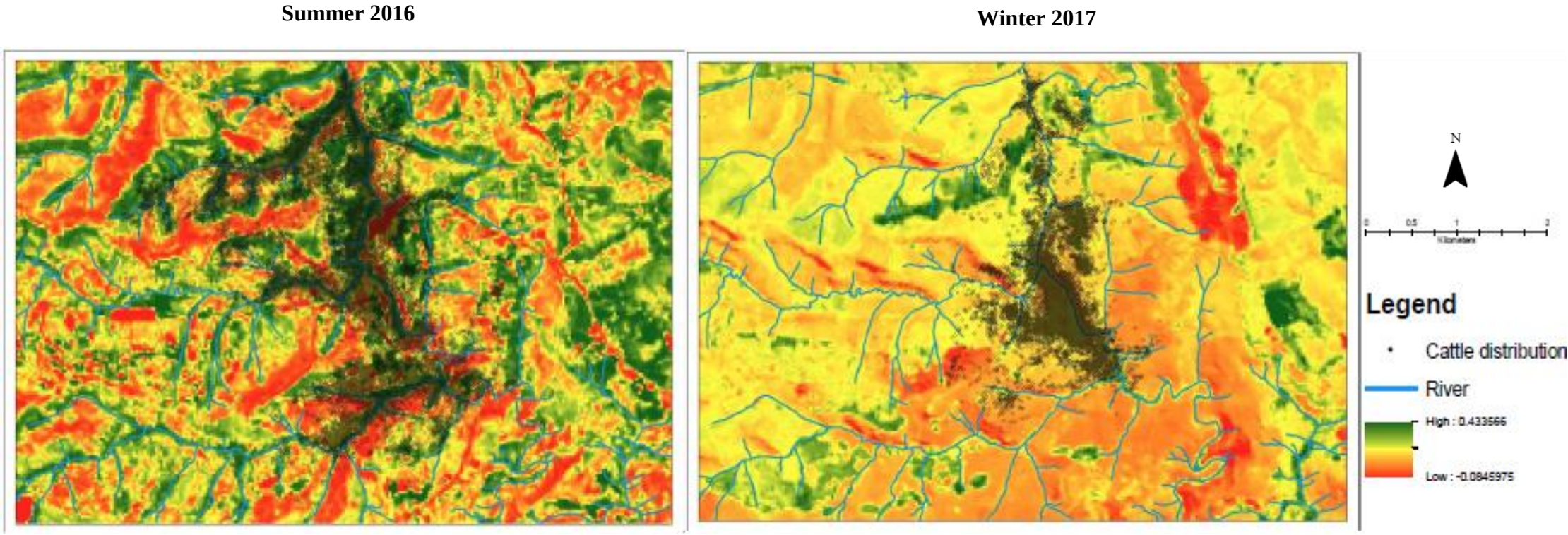

Figure 32: Livestock distribution data gathered using the GPS collars were mapped onto the Normalised Difference Vegetation Index (NDVI) raster layer for both summer 2016 and winter 2017.

4.1.2 Predictive modelling of livestock distribution using response surfaces

The results in this section address objective (III): to use a desktop method that will combine the measured physical landscape variables and the GPS location data to predict areas of potential livestock distribution in Mgwalana, T12 A and T35A-E. This was achieved by using PAT to combine GPS point distribution data with response surfaces that represent physical landscape variables in order to identify areas of potential distribution in the study site and in another catchment (quaternary catchment T35E).

Summer 2016

The *Query expression editor* in the PAT generates the ranges at which the GPS point locations occur on the different landscape variables, for both seasons, and the editor provides the range values selected by livestock in each landscape variable e.g. slope, aspect. The produced output raster layer for summer 2016 (Figure 32) indicates the potential distribution of livestock from areas with potentially no livestock presence, to areas with the highest potential distribution. The combination of the areas near homesteads, areas on the north-facing slopes and the wetness on surface of the landscape seem to have moderate to high livestock potential distribution. On the northern (east and west) facing slopes, the areas between rivers have moderate to high potential distribution as well. Table 5 shows the pixels and the percentages in each class; the class being the potential distribution from no potential distribution (Class 0) to the highest potential distribution (Class 5). The areas that are most likely to have a moderate to the highest livestock potential distribution should be given attention in rangeland management strategies as they can be prone to degradation. The validation dataset (25% of the GPS data for summer 2016) was used to test the accuracy of the predictions, and to indicate in which classes the GPS point location data would fit (Table 5).

Statistical analysis

A chi-squared test was carried out to test whether there was a significant difference between the expected (the predictive map with classes 0-5) and the observed (the 25% validation point dataset). The chi-squared test was done using the proportional adjustments of the expected and the observed. For summer 2016 the chi-square value=0.5555943, a value close to zero meaning that the observed fits the expected well. The p value=0.989946 providing the confidence to accept the null hypothesis that there is no significant difference between the observed and the expected (Figure 33).

Predicted potential distribution for summer 2016

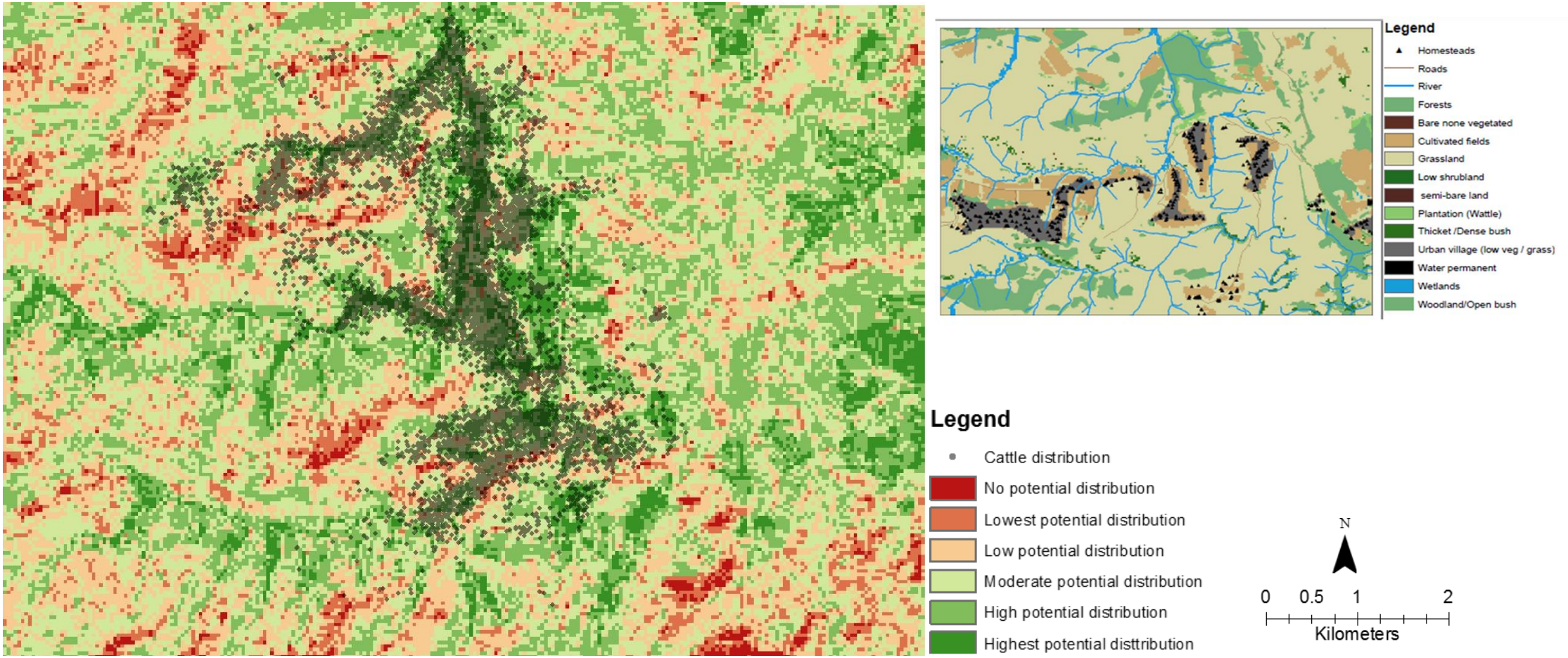

Figure 33: Map of areas of potential distribution of livestock from no potential distribution (red) to the highest potential distribution (green), mapped with the model validation dataset for summer 2016. Areas that have highest distribution of livestock are near homesteads and along the rivers; areas of no potential distribution are relatively few patches on the landscape.

Table 5: Potential distribution ranked from the lowest to the highest; number of pixels within each class, and the number of validation points existing within those ranks for summer 2016. Class 3 (moderate potential distribution) shows that livestock will be within this class 34.31% of the time. The highest (%) of validation points show selectivity of class 4.

Potential distribution ranked from low to high	No. of pixels in each class (0-5)	Percentage of predicted classes	No. of validation points within potential distribution ranks	Percentage of validation points on predicted distribution
0= no potential distribution	730	1.53%	28	0.17%
1= lowest potential distribution	3903	8.20%	402	2.44%
2=low potential distribution	11414	23.98%	1993	12.09%
3=moderate potential distribution	16332	34.31%	4610	27.97%
4=high potential distribution	12101	25.42%	5699	34.58%
5=highest potential distribution	3124	6.56%	3750	22.75%

Table 6: A chi-square test was used to test if there was a difference between the expected (predictive classes) and the observed (Validation points). The p value= 0.989946 (accept the null hypothesis) there is no difference between the expected and the observed.

Case	Observed vs. Expected Frequencies (Spreadsheet4) Chi-Square = .5555943 df = 5 p = .989946 observed OS	expected ES	O - E	(O-E)**2 /E
C: 1	0.001699	0.015335	-0.013636	0.012125
C: 2	0.024390	0.081989	-0.057599	0.040464
C: 3	0.120920	0.239770	-0.118850	0.058912
C: 4	0.279699	0.343080	-0.063381	0.011709
C: 5	0.345771	0.254201	0.091570	0.032986
C: 6	0.227521	0.065625	0.161896	0.399398
Sum	1.000000	1.000000	-0.000000	0.555594

Winter 2017

The same procedure used in summer 2016 was used in winter 2017 to predict the potential distribution of livestock by using GPS point location data and the response surfaces in PAT. The predicted potential livestock distribution was determined in classes from areas that were likely to have no livestock distribution to areas with the highest potential distribution (Figure 34). Moderate to high potential distribution occurred in areas near the homesteads, near the rivers; and on the north facing slopes. Areas with low potential livestock distribution were in areas with high elevations, low and high NDVI values, low and high TWI values, steep slopes and south-facing slopes. The produced predicted potential livestock distribution was in a range of classes where 0 = no potential distribution and 5 = highest potential distribution (Table 6). The number of pixels per class were counted and the percentages were calculated to determine how much space (in percentage) each class presented, relative to the total study area. Thereafter, the validation dataset (25% of the GPS point data) was used to test the accuracy of the predicted potential livestock distribution and to also determine how much of the GPS point data was in each class (Table 6).

Statistical analysis

A chi-squared test was done to test whether there was a significant difference between the expected (the predictive map with classes 0-5) and the observed (the 25% validation point dataset). The chi-squared test was carried out using the proportional adjustments of the

expected and the observed. For winter 2017, the chi-square value=0.9091587: this value is close to zero and means that the observed fits the expected well. The p value=0.969555, which provides the confidence to accept the null hypothesis that there is no significant difference between the observed and the expected.

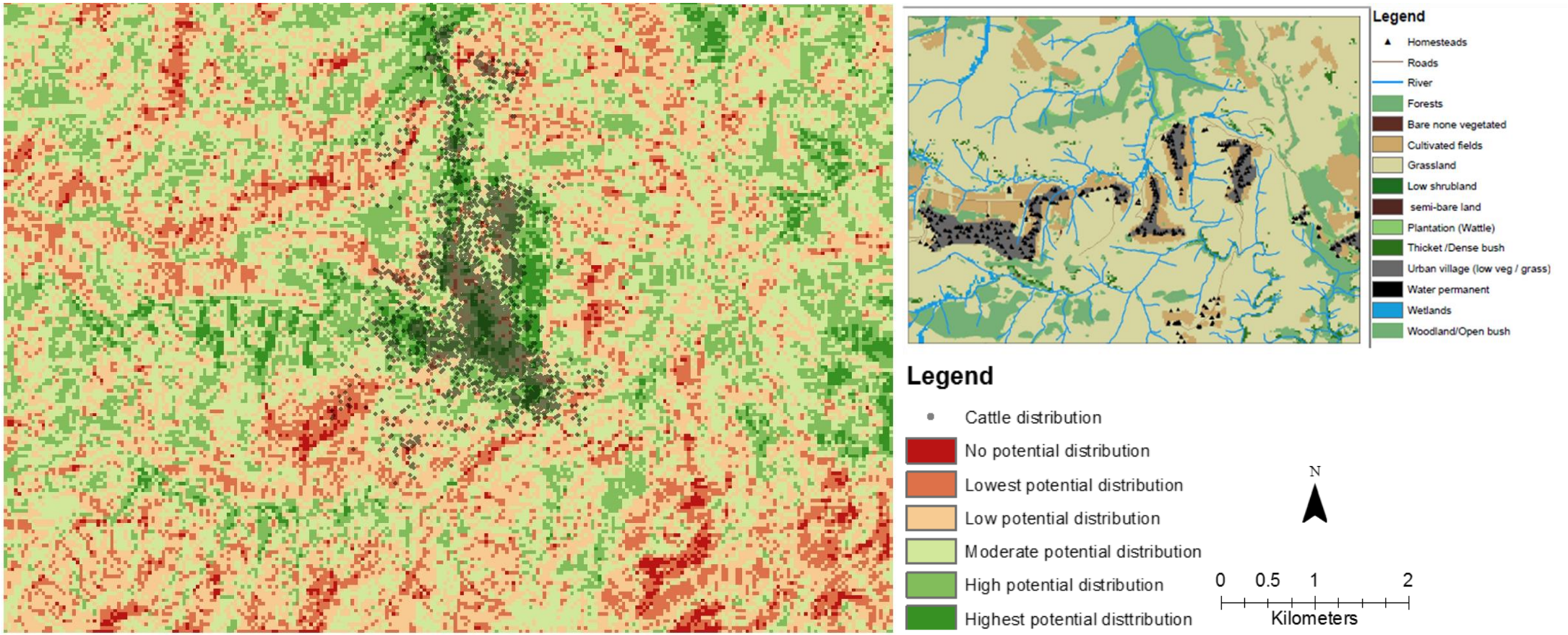

Figure 34: Areas of potential distribution of livestock from no potential distribution (red) to the highest potential distribution (green), the mapped with the model validation dataset for winter 2017. The areas with the highest distribution of livestock are near homesteads and along the rivers; areas of no potential distribution are relatively higher

Table 7: Potential distribution is ranked from the lowest to the highest, the number of pixels within each class and the number of validation points existing within those ranks for winter 2017. Class 3 (moderate potential distribution) shows that 33.94% of the time, livestock will be within this class. The highest (%) of validation points show selectivity of class 4 for winter 2017, a similar pattern to that of summer 2016.

Potential distribution ranked from low to high	No. of pixels in each class (0-5)	Percentage of predicted classes	No. of validation points	Percentage of validation points on predicted distribution
0=no potential distribution	825	1.73%	11	0.14%
1=lowest potential distribution	6126	12.87%	194	2.48%
2=low potential distribution	14549	30.56%	893	11.42%
3=moderate potential distribution	16157	33.94%	2560	32.74%
4=high potential distribution	8540	17.94%	3030	38.75%
5=highest potential distribution	1407	2.96%	1132	14.48%

Table 8: A chi-square test was used to for differences between the expected (predictive classes) and the observed (validation points). The p value= 0.96555 (accept the null hypothesis) shows there is no difference between the expected and the observed. The chi-square value=0.9091587 shows that the observed fits the expected well

Case	Observed vs. Expected Frequencies (Spreadsheet4) Chi-Square = .9091587 df = 5 p = .969555 observed OW	expected EW	O - E	(O-E)**2 /E
C: 1	0.001407	0.017330	-0.015924	0.014631
C: 2	0.024808	0.128687	-0.103878	0.083853
C: 3	0.114194	0.305626	-0.191431	0.119905
C: 4	0.327366	0.339404	-0.012039	0.000427
C: 5	0.387468	0.179397	0.208071	0.241329
C: 6	0.144757	0.029556	0.115201	0.449014
Sum	1.000000	1.000000	0.000000	0.909159

T12A and T35A-E

The PAT was used to predict potential distribution in quaternary catchments T12A and T35A-E, and the process was carried out using the response surfaces (slope, aspect, TWI and NDVI). Elevation was not appropriate to include in quaternary catchments as it varies and can underestimate or overestimate livestock potential distribution. The advantage of using PAT was being able to use the GPS point location data acquired from Mgwalana in summer 2016 and winter 2017, in order to predict potential livestock distribution in quaternary catchments T12A and T35 A-E (Figures 34, 35, 36, 37).

The predicted potential livestock distribution for summer in T12A is classed from areas with no potential distribution to areas with the highest potential distribution. The northern parts of quaternary catchment T12A appear to have more areas with higher potential livestock distribution (green) than to the southern parts of the catchment (Figure 34). For winter, areas with the highest potential distribution (green) diminish and moderate to high potential distribution increase (yellow) (Figure 35). Table 7 shows the classes from areas with no potential distribution to areas with the highest potential distribution. The results show that areas with the class = moderate potential distribution (~34%) and class =high potential distribution (~32%) dominate. Areas with the highest livestock potential form only 13% of quaternary catchment T12A.

A similar approach was used with the quaternary catchments T35A-E. The GPS location data recorded for summer 2016 and winter 2017 in Mgwalana were used with response surfaces (slope, aspect, TWI and NDVI) to predict potential livestock distribution in quaternary

catchment T35A-E for both seasons (Figure 36 and 37). The potential livestock distribution map shows that summer has the highest potential livestock distribution (green), mostly the central quaternary catchment T35D and there are no potential distribution areas dominant in T35A, T35B, and T35E. However, in winter, areas with high potential distribution are fewer than in summer, and winter has more no ‘potential distribution areas’ by just ~1% (Table 8).

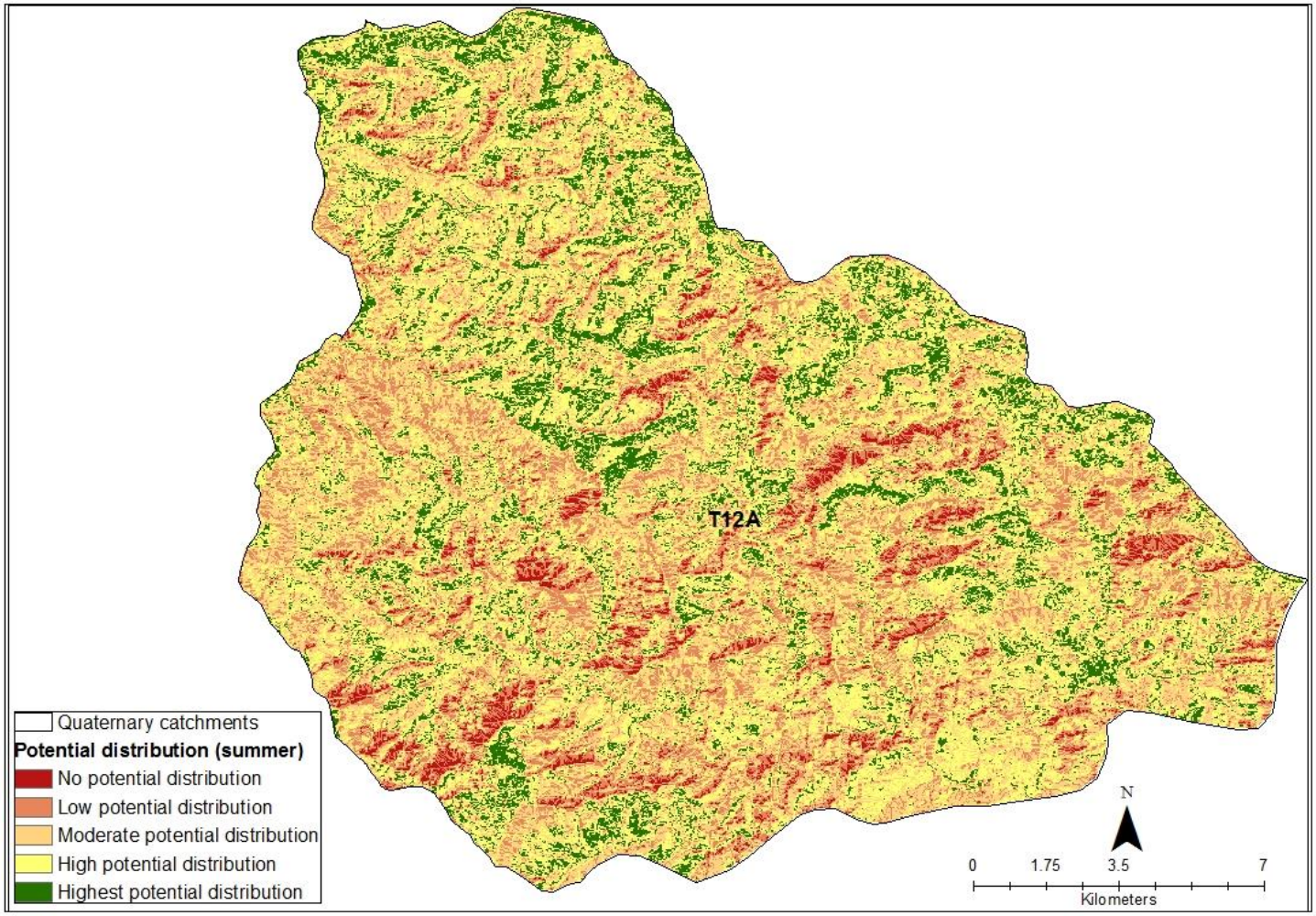

Figure 35: Livestock potential distribution in quaternary catchment T12A generated using GPS point location from Mgwalana in summer 2016.

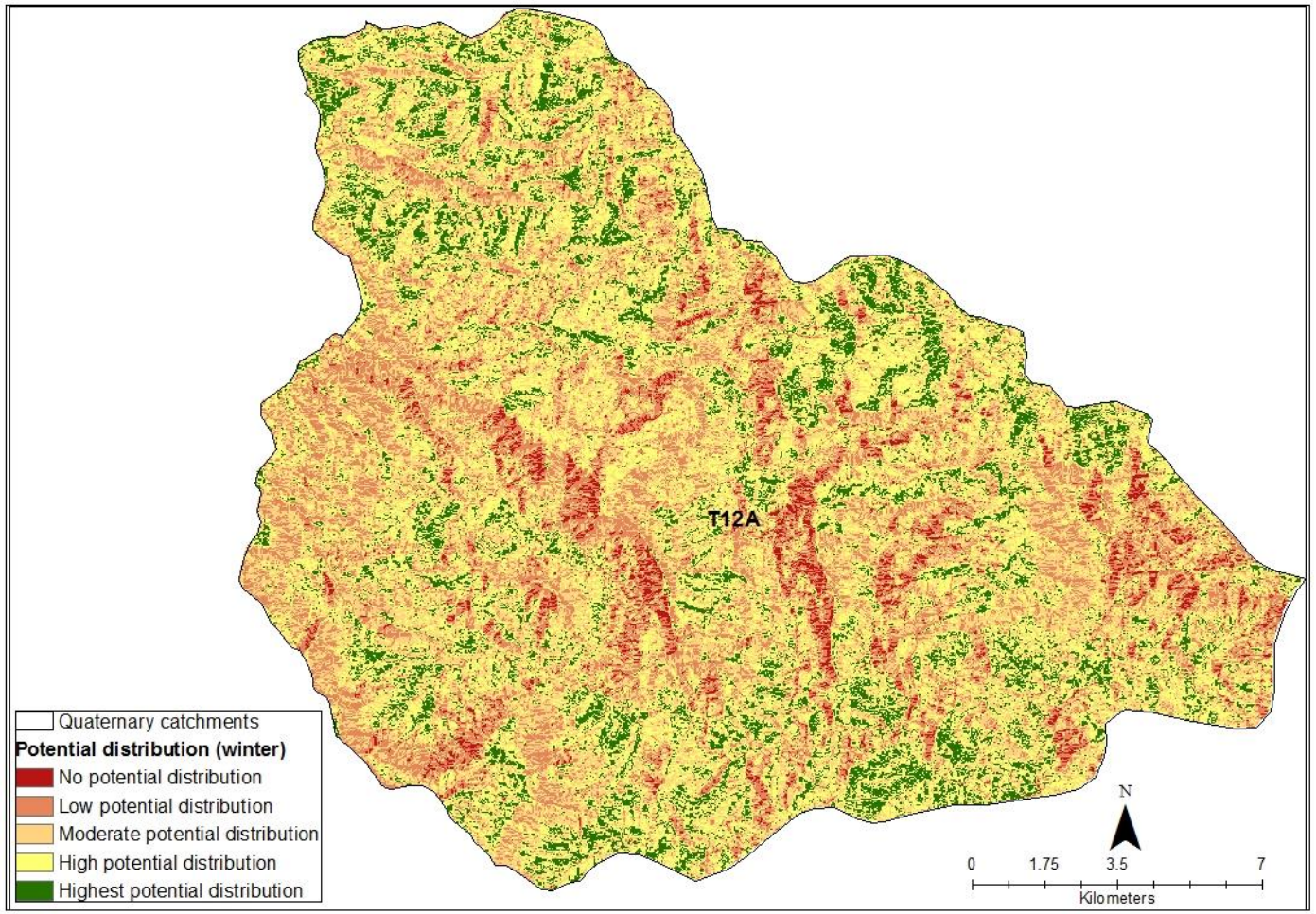

Figure 36: Potential livestock distribution in quaternary catchment T12A generated using GPS point location data from Mgwalana in winter 2016.

Table 9: Predicted livestock potential distribution in T12A in summer and winter using GPS point location data from Mgwalana in summer 2016 ad winter 2017.

Potential livestock distribution in T12A in summer and winter TOTAL PIXEL COUNT FOR CATCHMENT T12A: 333 897				
Livestock potential distribution	Number of pixel cells (summer)	Percentage	Number of pixel cells (winter)	Percentage
No potential distribution	12861	4%	10958	3%
Low potential distribution	58219	17%	64663	19%
Moderate potential distribution	113482	34%	114652	34%
High potential distribution	105197	32%	101842	31%
Highest potential distribution	44138	13%	41782	13%

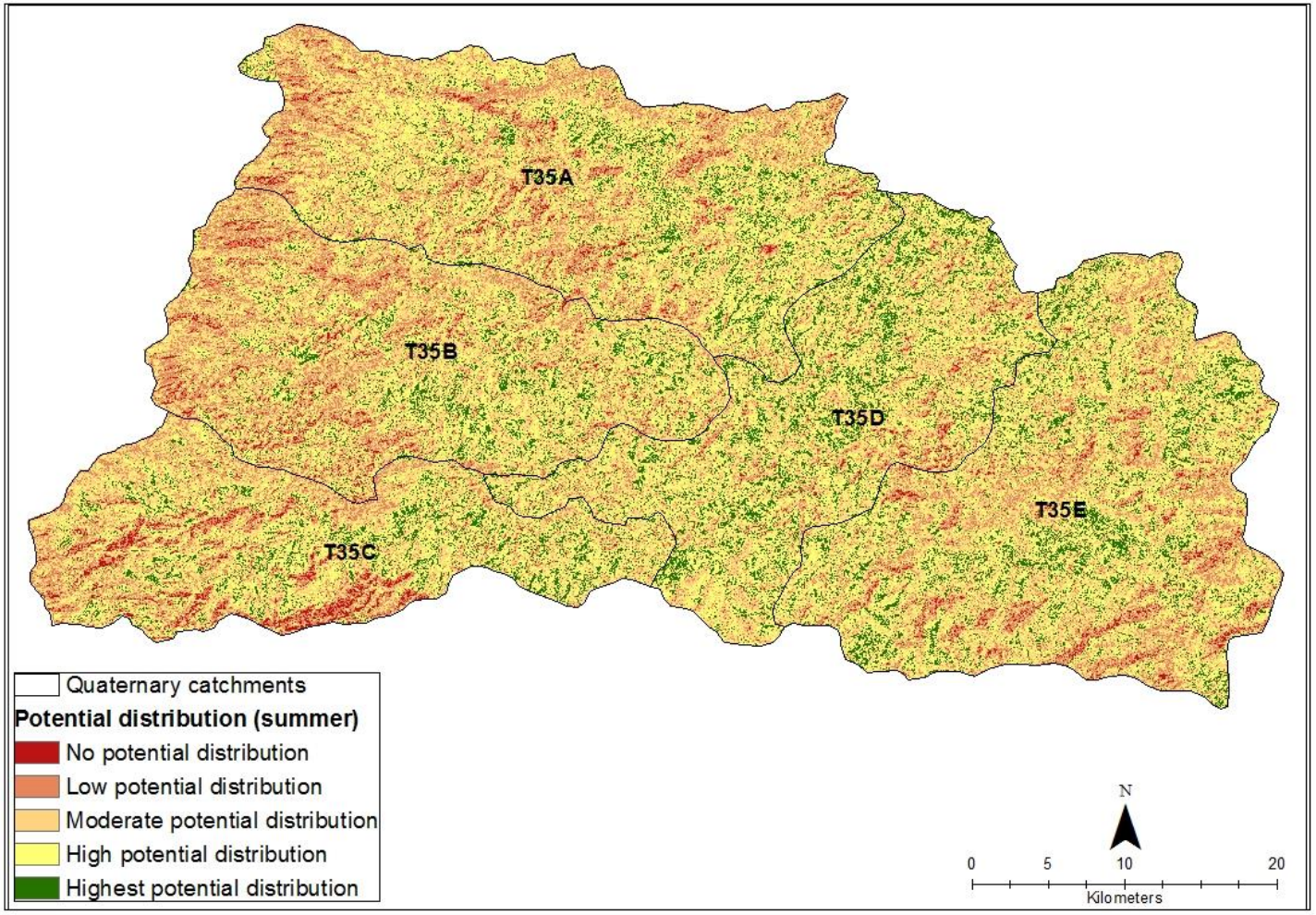

Figure 37: livestock potential distribution in quaternary catchments T35A-E for summer generated from GPS point location data collected in Mgwalana in summer 2016 and winter 2017 together with the response surfaces.

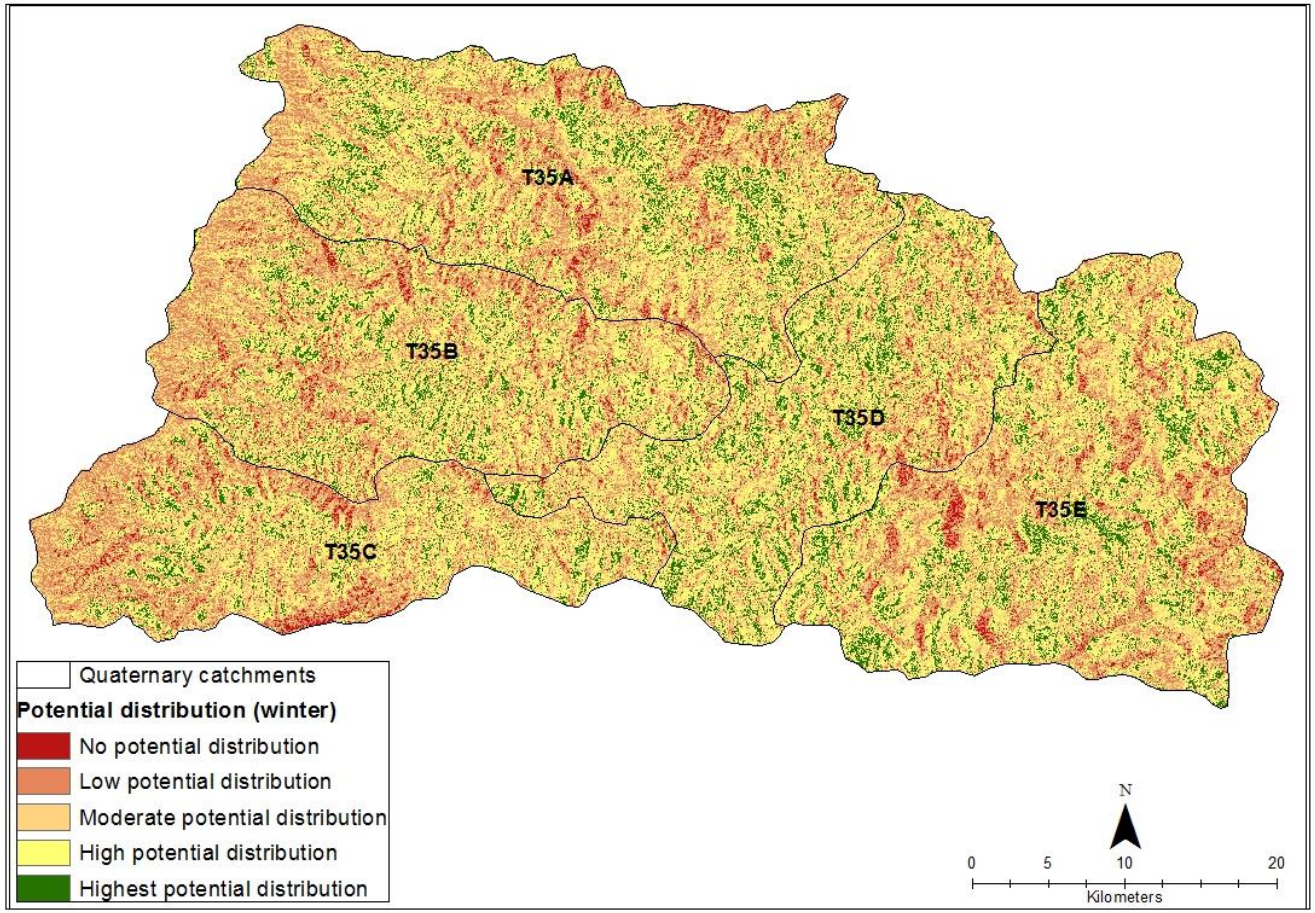

Figure 38: Potential livestock distribution in T35A-E generated from GPS point location data collected in Mgwalana in summer 2016 and winter 2017 with the response surfaces of the quaternary catchments.

Table 10: The livestock potential distribution in quaternary catchment T35A-E generated from GPS location data collected from Mgwalana in summer 2016 and winter 2017.

Livestock potential distribution in T35A-E in summer and winter TOTAL PIXEL COUNT FOR CATCHMENT T35A-E: 2 750 609				
Livestock potential distribution	Number of cells (summer)	Percentage	Number of cells (winter)	percentage
No potential distribution	92510	3%	104124	4%
Low potential distribution	483049	18%	568972	21%
Moderate potential distribution	960863	35%	961545	35%
High potential distribution	884448	32%	805256	29%
Highest potential distribution	329739	12%	310712	11%

Chapter 5: Discussion and conclusion

5.1 Discussion

The study aimed to link monitored livestock distribution to physical landscape variables in Mgwalana, and to use the modelled relationship to predict potential livestock distribution in quaternary catchment T12A and T35A-E. The physical landscape variables selected were slope, aspect, elevation, topographical wetness and vegetation greenness, because they influence livestock distribution (Chapter 1). The GPS point location data collected during summer 2016 and winter 2017 from the monitored livestock was combined with the physical landscape variables to predict potential distribution in areas where actual distribution is unknown. For this study, the areas were quaternary catchment T12A and T35A-E. In this chapter, the results from (1) linking livestock distribution to physical landscape variables in Mgwalana to determine resource selectivity and (2) the predictive modelling of livestock distribution are discussed to explain the findings.

Understanding livestock distribution patterns is important to range management, particularly in communal lands as they are a common resource with access to all, but are minimally managed (Kotzé *et al.,* 2013). This study has used GPS location and physical landscape variables to identify areas that are hotspots of maximum use. As indicators of change in range condition and management, they will be first visible in areas of maximum use (Lange 1969; Sanderson *et al.,* 2010). In attempt to address the issue of rangeland degradation the study identified landscape preference in the wet and dry seasons.

Water sources

The TWI was used to represent areas with wetness from the least to the highest; the numbers have no specific meaning, they merely represent areas of wetness from low to high. Based on the literature, it is expected that in semi-arid regions, livestock focus their activities near water sources, which can vary from season to season depending on animal water requirements and water availability. In summer 2016 and in winter 2017, livestock selected mostly the TWI within the same range. Table 9 shows the TWI values and the livestock selection within the TWI intervals.

Table 11: Integration of physical landscape variables classified by TWI values and the corresponding physical landscape variables, ranked by the frequency of livestock visits within the intervals and the reasoning behind their selections.

Ranks based on livestock frequent visits	**TWI value intervals**	**Interpretation based on physical landscape variables and land cover**
1	6-9	The TWI values were the areas classified as grasslands on the land cover map. The grasslands covered most of the landscape.
2	9-12	The areas within this interval were near the rivers and in some parts, these were seasonal wetlands on the land-use maps.
3	12-15	The areas within this interval were classified as rivers. Their NDVI values are higher than the surroundings, due to the riparian vegetation.
4	4.58-6	These areas are also near the rivers; however, they are on south, south-east, south west and west-facing slopes.
5	15-21.02	These areas have the highest wetness. They were identified as depression zones as their slope values were close to zero and the surrounding slope values were higher.

Rank 1 in Table 9, shows that livestock spent most of the time on the grasslands near the river, indicating that livestock were either grazing, resting or ruminating frequently rather than visiting water sources. Also, the open-space grasslands cover more of the area than the rest of the other features such as water, forests and homesteads (see Chapter 3.1.2 land cover map). Rank 2 is classified as wetlands on the land cover map; these areas are attractive to

livestock as they have a higher NDVI value than the nearby areas. The areas within rank 3 were identified as the rivers, the livestock use the rivers for drinking water and keeping cool in the heat. The NDVI values were also high in these areas which attract livestock in terms of grazing material. These findings are similar to those of Kotzé *et al.,* (2013) who compared grazing gradients (from water points moving away) in communal lands and commercial farms of Kuruman (arid savanna) in the Northern Cape Province. They found that water sources and availability are one of the main influences of livestock distribution, and the highest number of animal activities occur within these areas. Rank 4 includes areas that were also relatively close to the rivers but were on southern facing slopes that livestock avoid because they are cooler and have forage material that is not as palatable than on the northern facing slopes that receive more solar radiation. Rank 5 had the highest wetness but was the least visited by the livestock, probably because, based on slope, the areas were identified as depressions on the landscape. These depressions could be depressional wetlands which can supply water and forage for the livestock, but because they are relatively small in area compared to the rest of the landscape, they might not be as important to livestock. This hypothesis would need testing in the field since Teuber *et al.,* (2013) found contrasting results: that these depressional wetlands were overgrazed by livestock as they were attractive because of the diverse species.

Elevation

Comparison of the distribution of livestock based on how often they were found at each elevation interval, indicates that, though livestock can be expected to spend most time within the interval of elevation <1300 m, this is not the case. Because the distance to the terrain at elevation <1300 m is far from the homesteads, livestock do not spend much time in these areas. There is generally a shift to the right (eastward) from summer 2016 to winter 2017 (Figure 20). In summer 2016, livestock spent most of the time between elevations of 1300-1320 m and the time spent decreases as the elevation increases. In winter 2017, however, livestock spent most time between elevations of 1320-1340 m. Sometimes livestock tend to deplete most of the palatable grasses during the wet season and are forced to shift to a higher elevation in winter.

During warm weather livestock can go up and graze in areas of higher elevation; however, because it is cold in winter, livestock tend to avoid areas of high elevations, as is evident when comparing the highest elevations livestock visited during summer 2016 and winter 2017. These results coincide with the study conducted by Bennett and Barrett (2007) who

investigated rangeland management in two villages in the central Eastern Cape. Part of their results show that, in the Guquka village, livestock spent time in the mountainous areas during summer,but in winter they would concentrate their grazing activities in low areas.

Slope

Slope influences the ease of walking for livestock; steep slopes restrict livestock to access of resources while gentle slopes allow the animals to forage material and water sources. Studies have shown that the distribution of livestock decreases by almost half when the slope is greater than 5° (George *et al.,* 2007; Sanderson *et al.,* 2010). This study indicates that, in both seasons, livestock favoured relatively gentle slopes of the areas and this diminished as the slopes became steeper. However, the tremendous decline which was not found when the slope was exactly greater than 5°, But the massive decline was between 12° and 18°. This could have been because the livestock used up the palatable forage material in these lower slopes, forcing them to climb up to hillslopes in winter. Homburger *et al.,* (2015), found that terrain slopes and vegetation were the main environmental determinants of cattle distribution in the subalpine pastures. Although this study cannot prove this, or at least compare physical landscape variables based on their importance, it shows that steepness does contributes substantially to livestock distribution as there is a massive decline in distribution when slope increases.

Aspect

In the southern hemisphere, north-facing slopes receive more solar radiation than the south-facing slopes, therefore typically livestock are attracted to the north-facing slopes. East and west facing slopes receive solar radiation based on sunrise-noon and noon-sunset. This study showed that in summer 2016, there was not much of a difference between the preferred north, north-east, north-west and the east facing slopes. In winter 2017, however, there was a strong preference of north-east facing slopes more than north-facing and east-facing slopes. This is because during winter the days are short whilst the nights are long, therefore the east-facing slopes receive solar radiation more than the west facing slopes. Also, the northern facing slopes (north-facing and north-east) receive maximum solar radiation at the time livestock are released from kraals to begin their daily activities in rangelands.

Vegetation

Normalised Difference Vegetation Index (NDVI) calculated using the Near Infrared band and the red band of Landsat 8 satellite imagery was used to represent the vegetation. The common understanding is that forests tend to have the high NDVI followed by shrubs and grasses. According to the sentinel site (https://www.sentinel-hub.com/eoproducts/ndvi-normalized-difference-vegetation-index) NDVI approaching -1 corresponds to water and values close to zero (-0.1 to 0.1) are rocks, sand or bare soil and snow.

During summer 2016, the range of NDVI values for the entire landscape were (-)0.03-0.52. The livestock generally selected the NDVI between 0.08 and 0.32. These areas included the grasslands and areas near homesteads. Livestock were mostly found in areas with 0.20-0.26 these areas were patches of veld in the north-facing slopes. During winter 2017, the NDVI available in the area are (-) 0.08-0.43, the maximum value is lower compared to summer 2016 because winter is the dry season (minimal rainfall) therefore vegetation decreases. The livestock were generally found between the NDVI of 0.08-0.26, but during winter 2017, most of the livestock were found within the NDVI values of 0.16 -0.18. The forests were not within this range, the areas were near the homesteads and were on the north-facing slopes. Though it is not clear which species are selected by the livestock (palatable) and which are avoided (undesirable), the NDVI at least indicates selection based on vegetation types (grasslands, forests). This is a limitation that needs to be considered when using such indices.

Predictive modelling

The Predictive Analysis Tool (PAT) was used to generate areas of potential distribution from the GPS point dataset with the response surfaces. The Query Generator within PAT generated a predictive analysis query based on GPS point dataset and the response surfaces as inputs. The Query Generator uses the set of GPS points to extract values of the response surfaces, then pick up the same conditions that the GPS points occurred in on the physical landscape variables on the rest of the landscape. Therefore, if an area met all five parameters, this meant that the location had the highest potential distribution of livestock, and if did not meet any parameters then the area had no potential for livestock being there. `

This is the first study, to our knowledge, that has examined potential distribution based on existing GPS location data and physical landscape variables in Mgwalana. The results show that in both summer and winter the areas around the homesteads and near rivers have the

highest potential of livestock distribution. Areas around the homestead are attractive to livestock because of the neglected cultivated lands and because livestock use less energy walking to the kraals in the evening. This result is in line with Moyo *et al.,* (2013) findings while comparing seasonal habitat use and movement patterns in two rural areas namely Magwiji and Mnyameni situated on the north eastern and south eastern parts of the Eastern Cape Province. In summer there are more areas of high potential distribution as compared to winter. This is an expected result because during summer, there is more forage available and water sources due to more rainfall (Mapiye *et al.,* 2009a). Whilst the contrary occurs in winter, rangelands are dry and forage material is limited and restricted near riparian zones as they remain attractive and close to drinking water (Metzger *et al.,* 2005).

Studies have found livestock activities (grazing, resting and walking) cause range degradation including trampling, the removal of plant material and thus exposing soils which promotes erosion (Kie & Boroski 1996; Velázquez-Martínez *et al.,* 2010; Homburger *et al.,* 2015). The identification of areas that are most likely going to have distribution is relevant for Mgwalana (Figure 40), quaternary catchment T12A (Figure 41) and quaternary catchment T35A-E (Figure 42).

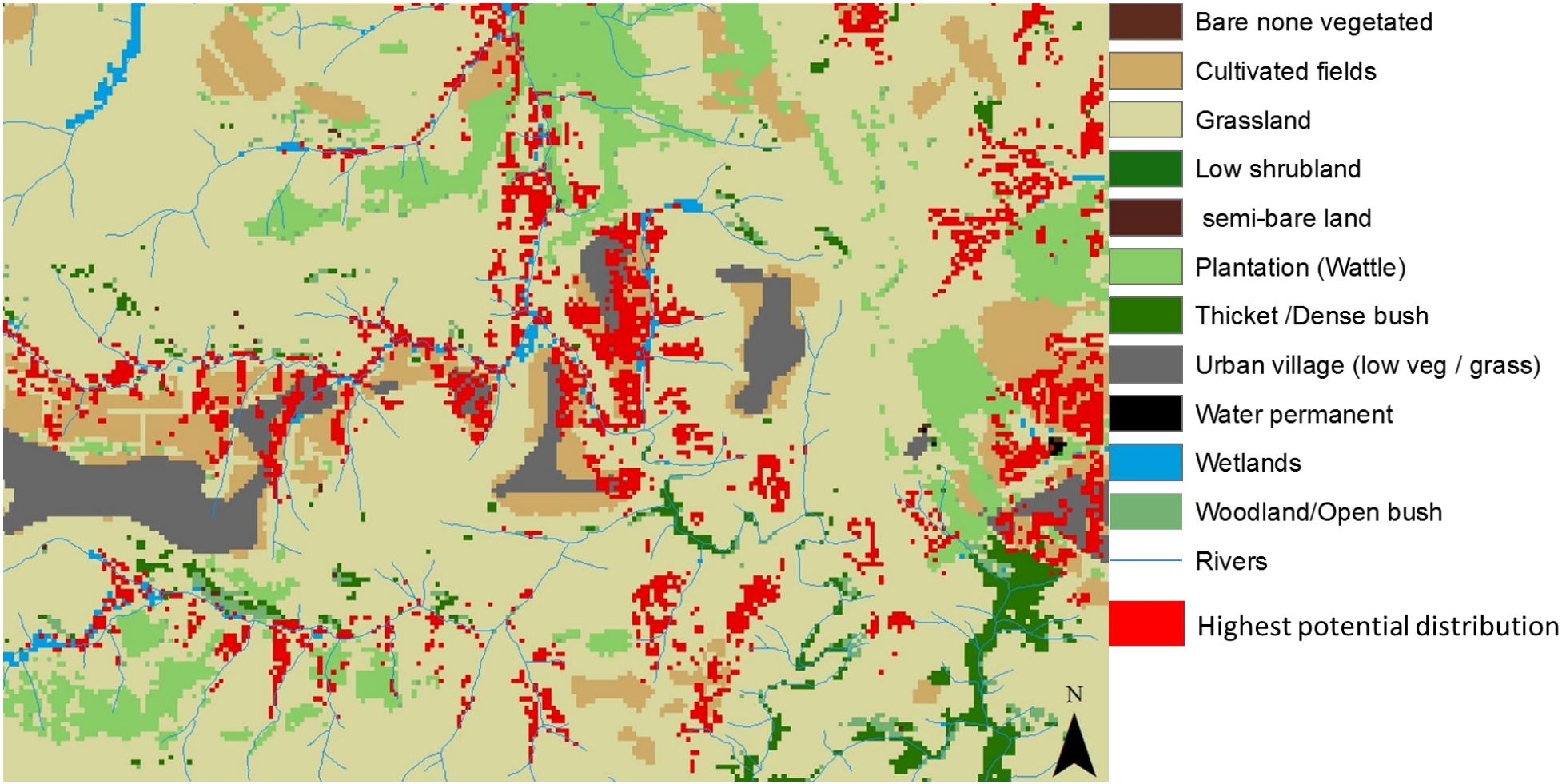

Figure 39: Areas on the Mgwalana landscape that have the highest potential of livestock distribution. These areas should be prioritised as they are prone to degradation.

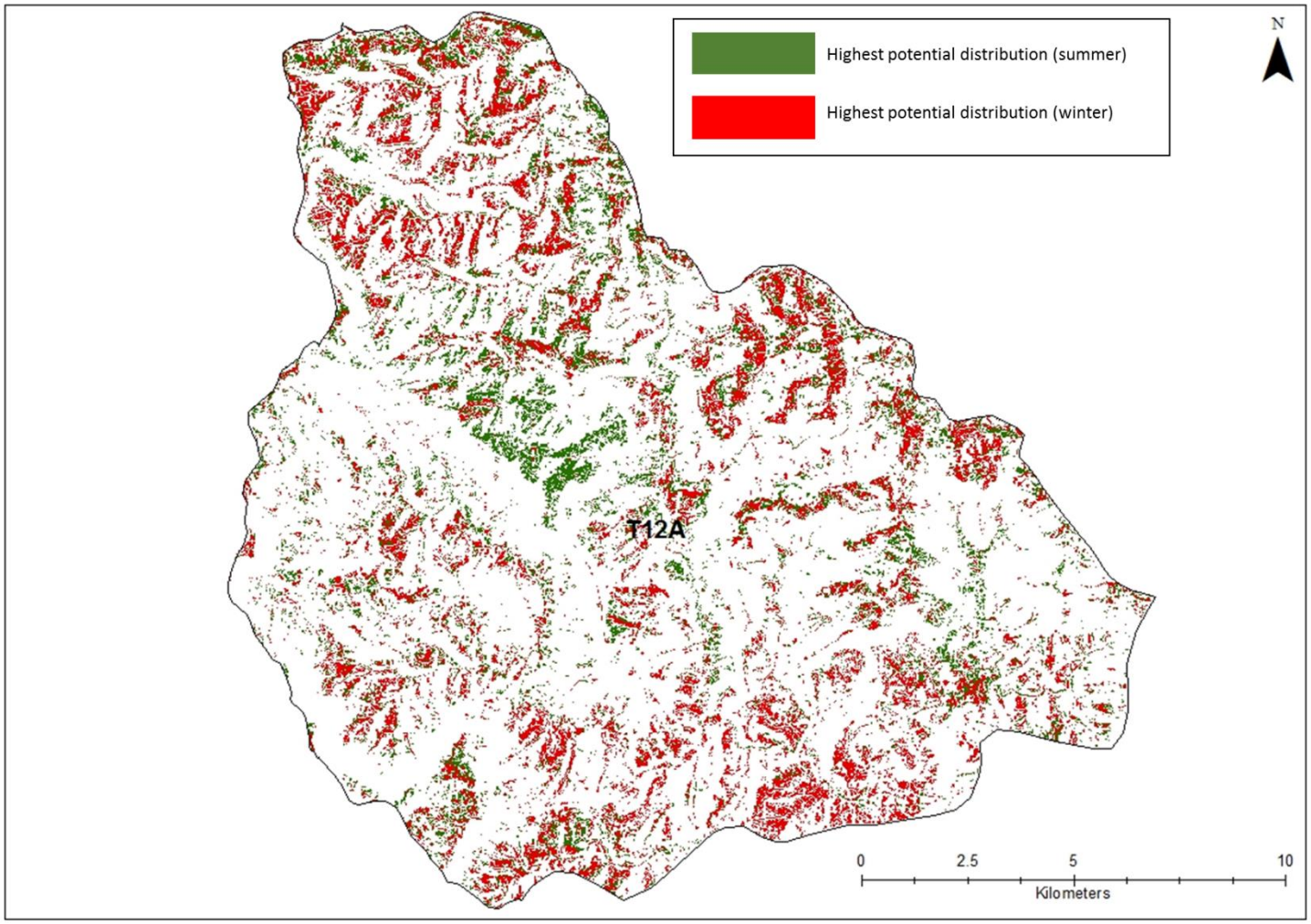

Figure 40: The areas with the highest potential distribution in quaternary catchment T12A. These areas are prone to degradation by livestock.

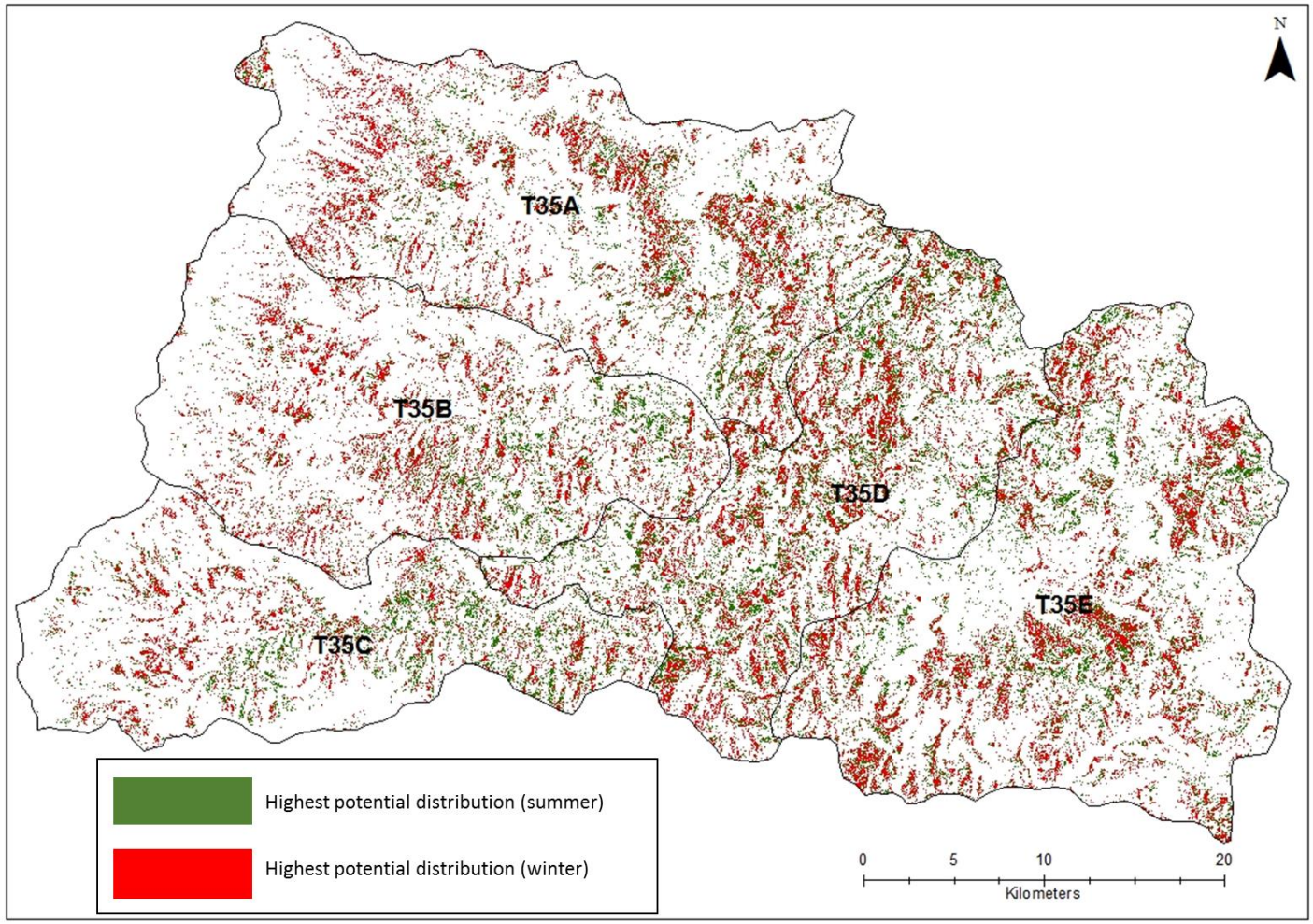

Figure 41: The areas of the highest potential distribution of livestock in quaternary catchment T35A-E. These areas should be prioritised as they are prone to degradation caused by livestock.

The main limitations of this study are:

Autocorrelation

The frequency set for GPS technology to pick up location of an animal on the landscape is a challenge and it is difficult to obtain accurate animal movement while avoiding autocorrelation (Cushman & Huettmann 2010). Autocorrelation causes biased estimates on home range size which is the actual area travelled by the animal in search for resources, and could affect the statistical analysis of data (Otis & White 1999). Perotto-Baldivieso *et al.,* (2012) advised interval time greater than two hours between GPS fixes to minimise autocorrelation whilst increasing data independence in cattle monitoring studies. Therefore GPS studies that do not consider spatial autocorrelation should be interpreted with caution (Homburger *et al.,* 2015). There are limitations to how to deal with data collected at a set time interval. The fact that in this study animals were returned to the kraal/household each night, means that the home range will focus on this area. It is the nature of the animal's behaviour and the human influence, and there is nothing that can be done to correct this problem with these data.

GPS provide location data only

Though it is common practice to infer livestock activity based on GPS location data, it is important to ground truth to assure accurate data. Since GPS technology provide location without the identification of activity. This study was based on GPS location data, it is not possible to discriminate animal activities with a simple GPS position. However, the animal activities were distinguished and considered based on the understanding of people-livestock interactions. For instance, the livestock were guided to nearby rangelands at 6am every day and kraaled in homesteads boundaries at 6pm, in this period it is assumed that livestock are grazing, drinking water, ruminating and walking. Before 6am and after 6pm the monitored livestock were not active but are resting. To overcome this limitation, the collars fitted on the neck of the animals can be fitted with other sensors such as accelerometers to determine the movement of the animal's head.

Predictive modelling restrictions

The model selected areas of potential livestock distribution based on ecological infrastructure properties, water sources, vegetation greenness, elevation, slope, and aspect. It does not include social factors such as the population demographics in relation to land-use, or distance

from the homesteads to avoid stock theft. Also, in this case ground-truthing should be used to support and validate the model outputs.

Model application

Though the study was conducted in communal rangelands within a grassland biome, the GPS use and predictive modelling can be applied in a different system such as the savanna biome. However, the researcher would have to pay attention to the accuracy of GPS tracking under trees, as that influences efficiency. Another element to consider would be the selection of influential physical landscape variables; these would vary in different biomes and climatic regions, for instance, in regions where water is not a limiting factor and, livestock have plenty of water compared with a water-scarce area where livestock concentrate on the water source that exists when the rest of the landscape is dry.

5.2 Conclusion

The prediction of livestock distribution patterns in communal land is an important part of range management. The research question namely "Where do livestock spend time in the wet and dry seasons?" was addressed by fitting GPS collars to livestock to track the location of selected individuals through both the dry and the wet seasons. The main findings showed that, when GPS location data is related to landscape physical variables, resource selectivity can be identified. The use of GPS collars is effective in monitoring free-range domestic livestock on communal rangelands and provides the framework to develop a predictive model of landscape use. Direct observations of the behaviour of animals may have improved the quality of the model as it was not certain what the animal's behaviour was at each observation. The research question "How can areas of potential livestock distribution be identified in other catchments where actual distribution is unknown?" was addressed using ArcGIS PAT, a modelling tool used to identify areas that have the potential for selection by livestock. The identification of these areas was based on the GPS location data combined with the readily available landscape physical attributes. The physical landscape variables were selected based on their availability throughout southern Africa and their potential for being used to predict distribution outside of the study area. The PAT successfully extrapolated existing selectivity from the Mgwalana rural area to quaternary catchment T12A and T35A-E. Even though the model effectively applied the concept to other catchments, ground-truthing needs to be conducted to determine model error levels.

Recommendations

The use of GPS technology and predictive modelling is efficient for monitoring livestock and provides fundamental knowledge of distribution patterns that can be part of range management strategies to serve as an intervention to reduce degradation and improve ecosystem health. The range management strategies need to be developed through the institutional involvement of the government, NGOs, and local community members working together with the same common goal of improving range condition. In this process, community involvement in making decisions about their rangelands confers a sense of responsibility when it comes to taking care of ecological infrastructure. The success of the range management strategy to be applied should be based on meetings that include community members, government officials and the NGOs that are involved. The actions recommended based on the findings of this study are:

1) Prioritising and fencing areas with the highest potential distribution as these areas are prone to degradation because they are favoured for selective use by livestock. However, fencing off these areas could be expensive and, as a substitute for fencing, livestock could be monitored and restricted within these areas.
2) Seasonal veld assessments should be carried out to determine plant composition, biomass and diversity in order to monitor and identify vegetation deterioration when it occurs.
3) Implementing rotational grazing strategies which enforce grazing and resting camps during the wet and dry seasons would improve vegetation growth and soil restoration.

The above recommendations can be successful if the stakeholders are committed, funding from organisations including the government is made available, and citizen science is practised (training and involving local community members in collecting and analysing ecological data). If effective governance systems are incorporated to practise natural resource management, the potential exists to improve community livelihoods through ecological goods and services. However, if the community's motives for rangeland use are different from those suggested above, government participation is lacking, and if the implementation (action) does not take place intervention will be impeded.

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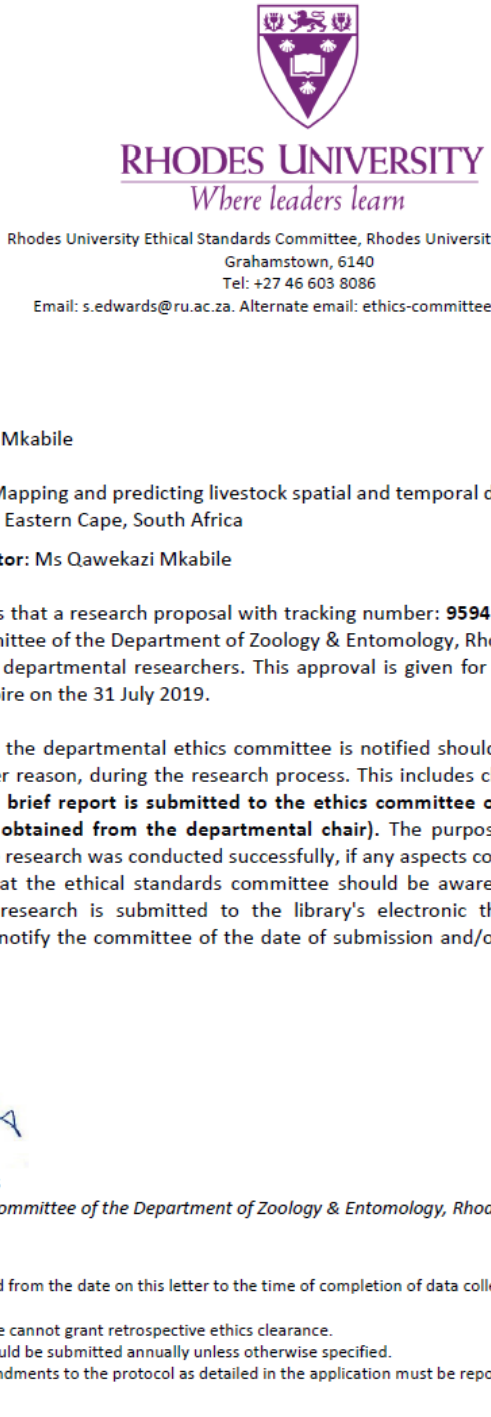
Appendices

Appendix 1: Ethics clearance letter



RHODES UNIVERSITY
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Rhodes University Ethical Standards Committee, Rhodes University, P O Box 94,
Grahamstown, 6140
Tel: +27 46 603 8086
Email: s.edwards@ru.ac.za. Alternate email: ethics-committee@ru.ac.za

Date: 05-07-2018

Dear Ms Qawekazi Mkabile

Ethics Clearance: Mapping and predicting livestock spatial and temporal distributions in the communal rangelands of Cala, Eastern Cape, South Africa

Principal Investigator: Ms Qawekazi Mkabile

This letter confirms that a research proposal with tracking number: **9594184** was given ethics clearance by the Ethics committee of the Department of Zoology & Entomology, Rhodes University, after review of the application by departmental researchers. This approval is given for the duration of the project (1 years), and will expire on the 31 July 2019.

Please ensure that the departmental ethics committee is notified should any substantive change(s) be made, for whatever reason, during the research process. This includes changes in investigators. **Please also ensure that a brief report is submitted to the ethics committee on completion of the research (the form can be obtained from the departmental chair).** The purpose of this report is to indicate whether or not the research was conducted successfully, if any aspects could not be completed, or if any problems arose that the ethical standards committee should be aware of. If a thesis or dissertation arising from this research is submitted to the library's electronic theses and dissertations (ETD) repository, please notify the committee of the date of submission and/or any reference or cataloguing number allocated.

Yours sincerely,

Dr Shelley Edwards
Chairperson: Ethics committee of the Department of Zoology & Entomology, Rhodes University.

Note:
1. This clearance is valid from the date on this letter to the time of completion of data collection as designated in the application.
2. The ethics committee cannot grant retrospective ethics clearance.
3. Progress reports should be submitted annually unless otherwise specified.
4. Any changes or amendments to the protocol as detailed in the application must be reported to the departmental ethics committee.

Figure 42: Ethics clearance letter from the Rhodes Ethics Committee

Appendix 2: R-scripts

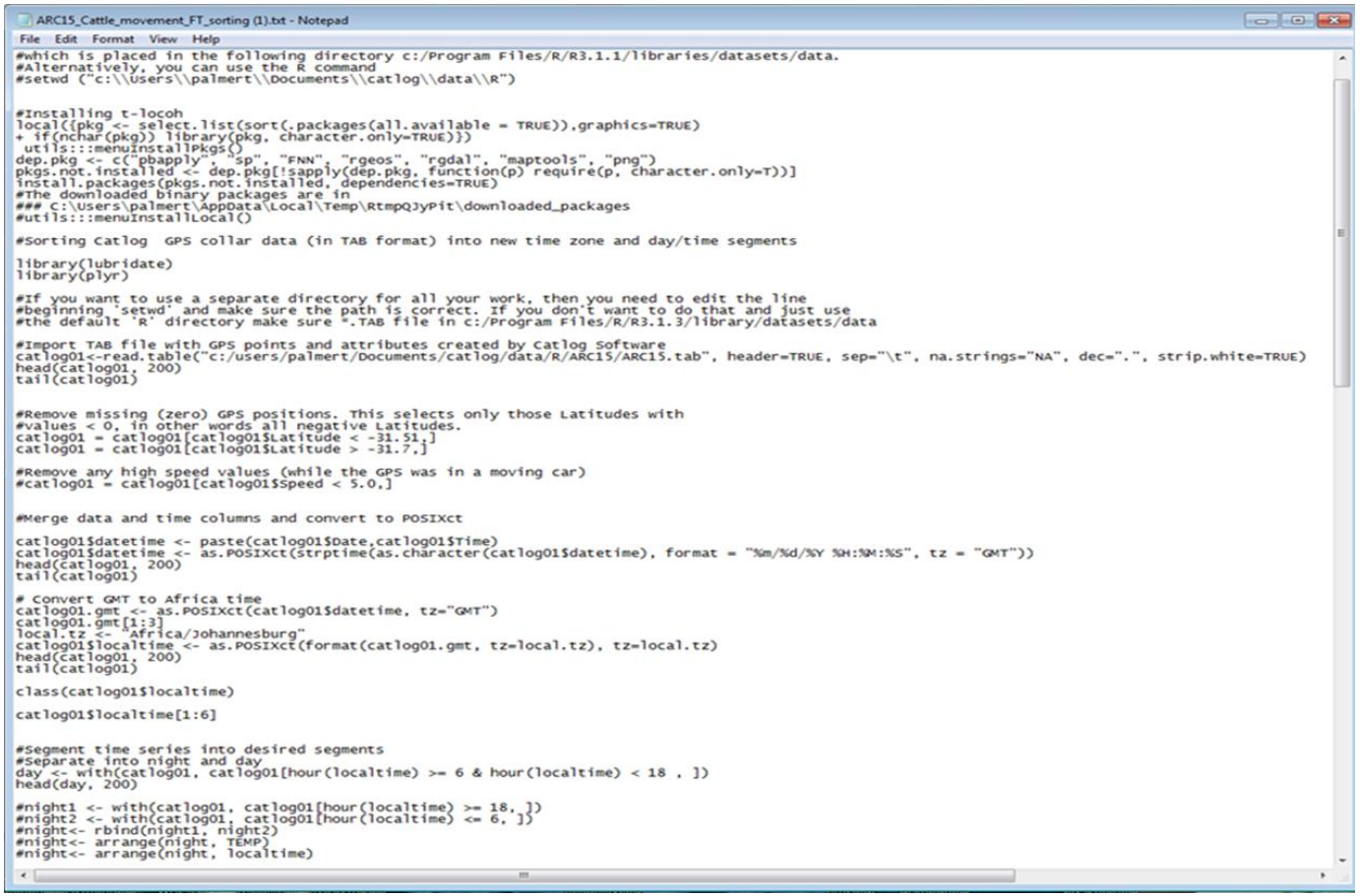

Figure 43: The script used to prepare and clean the GPS point location data Part 1.

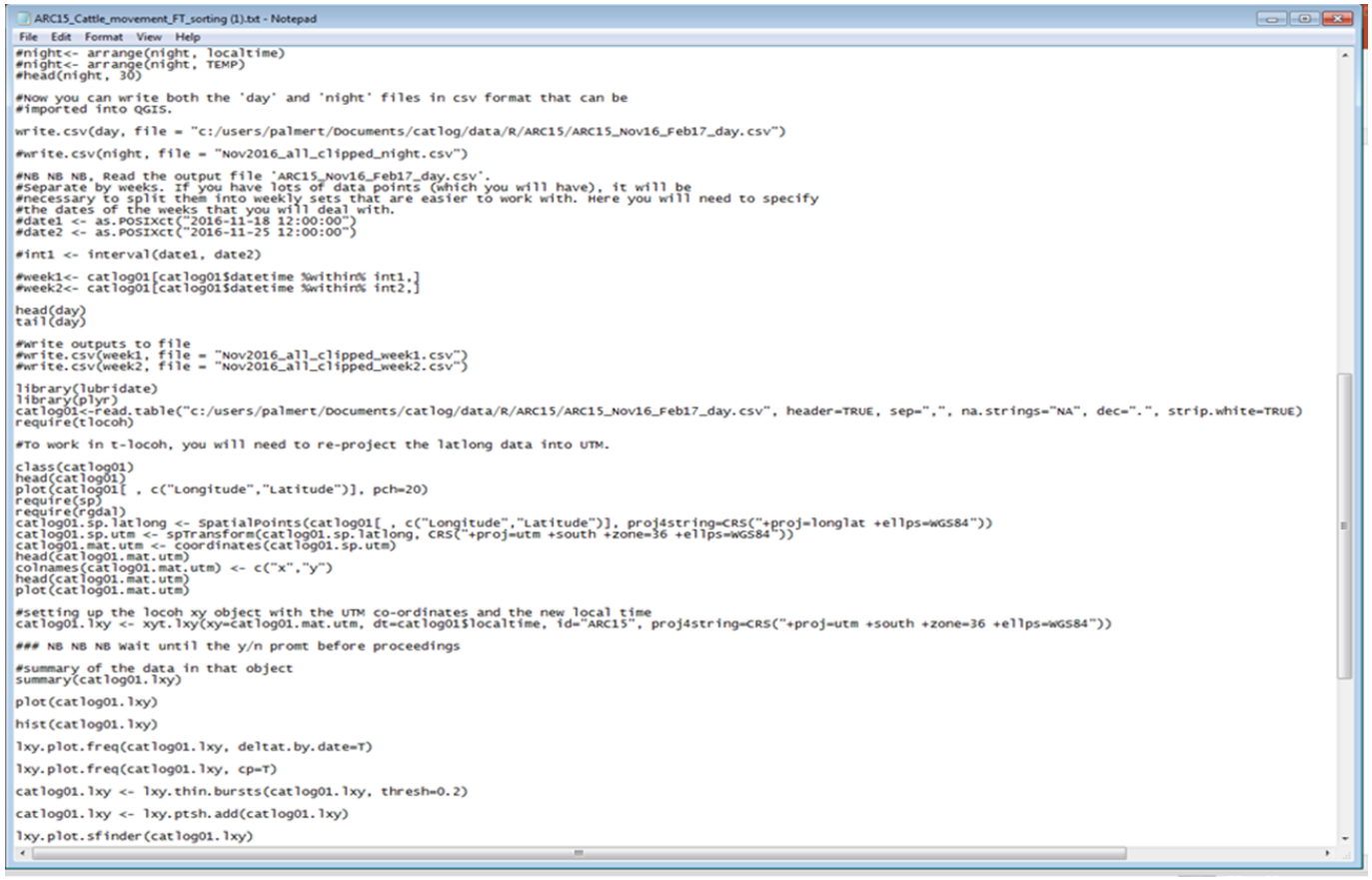

Figure 44: The script used to prepare and clean the GPS point location data Part 2.

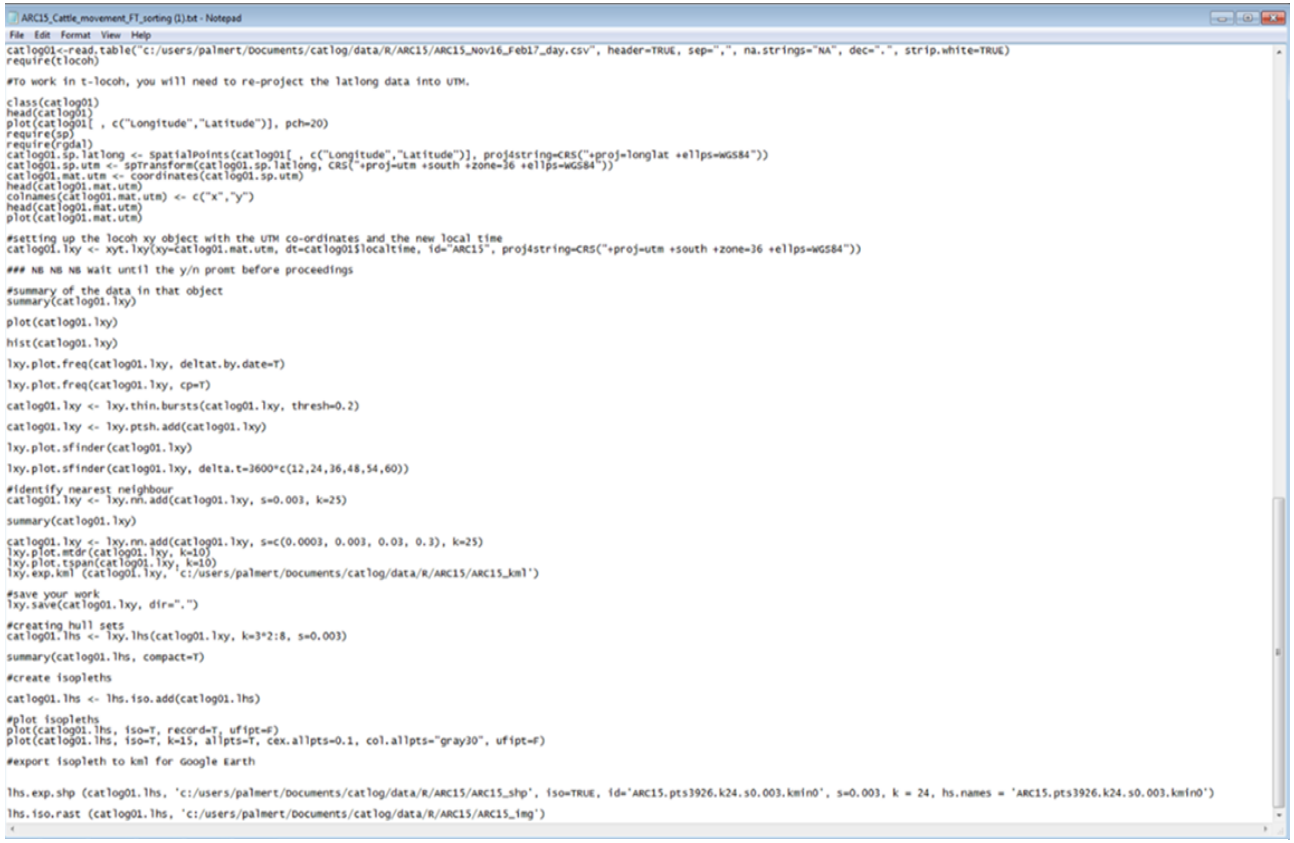

Figure 45: The script used to prepare and clean the GPS point location data Part 3.

Appendix 3: The query expression editor

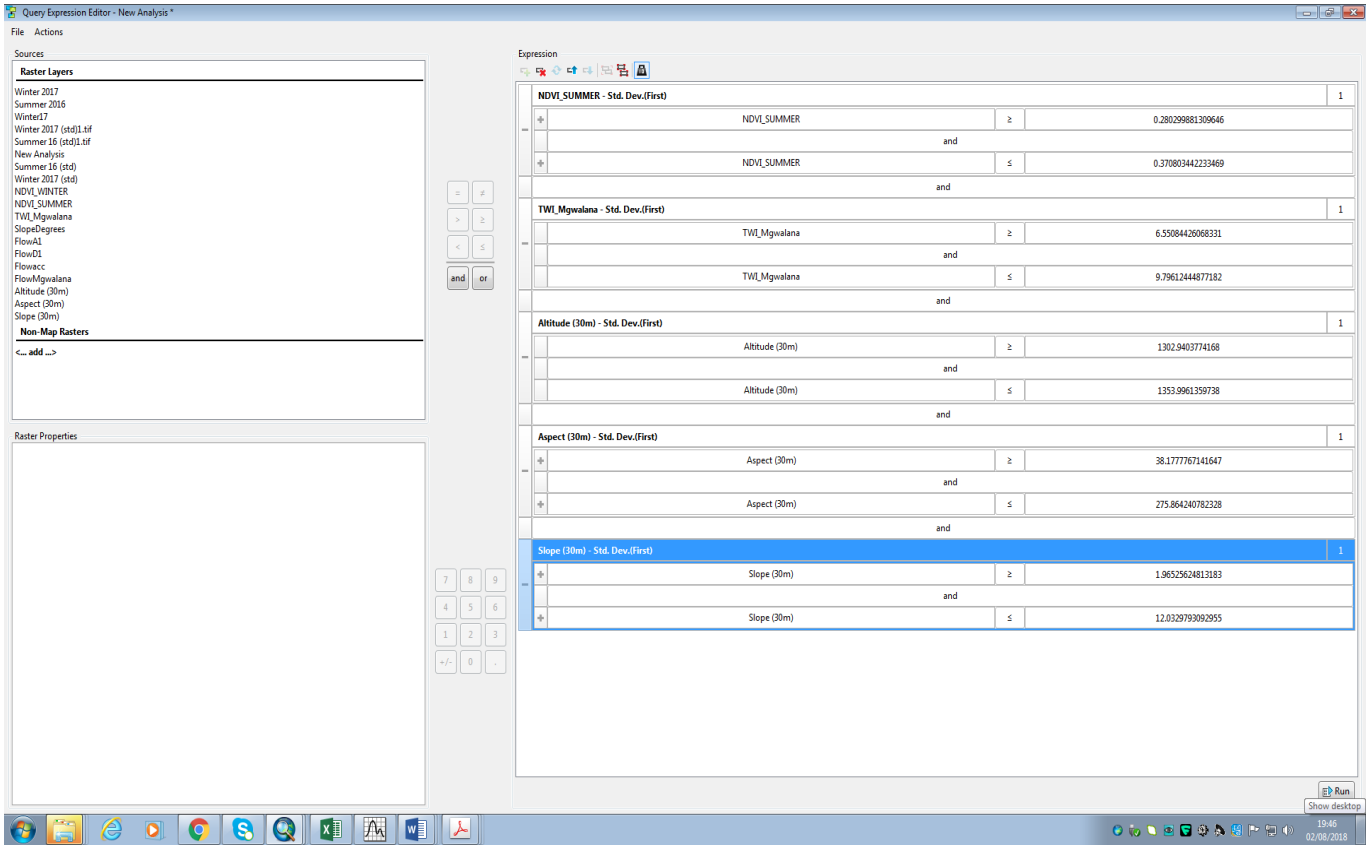

Figure 46: The *Query generator* uses the GPS point data to extract ranges from the raster response surface layers (representing physical landscape variables), the *expression editor* shows these ranges of each physical landscape variable. The screen shot show the ranges within the landscape variables that were selected by livestock in summer 2016.

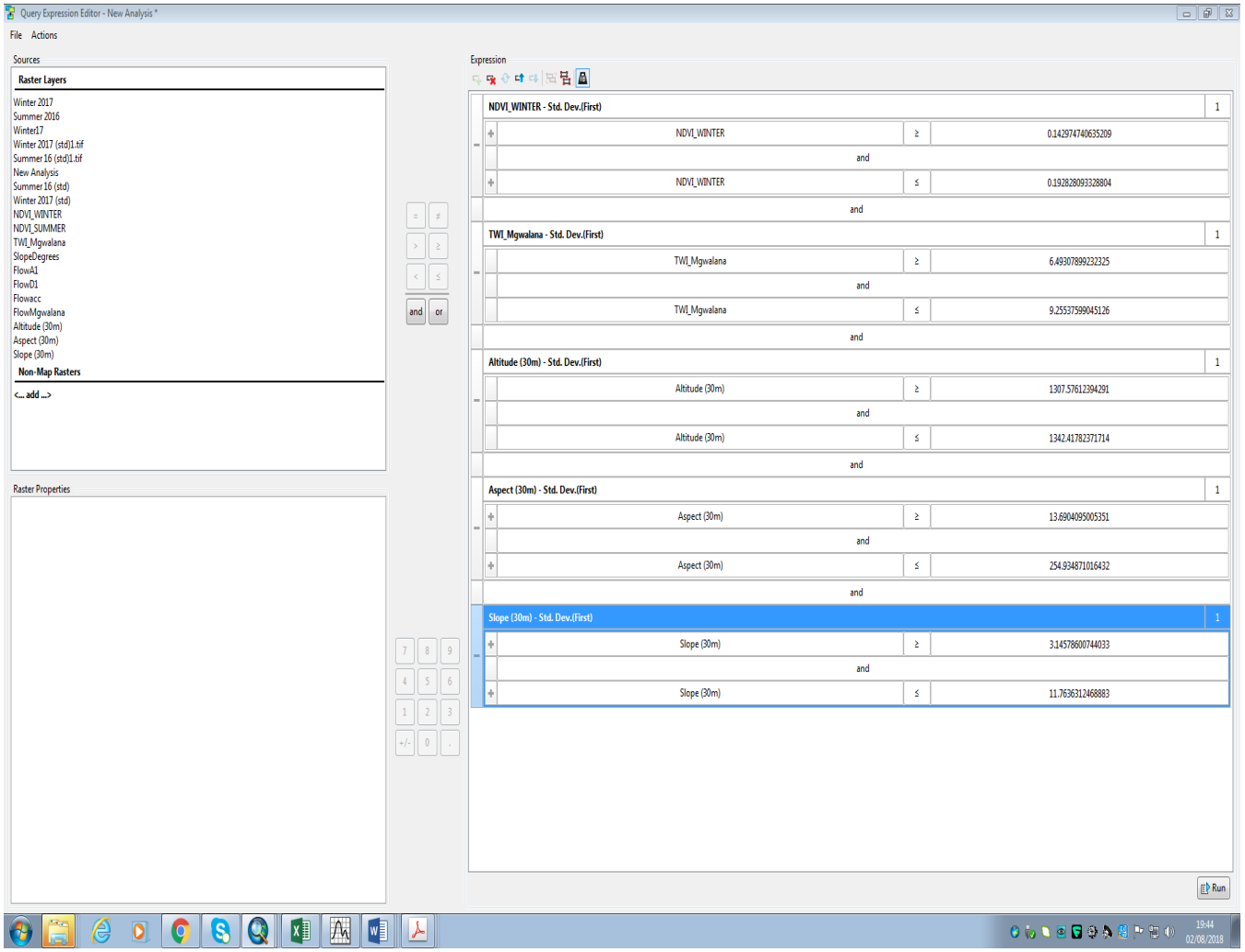

Figure 47: The *Query generator* uses the GPS point data to extract ranges from the raster response surface layers (representing physical landscape variables), the *expression editor* shows these ranges of each landscape variable. The screen shot show the ranges within the response surfaces that were selected by livestock in winter 2017.