In a novel landscape, in the Eastern Cape, South Africa, what are the key vegetation resources that support livestock production?

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Contents

CHAPTER 1: INTRODUCTION

1.1 Background & Significance to Study

South Africa has seen some of the most significant environmental and social changes observed in modern history, and these define the complex conditions still seen today as well as influence choices to plan and prepare for the future (Bäse, Helmschrot, Schmied, & Flügel, 2006). Climate change, water scarcity and land degradation are some examples of the major environmental issues being faced, which have only been exacerbated by years of political and economic instability (Crist, Mora, & Engelman, 2017). Soil erosion and its associated consequences are one of the country's main concerns, severely impacting agriculture and aquatic systems, and providing a stark risk to agricultural production and water supply (Dominguez, Madejón, López-Garrido, Marañón, & Murillo, 2016).

Livestock farming and its association with land degradation has been a concern for the landscape condition in South Africa since the arrival of European settlers in the country (Rowntree, 2014), and centuries of intensive farming of sheep, goats and cattle have significantly altered landscapes across South Africa (Rowntree, 2014). Various legal and economic decisions in that time have also contributed significantly to this situation; the 1913 Natives Land Act – one of the early pieces of legislation designed to segregate South Africans on the basis of their race - concentrated millions of black citizens and their livestock into a minority of the land area. With the introduction of Apartheid legislation in 1948, the government attempted to establish self-governing and self-sufficient homelands - "countries" that were intended to be separate from white South Africa (Bäse et al., 2006). These homelands endured until the end of Apartheid in 1994, but decades of adverse management prior to this, along with the continued concentrated land use and limited resources in these locations have led to some of the highest levels of land degradation in the country (Rowntree, 2014). Despite these dramatic political and environmental disturbances, these former homelands continue to support around 32 per cent of the human population, highlighting their vital importance for sustaining current livelihoods, as well as their present resilience to years of mismanagement (Bennett & Barrett, 2007).

In the Tsitsa River Catchment, population growth, centralised villages, soil contouring, animal fences and limited herding practices are some examples of the environmental and social changes that have been observed in the area (de Wet, 1989). This is contrasted to the traditional settings that were characterised by scattered homesteads, expansive rangelands and dispersed use of vegetation (de Wet, 1989), which were rapidly transformed by the economies and practices implemented by Europeans (Beinart, 2008). These distinct and rapid changes in land use have drastically affected ecosystem functions and feedbacks, as well as species composition and diversity (Van Tol, Akpan, Kanuka, Ngesi, & Lange, 2016). These modifications are often permanent as it would require an impractical restructuring of human populations and their associated practices in order to reverse them; the conditions create a complex scenario where traditional knowledge and land use that was once very successful may no longer be possible or relevant due to the scale of change that is often observed.

The Tsitsa River is the largest remaining river that is without a dam in South Africa, and so the government has pledged to install two major dams for irrigation and hydroelectricity, under the Mzimvubu Water Project. These dams are intended to supply water and electricity to surrounding communities as well as the large neighbouring urban areas of Mthatha and Tsolo. However, large areas of the Tsitsa Catchment (~494 000 ha) are degraded, posing the possibility that if these dams were to be created, they would inevitably fill with sediment and silt within a few decades. To address these issues, the Tsitsa Project was established in 2014 to co-ordinate actions by government, developers and local communities in order to restore the landscape condition and prevent soil erosion, as well as to improve the livelihoods of the people who live there (Fabricius, Biggs, & Powell, 2016). Research into the landscape condition as well and the environmental interactions with local communities are therefore highly necessary in order to guide restoration practices to their best effect. The economic necessity for livestock production in the catchment indicates its urgent need for a better understanding of its current effects on the catchment landscape and vegetation.

The overall goal of this study is to contribute to the knowledge needed to manage the area in a sustainable way. This paper will therefore examine the key vegetation resources that support livestock production in an area of the Tsitsa River Catchment, by describing the various types that exist, and by determining their relative production levels of usable livestock forage.

1.2 Research aims and objectives

The Tistsa River Catchment is in the northern part of the Eastern Cape province of South Africa; during the Apartheid era, it was entirely within what was known as the Transkei homeland. The highly eroded soils and limited economic capacity that currently exist there are typical of many contexts seen in former homelands, highlighting the aftermath of apartheid policies (Bäse et al., 2006).

This area may be described as a novel landscape. The terms "novel landscape" and "novel ecosystems" can be used to describe a geographical area where transformation in the physical conditions has been seen over generations as a result of a host of factors, although the precise definition of such a landscape has generated much academic debate (Truitt et al., 2015). The concept of a novel landscape and its application to the Tsitsa River Catchment will be discussed in more detail in Chapter 3, and the discussion and research will show that the selection of appropriate strategies for managing changing ecosystems is challenging (Seastedt, Hobbs, & Suding, 2008). In the context of the Tsitsa River Catchment, an analysis of the current geographical conditions within the framework of a novel landscape is useful in order to develop a consistent approach and actions for the future management and conservation of the area. Research in the area will contribute to the identification of applicable conservation / management actions for vulnerable key resources and some possible implications regarding this will be outlined.

As mentioned above, the Tsitsa River is the site of a major dam and irrigation project overseen by the South African Government's Department of Human Settlements, Water and Sanitation (DHSW&S). Related to this, the Department of Environment, Forestry and Fisheries (DEFF) has invested in the Tsitsa Project is an ambitious enterprise that aims to restore and maintain the catchment's ecological infrastructure in a healthy condition, helping to sustain and improve the livelihoods of people situated in the area (Fabricius et al., 2016). One of the project's primary purposes is to mitigate erosion and sedimentation and their associated risks, while improving soil quality and fertility around the catchment (Fabricius et al., 2016).

This study is situated within the context of the Tsitsa Project; the research will determine some of the effects of historical land-use change and intensive grazing on the landscape condition, in an area with limited resources for adequate land management and livestock control.

There are four research objectives:

- To describe the Tsitsa River Catchment novel landscape in the context of historical land use and state-funded interventions.
- To describe the current rangeland conditions found in the Tsitsa River Catchment.
- To determine the primary production of these rangeland conditions as an indicator of rangeland performance.
- To describe the reflectance attributes of these novel landscapes using Earth observation.

The starting point to gather information required to meet the objectives is three key questions:

1. After human disturbance, what are the components of the novel landscape that have developed?
2. How is it best to describe these components?
3. How do these landscape units perform in terms of their production?

1.3 Structure of the thesis

Following this introduction, the structure of thesis will be as follows:

Chapter 2 will describe in more detail the context of the Tsitsa River Catchment area, its history and the specific socio-economic conditions that led to the current geographical state of the landscape.

Chapter 3 will focus on the conceptual framework of the research. There will be a discussion of novel ecosystems and the implications of this approach to conservation and development strategies, and the relevance of this to the study area will be considered.

Chapter 4 will concentrate on the research methods used with some discussion of novel landscape identification, aerial photography and satellite imagery, livestock numbers, Earth observation, very high-resolution Digital Globe Imagery, maps and histograms, and current rangeland condition and production modelling.

Chapter 5 will be a final discussion and conclusions.

CHAPTER 2: HISTORICAL AND GEOGRAPHICAL CONTEXT OF THE STUDY AREA

Introduction

The current situation regarding the land condition in the study area is the result of natural and human-derived change, decisions, disasters, improvements and neglect over millennia. It could be argued, however, that the most significant changes have occurred in the area's relatively recent past – the last century or so – since the changes in that period were more rapid, dramatic and life-changing for the people directly affected. Moreover, the impact of these changes is evident in the land condition today – the study area's history explains why and how it has become the particular landscape it is. It is important to understand the history; knowing the history and therefore the reasons for the existing situation makes it possible to plan for change or management in the area.

This chapter outlines the recent human history of the study area and the direct way in which this has created the conditions there that currently exist, as well as a description of the current geographical features present in the area.

2.1 Socio-economic history and background of the study area

The political and economic reasons for the introduction of the 1913 Natives Land Act in South Africa are complex, but the effect was that millions of black people were legally forced to live on a fraction of the total land mass. Moreover, this land was in predominantly rural areas and was made up of some of the poorest soil for farming in the country. The Act made into law the delineated boundaries of all the African reserves that had been established prior to 1913; it created "scheduled areas" encompassing just over 7 per cent of the land in the whole country. The most important provision of the Act was that Africans could no longer buy, lease or acquire in any way land that was outside a scheduled area, and one of the long-term results of this was soil erosion on a scale that seriously undermined agriculture. After the introduction of Apartheid legislation in 1948, these reserves became the cornerstone of the homeland system (Feinberg, 1993).

Of the 10 homelands created, the three biggest were KwaZulu, Bophuthatswana and the Transkei – the Transkei being the location of the study area in this research, the Tsitsa River Catchment. These three homelands alone contained 70 per cent of the land area allocated to all the homelands and more than 60 per cent of the population housed by all 10 homelands (Butler *et al*, 1977). The Transkei was just over 9 million acres in extent and was situated in the south-eastern part of South Africa. Along with the Ciskei, it was the nominal "home" land of Xhosa people, whether they actually lived there or not. The former Transkei is now part of the modern-day Eastern Cape and the Tsitsa River Catchment is in the northern part of the province, in the Elundini Municipality.

2.1.1 Conservation and betterment in the homelands

Following the 1913 Land Act, by the 1920s it was commonly held that African reserves were becoming highly eroded. An emphasis on conservation in the homelands became a priority for the government and environmental regulation was seen as key for white farmers' agrarian production. Diseases such as scab were seen as a threat to white-owned livestock and that erosion in the homelands could affect the water supplies, dams and pasturages of white farmers. Saving the soil was prioritised around the country and this was seen as a fundamental requirement for progress in black as well as white agriculture. It was thought that the "soil had to be saved if Africans were to develop". Generally, conservation strategies were rooted in colonial thinking and the environmental welfare of the country was often used as a justification for large-scale intervention in African affairs.

Changing concepts of the role of the state within economic affairs, segregationist policies and political control, and the commitment to establishing a migrant, rather than an urban African labour force, were factors that all played a role in the regulations that were put into place in homelands. The importance of cattle in African culture as symbols of status and wealth, as well as a means of living, was well recognised by the government; Africans were frequently enthusiastic participants in this pastoral economy and often the first to implement many of the policies and strategies developed for livestock management. Income received from migrant workers in urban settlements and farms was important in the homelands and was mostly invested in livestock. African livestock numbers were shown to increase simultaneously with those owned by white farmers.

However, traditional methods of “shifting cultivation” that worked when land was plentiful were now redundant due to land shortage and population increase, and plough cultivation with teams of oxen became common. The growing population in the homelands attempted to farm the declining land with more intensive techniques while the government viewed peasant farming as requiring too much land and in direct conflict with the environment.

A central policy was developed in the 1930s in order to control levels of erosion, involving farming on the contour and the creation of terraces on the landscape. A common method was known as ridge terracing - the creation of ridges of earth, two feet high, along the contour at regular vertical drops. These were intended to act as buffers against rainfall to prevent the water runoff from gaining a high velocity and having more erosive capability. The ridges were then planted with grass or *Agave* to hold the soil in place. In the Transkei, grass strips were better suited to local soils and were preferred on these banks. The amount of labour required for landscaping on this scale had to be supplemented with large machinery such as tractors, controlled by white labourers. The work was often done hurriedly and carelessly.

By 1940, 1,200 miles of contour banks had been created in the homelands. However, by 1941, people were already noticing problematic issues. Banks were collapsing after heavy rainfalls because they were vulnerable to water that welled up behind them and eventually broke through, especially before vegetation was established. Gaps between contours were then reduced in order to slow water flow even more, further decreasing the amount of land available for cultivation. After work ceased in 1940, the costly and time-consuming task of upkeep was left to small maintenance teams. These had to deal with hostile landowners who were unhappy with the modifications and had frequently ploughed over them. The banks and terraces had been constructed with no regard for existing plots and they resulted in the area for cultivation being much reduced.

Those farmers who neglected banks and refused to fence off eroded areas were fined. Blame was directed at black people by the government for their lack of maintenance of these contours but the intensive maintenance was simply too much for the impoverished farmers and, once these banks had been broken through, they only served to channel rainwater and lead to the creation of gullies and further erosion. Resistance to the alterations was common, further leading to reduced maintenance and success, and simply heightened the call for more land. The government dismissed these calls saying: “they cannot care for what they already have” (Beinart, 2008).

The continuing degradation of the land was beginning to have a noticeable effect on the food security of Africans in the homelands in the 1950s. The stereotype of superstitious Africans who were resistant to progress developed and for the government, the time for “gentle persuasion” was over; scientific knowledge was used to create authoritative measures. The Tomlinson Report was commissioned to determine the requirements for establishing economically viable and sustainable African homelands (de Wet, 1989). The report found that the establishment of these homelands would fail unless a vast economic investment was made to implement policies and to purchase land for the growing African population and it cast doubt on the government’s attempts to establish permanent Bantustans. However, many of the proposals in the Tomlinson Report were ignored or implemented poorly (de Wet, 1989).

Attempts to “better” the landscape were made by the government, aiming to “combat erosion, conserve the environment and develop agriculture in the homelands” (de Wet, 1989). “ ‘The Minister [of Native Affairs] may... declare a land unit a betterment area and thereupon – any rights which any person occupying land within that area may have to graze stock... shall cease; the cultivation and use of all agricultural land within that area shall be subject to such rules, orders, notices, directions or prohibitions as the Native Commissioner may deem fit to impose...’ – Proclamation 116 of 1949” (Stubbs, 2013). Betterment was manifested in multiple agricultural schemes around the country, involving the redistribution and improvement of land and livestock, and the resettlement of millions of people in homelands (de Wet, 1989).

In many areas, particularly in the Ciskei and certain areas of the Transkei, land was fenced and divided, and special designations given for residential areas, arable land and grazing commons. Each household was given access to a piece of arable land and a grazing commonage “sufficient for full-time subsistence” (de Wet, 1989). Areas deemed too degraded were removed from use, in most cases leaving communities with less arable land than before, and if there was not enough land to be divided amongst the people they were forced to a new location where there was deemed to be more space (de Wet, 1989). Centralisation became a major focus in these schemes, intending to take people from their remote familial clusters scattered across the landscape, and put them in common villages, which could then be urbanized (de Wet, 1989). It was hoped that urban areas in the homelands would decrease the rate at which Africans were moving into urban areas in Apartheid South Africa (Beinart, 2008).

According to de Wet (1989), through betterment, the physical environment as well as traditional patterns of land use were permanently altered. People and livestock along with their associated food and water sources were concentrated around these new settlements (Beinart, 2008). De Wet also explains that before betterment, homesteads were scattered strategically across the land, placed in close proximity to supplies of water, firewood, pasture and farmland; livestock were grazed next to residential clusters and in the winter months were moved to the highlands. If grass and vegetation was poor around one village location, cattle were moved to more a productive one, emphasizing the flexibility of such a system. Once changed by betterment, land that was previously managed by tribal custom was physically divided and fenced into residential areas, arable land and grazing commons (de Wet, 1989).

African resistance against interventionist conservation strategies was well documented (de Wet, 1989). In the British colonies, resistance towards imperial rule was at its height in the 1940s and 1950s, coinciding with the height of government interventions through betterment and conservation (Beinart, 2008). In the end, betterment often became the mechanism by which concentrated land use significantly increased (de Wet, 1989). The crowding of livestock and cultivation, and the disintegration of social dynamics, left nothing but bitter resentment in the communities who were affected by these plans (de Wet, 1989). The implications of this are still highly visible today in the current landscape with its physical scars of these Apartheid policies and the lingering mistrust of outside intervention in livestock and farming affairs.

2.1.2 Drivers of Change

(Adapted from Beinart, 2008)

The expansion of European pastoral economies in countries such as South Africa, Argentina, Australia and New Zealand led to some of the most significant environmental transformations across the globe. The export of meat and wool became a massive global economy in which the South Africa was a significant provider. South Africa was unique because it had a diverse range of environments and vegetation types where indigenous livestock practices in the form of Khoisan fat-tailed sheep and Bantu cattle existed prior to European contact. Even after gold and diamonds overtook wool as South Africa's primary export in the 1890s, livestock farming remained successful and diverse, and South Africa became the second biggest global exporter of merino sheep wool by the 1920s.

The country's well-being was highly dependent on livestock for food, the economy and transport, however the environmental effects of this have been keenly observed and discussed throughout South Africa's history, and a great wealth of knowledge of management practices developed over time. The loss of indigenous vegetation, overstocking, disease, predators, invasive species (indigenous and exotic) were topics of significant thought and consideration and by the 1920s, as environmental limits began to hamper the export of wool and meat, various controls and strategies were developed and imposed on both white and black communities. Veterinary practices that increased fencing and reduced the movements of animals resulted in national livestock increases, even in traditional communal areas. Fenced paddocks were established to graze land rotationally and control erosion, putting an end to large expansive pastures where animals needed to be shepherded. Significant changes to herding and farming practices were made in both white and black communities - some made willingly or through the use of incentives, especially for white farmers, but interventionist approaches were common, especially in homelands. The thought processes behind this colonial pastoral economy were fundamental in shaping the landscape and management practices that are still seen today.

Degradation of grassland landscapes is often associated with communal tenure land ownership, for example asserted by Garrett Hardin in his well-known publication "The Tragedy of the Commons" (Hardin, 1968). Hardin asserted that environmental degradation was the unavoidable outcome of communal property ownership, due to the innate selfish behaviour of all humans, and the apparent lack of monitoring and regulation in these systems to prevent malpractices (Hardin, 1968). According to Hardin, in a pasture with common access, humans will always act to maximise personal gain and therefore make the logical decision to graze as many livestock as they can personally maintain. Fellow livestock grazers who share the pasture will see this behaviour and do the same, or risk losing out on the "free-for-all" and miss a common opportunity. Each individual is compelled to add more livestock until the environment can take no more and the process of degradation inevitably takes place (Hardin, 1968). In Hardin's view, a centralised government alongside privatisation is the only solution to such a problem, creating a scenario where individuals rely solely on their own resources for monitoring and regulation, and the consequences of over-exploitation affect their property alone (Hardin, 1968). This point of view typified most colonial attitudes to the communal properties held by indigenous peoples, and was expressed in the policies that were used in the management of many communal rangelands in South Africa after 1949 (Dietz, Ostrom, & Stern, 2008).

Much of the land that was in former homelands is either still under communal property regimes, established as "native reserves" in the 1913 Land Act, or it is part of recently commercialised farms transferred under land redistribution post-1994, or it is abandoned arable lands that have become communal grazing resources (Palmer & Bennett, 2013). High livestock populations, a lack of grazing management such as rotational grazing and resting, limited access to markets and poverty are evidence of the conditions found in impoverished, communally managed rangelands (Palmer & Bennett, 2013).

In many of these contexts, the deterioration of traditional and customary methods of governance, monitoring and regulation was synonymous with environmental degradation (Dietz *et al.*, 2003). Grazing was no longer defined by particular seasons and young boys who traditionally acted as herders went to school, leaving most animals to range freely (Bennett & Barrett, 2007). Many distinguish the true concept of common property - one with a well-defined group of users, a well-defined resource that is being managed, and an institutional arrangement that defines both of these - with that of open access, which many common areas now replicate (Bennett & Barrett, 2007). Open access regimes lack the legal ability to exclude people from access and users often have no legal rights to govern and regulate the resource being used (Bennett & Barrett, 2007).

Ostrom maintains that solutions lie in the promotion of participatory and adaptive governance strategies that promote strong monitoring, regulation and resilience through well-managed community efforts (Dietz *et al*., 2003). Well-defined boundaries, recognition of rights, collective arrangements, monitoring, conflict resolution and graduated sanctions are some examples of the characteristics Ostrom observed in successfully managed community resources (Dietz *et al*., 2003). Establishing frameworks in areas that lack these characteristics can be particularly challenging and will often require collective efforts, institutions to control access, as well as economic assistance to ensure successful implementation (Bennett and Barrett, 2007). In South Africa, private commercial farms offer a stark contrast to these systems of management, but inadequate and unequal access to land and grazing resources along racial lines demonstrate the difficulty in establishing such systems where there is already a severe lack of resources and infrastructure (Bennett & Barrett, 2007).

2.2 Climate and vegetation

2.2.1 Precipitation

Precipitation data for Tsolo Prison and the Mount Ayliff Prison for the period 1900-1998 was obtained from the former Computing Centre for Water Research (now part of the School of Hydrology and Agro-meteorology) at the University of KwaZulu-Natal to provide a perspective on the rainfall history of the region. In addition, modelled rainfall data were obtained from the TAMSAT (**T**ropical **A**pplications of **M**eteorology using **SAT**ellite) data and ground-based observations) database from the University of Reading (https://www.tamsat.org.uk/).

The long-term average annual rainfall of the Sinxaku area is approximately 610 mm (Figure 1, Table 1), falling during the summer months from October to March, making it a sub-humid environment (van Tol *et al*., 2016) (Figure 2). By fitting a linear curve to these data, there is a steady downward trend in mean annual rainfall, suggesting increasing aridity in this region.

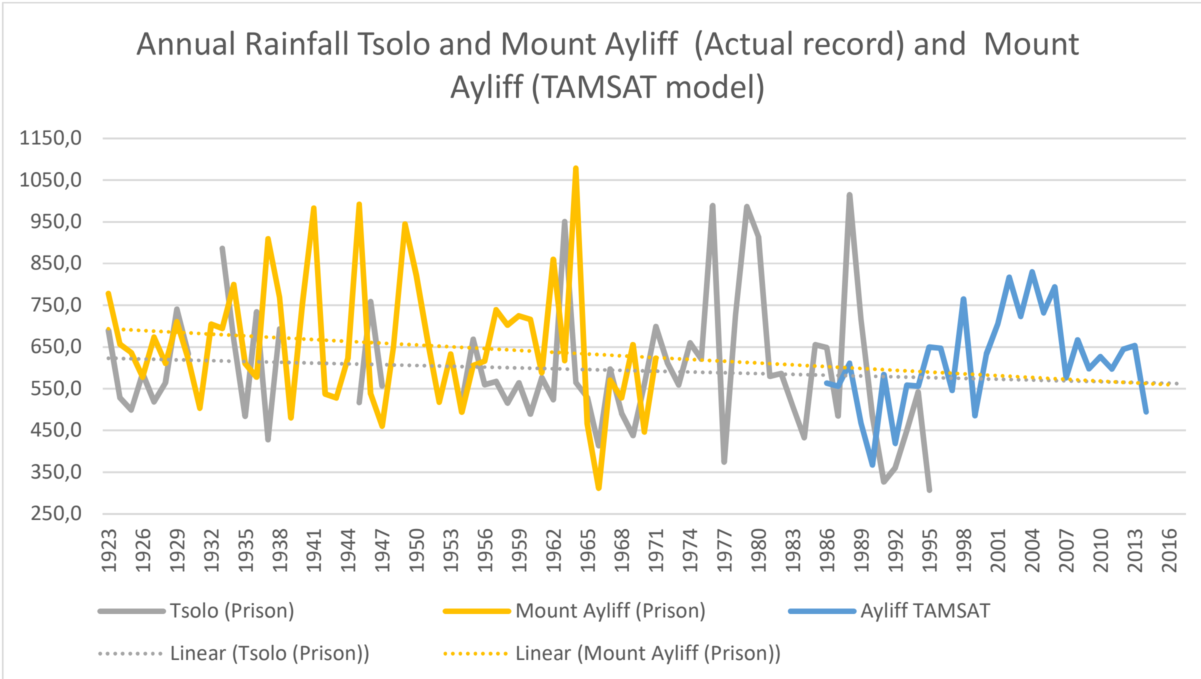

Figure 1. Long-term rainfall records from weather station in the region (Tsolo and Mount Ayliff Prison) extended to 2018 using the TAMSAT rainfall model.

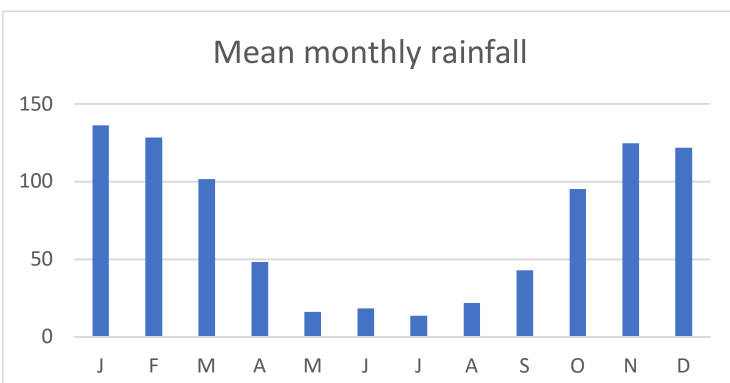

Figure 2. Mean monthly rainfall based on the monthly totals from the CHIRPS database.

Table 1. Mean annual rainfall for stations with more than 40 years of data in the region.

Station	Mean annual rainfall	Length of record (yrs)
Tsitsa CHIRPS	714	38
Tsolo (Prison)	613	42
Mount Ayliff (Prison)	659	49
Mount Ayliff (TAMSAT)	616	29

2.2.2 Vegetation

The region is predominantly within the Grassland biome, with small representative examples of the Albany Thicket and Forest biomes. The vegetation types found in the catchment comprise of four primary vegetation types on the landscape: Sub-Escarpment Grassland, Sub-Escarpment Savanna Bioregion, Drakensberg Grassland and Southern Mistbelt Forest (Mucina & Rutherford, 2006).

This is the grassland associated with the low-elevation areas along the flood-plain of the Tsitsa River. The original, undisturbed forms of this grassland type are extinct in the area, having all been ploughed during Betterment Planning. These low elevation areas now comprise of grasslands, mainly *Cynodon dactylon* and *Eragrostis plana.* These grasslands provide an important forage resource to both grazers (sheep and cattle) and browsers (goats).

Figure 3. Typical recovering East Griqualand Grassland, showing the occurrence of contours associated with Betterment Planning. Evidence that these lands have not been ploughed or cultivated for decades is in the prevalence of large termite mounds (Trinervetermes spp.) that are well established. These would not have been able to establish if regular ploughing had occurred.

Drakensberg Foothill Moisture Grassland: The moist grasslands of the high elevation areas still remain intact where they have not been invaded by black wattle or planted to commercial forestry (mainly pines).

Southern Mistbelt Forest: There is very little forest left in the general area. Wattle is abundant in large stands along the drainage lines, with few opportunities for native forest to establish.

Eastern Valley Thicket (Figure 4): A remnant version of the Eastern Valley Thicket occurs on the lower slopes of the mountains. It has been severely over-grazed by goats, but several diagnostics species (e.g. *Euphorbia triangularis, Searsia spp*) are still present.

Figure 4. Remnant Eastern Valley Thicket along the base of the escarpment where shales and mudstones from the Karoo Supergroup have been exposed.

2.2.3 Geology

The Tsitsa River Catchment area is predominantly underlain by sedimentary rock of the Karoo Supergroup. Throughout the catchment there are numerous formations that are characteristic. The upper catchment in the north west is dominated by Basalt Formations. Lower down the catchment are small portions of Clarens Formations (large sandstones) followed by more extensive Elliot Formations. The middle section of the catchment is dominated by Molteno Formations. The Tarkastad Formation dominates the lower extremities of the catchment in the east.

Throughout these formations there are dolerite intrusions, being especially common towards the east. The three lower formations are predominantly mudstone and sandstone. Soils derived from these bedrocks are characterised by their high erodibility and loose structure (van Tol *et al*., 2016). The areas around and including Sinxaku have also been noted to have duplex soils, a feature that leads to high levels of land degradation in the forms of rill and gully erosion (van Tol *et al*., 2016).

CHAPTER 3: THE NOVEL LANDSCAPES FRAMING

Introduction

In order to answer the key questions posed in the introduction to this paper, it is necessary to explain the concept of novel ecosystems and how they relate to the approach needed to manage certain landscapes.

The idea of restoring a landscape simply by replanting what grew there before humans began farming or by reintroducing the livestock that was successful in the distant past is being challenged more and more as different ideas about the purpose and methods of rehabilitation evolve.

The acceptance of change and working with the current landscape underpins the concept of novel ecosystems and enables conservationists, farmers and other land managers to plan a different way to work in the land's future. This chapter will explore the ideas and challenges of novel landscapes in the context of the Tsitsa River Catchment and why it forms the approach to the research carried out in this study.

3.1 Novel ecosystems and historical land use

A novel landscape is an area which, as a result of human disturbance, has seen permanent and fundamental changes in its species composition and landscape function when compared to its historical condition (Hobbs *et al*., 2009). Characterised by their rapid creation following land-use change, the breakdown of biogeographic barriers and altered species combinations, these landscapes have appeared in timeframes never seen before (Hobbs *et al.*, 2009).

The concept of novel landscapes is becoming increasingly relevant due to the rising extent of their emergence and the need to address the potential impacts from their creation (Milton & Dean, 2010). Recognising the changing biotic and abiotic pressures on landscapes, as well as how these systems can potentially be managed, is becoming apparent in environmental regulation (Belnap et al., 2012). Traditionally, rehabilitation efforts have focused on historical or undisturbed conditions as targets to emulate for success, environments that retain the biota and ecosystem characteristics that were present in the past (Milton & Dean, 2010). However, this paradigm raises challenges in many contexts with regards to conceptualising this environmental state of being and its associated traits (Hobbs *et al*., 2009).

Defining all change from a pristine condition as degradation can often create limitations in the expectations for future conservation and rehabilitation strategies (Crookes et al., 2013). For example, despite the disturbances that have taken place in landscapes such as the Tsitsa River Catchment, practices such as livestock farming continue to sustain a large population of livestock, providing vital economic benefits in these rural areas (van Tol *et al.*, 2016). Restoring this environment to its pre-colonial vegetation condition would require an almost impossible restructuring of the human populations and their associated activities, underlining the permanence of these landscape modifications (Beinart, 2008). The persistent and sustained provision of essential Ecosystem Services (the freely gained benefits that humans derive from nature) underlines the present value of these landscapes (Crookes *et al.*, 2013). It is becoming clear, then, that viewing all environments as degraded with regards to their historical condition can present unrealistic prospects for rehabilitation, and ignores the current potential for use and conservation (Milton & Dean, 2010).

Conceptualising these novel ecosystems as distinct but related environments to their historical counterparts can give insight into previously productive landscapes and provide a great deal of flexibility to account for human changes (Hobbs *et al.*, 2009). A common goal for conservation is to limit biotic and abiotic changes that take place in an environment; however this line of thinking needs to simultaneously account for such historical alterations (Milton & Dean, 2010). Restoration plans have to be wary of the economic cost of sustained interventions, whilst providing flexible boundaries for variability that can occur on the landscape (Belnap *et al.*, 2012).

Visualizing these new environments can, however, present its own set of challenges due to the rapid nature of their emergence and general uncertainty about the new biotic and abiotic interactions taking place within them (Hobbs, Higgs, & Harris, 2009). Ecosystems are always situated within a context of change throughout time, underlining the difficulty in establishing a distinct definition for when a novel landscape has appeared, and it can be argued that almost all environments have seen direct or indirect disturbance and change as a result of human activities (Hobbs *et al.*, 2009).

A hybrid system can be defined as one that has retained most of its historic characteristics such as nutrient load, hydrology and species diversity, but whose composition or function now lies outside its Historic Range of Variability (Hobbs *et al*, 2009). By contrast, a novel landscape has seen a complete transformation in composition and function, and is composed of entirely new species with different functional properties (Hobbs *et al*., 2009). It must be acknowledged that there are grey areas between these definitions and there can never be universally applicable boundaries for these new environments (Hobbs *et al*., 2009).

Determining the true historic state of these environments, the scale of time in which to look back and compare, as well as the subjective nature of interpreting these facts with regards to cultural, political and economic values present numerous obstacles in establishing environmental transformation and therefore restoration goals (Hobbs *et al*., 2009). Within one river catchment, numerous stakeholders may have different objectives for the landscape condition, including agriculture and forestry, ecotourism, subsistence farming and grazing, for example (Bäse *et al.*, 2006).

An additional factor is that many introduced species now provide valuable benefits in their new environments, both socially and ecologically; for example, the invasive Australian black wattle (*Acacia mearnsii*) and silver wattle (*A. dealbata)* are a valuable source of firewood and timber in the Tsitsa River Catchment and many other areas of South Africa (Oelofse et al., 2015).

This demonstrates the complex nature of restoring altered landscapes, and underlines the need to acknowledge the permanence of some environmental changes and their associated consequences and benefits (Belnap *et al.*, 2012). The land-use practices and the presence of new invasive species can dramatically alter soil's physical and chemical properties. Regular cultivation can change soil structure and reduce nutrient levels (particularly soil organic carbon (SOC)), whereas the presence of nitrogen-fixing trees can increase N levels and reduce pH (Gwate, 2018). These changes can affect the expected vegetation state that restoration hopes to achieve.

Livestock farming and its association with land degradation has been a concern for the landscape condition in South Africa since the arrival of European settlers in the country and centuries of intensive farming of sheep, goats and cattle have significantly altered landscapes across the country (Rowntree, 2014). Much of South Africa's land has been classified as degraded, especially that under communal tenure arrangements in the former homelands (Rowntree, 2014), but these areas continue to sustain around 32 per cent of the country's human population (Bennett & Barrett, 2007) and 41 per cent of the national cattle herd (Table 2). Interventionist policies, human population growth, soil erosion and disturbance by alien invasive species have led to permanent landscape modifications (Beinart, 2008). Recognising the Anthropocene, the epoch in which human activities have the dominant influence on the climate and environment, has called for a paradigm shift in conservation (Crist *et al*., 2017) and that the preservation of biodiversity must be balanced with increased economic opportunities as well as food security (Crist *et al*., 2017).

In the Tsitsa River Catchment, primary areas of vegetation production have been shown to provide essential ecosystem services that support substantial livestock herds (Bennett *et al*., 2007). Particular vegetation types are favoured over others and so grazing habits are not uniform throughout the catchment (O'Farrell *et al.,* 2007). Hill-slope seeps, riparian meadows, contour banks and unimproved native grasslands are examples of highly productive key vegetation resources that have been recognised as common feeding areas (O'Farrell *et al.,* 2007). It is thought that by recognising the most productive vegetation resources and determining their relative contributions, the limited resources for rehabilitation and management efforts can be focused on threatened, productive landscape elements (Crookes *et al.*, 2013).

Table 2. Cattle census data for each province in thousands. (Source: Department of Agriculture, Forestry and Fisheries, 2018).

Province	Total Cattle	Commercial Dairy	Beef and Dual Purpose	
			Communal	
Eastern Cape	3197	315	612	2270
Free State	2320	293	1962	65
Gauteng	276	75	201	N/A
KwaZulu-Natal	2805	318	955	1532
Limpopo	1181	18	420	743
Mpumalanga	1375	154	701	520
Northern Cape	491	25	466	N/A
North West	1816	114	1154	548
Western Cape	501	280	203	18
TOTAL	13 964	1592	6674	5696

3.2 Rainfall, crops and agricultural land abandonment

The environmental changes that have been observed in the Tsitsa River Catchment are largely as a result of government interference through social engineering, further exacerbated by global and local processes affecting agriculture (Beinart, 2008; de Wet 1989). Policies implemented through Betterment were often ineffective due to the lack of understanding of these social and environmental dynamics and gave little thought to the long-term viability of these plans. Local records from the Tsolo Prison in the Transkei (shown in 2.2.1) show rainfall was higher than average during the 1940s, when the designation of these agricultural areas was taking place, sitting at around 950mm. High-yield, rainfed crops such as corn were deemed to be a viable option for large-scale farming due to these high levels of precipitation. Yet these levels did not persist in the years following these interventions, reflecting the average rainfall seen in the area of around 700mm. This reduction and change in rainfall, combined with the absence of economic investment in these agricultural schemes are some of the reasons that led to their failure.

Without the economic investment needed, impoverished farmers were unable to farm the land on the industrial level needed to sustain such large human populations. There was little access to resources such as fertilisers, tractors and metal fencing. Many of these agricultural areas slowly failed due to this lack of monetary input, as well as the erratic changes in rainfall patterns that took place. One of the biggest reasons for a traditional dependence on livestock farming is its high flexibility for such environmental changes, indicating why it is often a successful livelihood in these areas. Many of these agricultural areas were slowly abandoned due to the high risk of failure of crops without adequate and steady investment in equipment and infrastructure, and there was often a return of these divided agricultural areas into areas that are communally grazed by livestock.

This process of de-agrarianisation led to the abandonment of many of these “arable” areas, now referred to as old, abandoned lands due to their continuing designation as agricultural areas but with an actual use as communally used grazing areas. This gradual process, as well as the diverse use of the landscape, shows how the degree of change and rehabilitation from a historical state is not uniform across a landscape due to the complex nature of these processes and the ways in which they took place over time.

Categorising whole environments simply as natural/unnatural or intact/degraded can often no longer reflect the complex variation that exists over these large and diverse landscapes, pointing to the need in view them as a complex mosaic of "patches" in varying states of modification (Hobbs *et al.,* 2009). Each patch may deliver assorted management challenges as well as opportunities in the various combinations of services that can be provided (Hobbs *et al.,* 2009). They may interact and affect larger-scale processes (e.g. water-flows, animal movements) across the larger environment, showing the need for conservation to acknowledge these diverse spatial changes (Hobbs *et al.,* 2009). Observing these distinctive primary characteristics and functions will therefore help to gain a greater understanding of the environmental dynamics that may exist on these larger landscapes, and how they might affect social systems.

CHAPTER 4: RESEARCH AND RESULTS

Introduction

As mentioned in the introduction to this paper, the research will aim to answer three keys questions:

1. After human disturbance, what are the components of the novel landscape that have developed?
2. How is it best to describe these components?
3. How do these landscape units perform in terms of their production?

The data to answer these questions will be gathered from four main areas:

- a detailed comparison of the current landscape of the Tsitsa River Catchment with the historical land use in the area;
- Earth observation and mapping of the current resources;
- field research and analysis of the current rangeland condition and production modelling;
- estimates of production from cover v biomass regressions for each cluster.

4.1 Novel landscape

4.1.1 Research

Analysis of historical aerial photography, historical satellite imagery and long-term rainfall databases

As a first approximation of the nature of change on these landscapes since the implementation of Betterment Planning, historical panchromatic aerial photography of the Tsitsa River Catchment was obtained from the Director General, Surveys and Mapping (DGSM) for 1958 and 1995. These panchromatic images are of very-high resolution (<1m per pixel) and provide clear evidence of the scale of the intervention (e.g. village creation, contouring) that was undertaken as part of Betterment Planning.

This date provides a comprehensive screenshot of the landscape at the height of its disturbance, just after Betterment had taken place, and with prior processes such as contouring still being apparent on the environment, and demonstrated the continuing processes of change on the landscape, such as agricultural abandonment, as well as passive rehabilitation.

Recent satellite imagery demonstrates the current state of being of the landscape, giving a useful contrast with the photographs from previous collections. Observations of significant land-use changes, land degradation and potential vegetation changes can be described from these comparisons. Google Earth Engine provides a time lapse feature giving access to a series of satellite images periodically recorded by Google Earth as far back as 1984 (although limited by resolution).

Combining these features enables one to gain a comprehensive understanding of the landscape changes that have been taking place prior to the 1950s and onwards, as well as raising questions about the possible ecological impacts these processes might have had on ecosystems in these areas. Several sites within the study area (each approximately 40-50ha in extent), representing a range of features (e.g. pre-colonial homestead arrangements, contoured lands, un-improved grasslands) were identified and the changes in these sites explored visually (eye-balled) over the time series available.

Livestock numbers

Livestock numbers for the magisterial districts of Tsolo (Figure 10) were obtained from the dipping tank records of the Eastern Cape Department of Rural Development and Agrarian Reform (DRDAR).

4.1.2 Results

Analysis of historical aerial photography and recent satellite imagery.

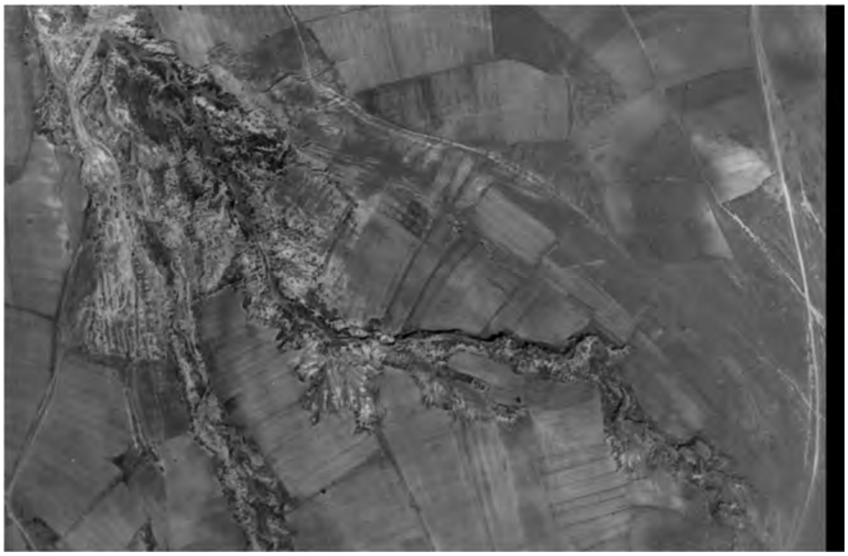

Figure 5: Panchromatic aerial photograph of the study area taken in 1958. From this image, the very-high precision of the contour preparation is obvious. This would have only been possible by using dumpy levels and graders to achieve the uniform surface texture.

Figure 6: An NDVI prepared from the very-high resolution Digital Globe imagery (2.5m spatial resolution), covering the same area in Figure 5. The texture of this 'active green signal' (a term used to describe the NDVI) from the grassed areas is a clear indication that grass cover is now even across most of the previously ploughed areas, and that there has been little or no change in the extent of the erosion gully since 1958.

Figure 7. Panchromatic aerial photograph of the study area taken in 1958.

Figure 8. An NDVI prepared from the very-high resolution Digital Globe imagery (2.5m spatial resolution), covering the same area in Figure 7. The texture of this 'active green signal' over the recovering grassed areas is once again a clear indication that grass cover is now even across most of the landscape, and that there has been little or no change in the extent of the erosion gully since 1958. Contour banks, representing 'run-on' areas of water flow, have a slightly higher NDVI than the 'run-off' areas that supply them with water.

Figure 9. The pre- (1958) and post-Betterment (2020) arrangement of homesteads within the Tsitsa River Catchment.

Betterment planning resulted in the re-arrangement of housing and homesteads (Figure 9). This had an important impact on the way households used the natural resources available to them (Palmer, A.R., personal communication).

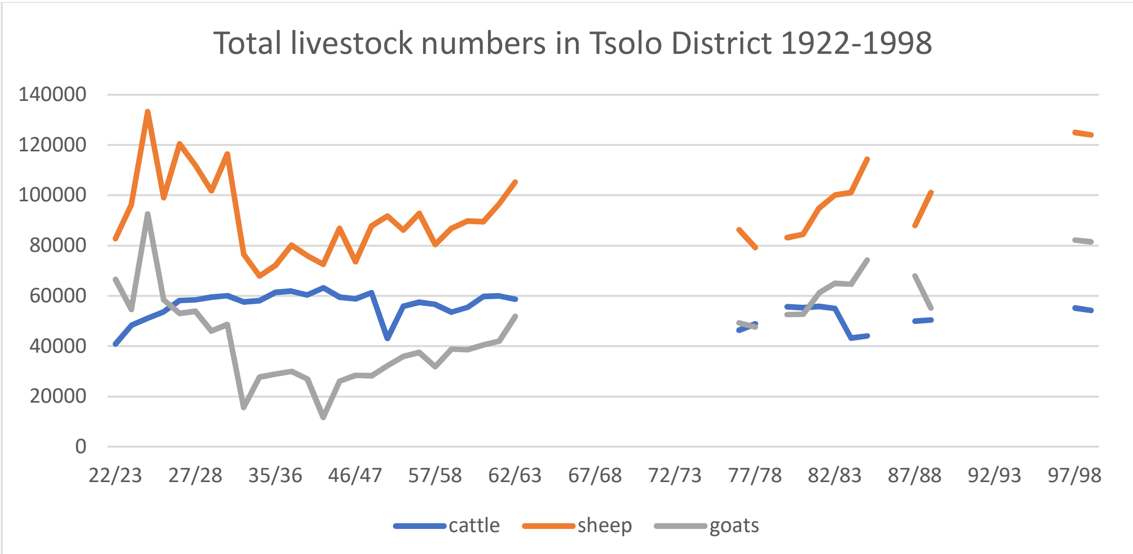

Figure 10.Total populations of sheep, cattle and goats for the Tsolo District from 1922-1998. This data was obtained from the records of the Veterinary Division of the Eastern Cape's Department of Rural Development and Agrarian Reform. Data collection for this district terminated in 1998 when the demarcation of magisterial districts was changed.

4.1.3 Discussion

The historical photography along with the livestock numbers indicate that the height of the large-scale landscape disturbances took place during the period of the 1940s/50s when Betterment was at its peak. The gullies that are now characteristic features of the environment were created primarily during the times of high disturbance, with ploughing, dividing and large-scale movement of people and livestock in these areas. In a rapid period of time, populations of people moved from being scattered across a large area into overpopulated conditions, and the results can be seen in the historical imagery.

Yet, when observing the landscape with the modern imagery, there has been no new creation of large-scale gullies since the time of these disturbances, indicating that since those initial changes, there have been no more alterations that have created such high levels of environmental change. In actuality, it appears from an initial observation that many of the gullies that were created have undergone a form of passive rehabilitation, with revegetation taking place in many locations, and the lack of spreading of these gullies across the landscape. Due to sociological processes such as rural-urban migration, there has since been an overall reduction of people living in these rural areas, and a movement towards large urban centres. With this being the case in the Tsitsa River Catchment, this then might indicate a reduction of human pressures on the landscape. Overall, the large-scale interventions that were seen in the 1940s/50s have not been repeated since and, accompanied by this overall reduction in the human population size, it has been shown that there is a possibility for this type of passive rehabilitation and the initial observation is that the landscape is on a trajectory of improvement.

4.2 Earth observation: mapping the current resources

Grassland vegetation is estimated to cover approximately 40 per cent of the Earth's land surface (Ren et al., 2018). Natural rangelands comprise most uncultivated landscapes in arid and semi-arid regions and support the livelihoods of many through the provision of ecological goods and services (Palmer & Bennett, 2013). However, many of these environments are under threat due to the rapid increase of urban development and agricultural crop production (Gwate, Mantel, Palmer, Gibson, & Munch, 2018). Land cover changes in the Tsitsa River Catchment show a decline in the area of unimproved grassland and an increase in woody cover from invasive alien plants (Gibson, Münch, Palmer, & Mantel, 2018; Münch et al., 2017)

Vegetation canopy cover provides shade and lowers soil temperature, causing moisture to precipitate in the form of dew, mist or rain, and creating a positive cycle for vegetation growth and moisture accumulation (Tsalyuk, Kelly, & Getz, 2017). Soil humus and root biomass retain soil moisture and are lost in the process of defoliation on a landscape (Ren et al., 2018). Nutrient cycling from these plant components are integral for the maintenance of soil quality, structure and fertility (Lal, 2015). The biomass stored in both grassland canopy cover and root biomass account for the bulk of carbon sequestration within these arid environments, underlining the importance of these resources in the context of climate change and high rates of global carbon emissions (Tsalyuk et al., 2017).

Invasion by alien woody species as a result of disturbance has been shown to cause an increase in rates of evapotranspiration (ET) on a landscape, causing an overall decline in water availability in these areas and large alterations to landscape hydrology (Gwate et al., 2018). Riparian vegetation, the plant ecosystems that exist around freshwater resources, plays an essential role in the control of soil and sediment that flow into aquatic systems (Sieben et al., 2016). The off-site effects of erosion include the mobilisation of sediments within aquatic systems, causing large-scale degradation to these ecosystems (Van Tol et al., 2016). Dams and reservoirs that are located within these systems face the issue of being filled with sediment, significantly reducing the carrying capacity for water (Van Tol et al., 2016). Silted, shallow dams will increase the evaporation of water out of these systems, as well as increase the costs for treating water (Van Tol et al., 2016).

Livestock production is one of the ecosystem services provided by grassland biomes, occurring on extensive ranches under freehold tenure or collective ranching under communal land tenure (Palmer & Bennett, 2013). Yet heavy, continuous disturbances through over-grazing and defoliation have altered the majority of landscapes and their associated vegetation around South Africa (Beinart, 2008). The reduction of vegetation cover leaves soil exposed to rainfall and wind, the treading of animals, and reduced root biomass, and puts it at a high risk for erosion and invasion by alien species (Lal, 2015). In the Tsitsa River Catchment, invasion by alien invasive plants (IAPs) is mediated through disturbance and abandonment of cultivated areas (Scorer, Mantel, & Palmer, 2019).

In arid and semi-arid areas, the links between drought, land management and desertification have been well documented (Vetter, 2009). It has been suggested that rangelands can exist within alternative vegetation states, characterised by the dominance of different functional groups such as trees, shrubs, perennial or annual grasses (Vetter, 2009).

The state-transition model (also known as the ball & cup model, Figure 11) has been used to describe this process of state change; with biotic and abiotic factors combining to force disturbed environments into altered states (Vetter, 2009). Abiotic factors, for example soil quality and rainfall, are often the largest determinant of primary production in rangelands, and also control the thresholds of a certain state and the amount of disturbance required to alter this state (Walker, Holling, Carpenter, & Kinzig, 2004). Acidic soils and low annual rainfall for example, will lower a state threshold and the amount of disturbance required for a state change, making it easier for biotic factors to cause a state transition (Walker et al., 2004).

Biotic factors such as livestock grazing and over-competition are often the mechanisms that cause a state transition in rangelands when environmental thresholds have been lowered (Vetter, 2009). Droughts are an example of a sustained abiotic pressure on an environment and are a common scenario where minimal disturbance can lead to a drastic change in vegetation (Vetter, 2009). Continuous overgrazing in these times of sustained pressure can lead to a dramatic loss of perennial grasses and shrubs, and can compound the overall grass mortality that already occurs during drought (Moyo, Dube, Lesoli, & Masika, 2010). Low grass density reduces the competition for woody shrubs in these environments and when large rainfall events do occur they are often more favourable for the seeding of woody shrubs (Moyo et al., 2010). Often these new environmental conditions put constraints on internal feedbacks such as soil changes and altered hydrology (Sieben et al., 2016). Resilience is described as the ability of an environment to retain its current state despite the disturbances that it is subjected to (Walker et al., 2004). Some of the most "degraded" states can be the most resilient as a result of these alterations, highlighting why state transitions can often be permanent or take significant effort to undo (Vetter, 2009).

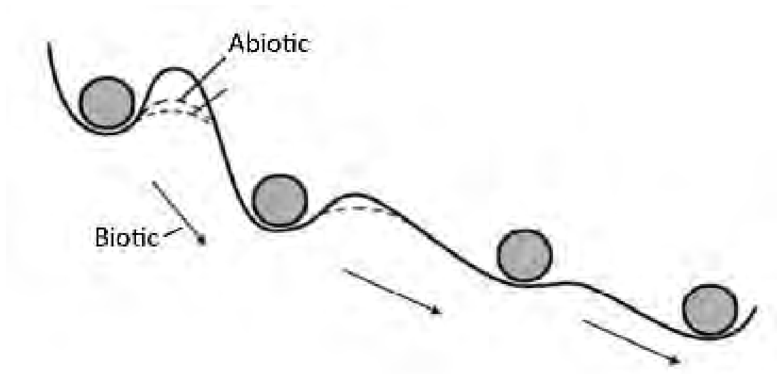

Figure 11: Ball and cup model of transitions between states in an ecosystem (Adapted from Vetter, 2009).

Rangeland degradation can be regarded as the "reduction of the capacity of the land to support society and development", and is often seen in the form of altered species and reduced biomass (Palmer *et al*., 2010). A change in the quantity and quality of forage material on the landscape is observed, seeing a rise in less palatable woody species and a loss of palatable grass species (Palmer *et al*., 2001). Rangelands have varied and diverse vegetation types which can be exploited by livestock farmers (Samuels, Cupido, Swarts, Palmer, & Paulse, 2016). Livestock choose their preferred grasses and shrubs, which are most palatable to them, in a process known as selective grazing (Samuels et al., 2016).

In communally managed rangelands, multiple livestock species (goats, sheep, cattle, horses, donkeys) are often kept to exploit different habitats within the rangeland to produce a wider range of livestock products such as milk, wool, skins and meat, and to reduce overall competition amongst animals when resources are scarce (Samuels et al., 2016). Despite the varied nature of grazing, primary areas of production have been shown to supply essential ecosystem services to livestock in the Tsitsa River Catchment (O'Farrell *et al*., 2007). Hill slope seep wetlands, riparian meadows, contour banks and natural grasslands are examples of productive vegetation resources that have been recognised as common feeding areas (O'Farrell *et al*., 2007). Selective grazing can simultaneously create and maintain grazing lawns, highlighting its potential for conserving rangeland condition (Bennett *et al*., 2007). Patches of highly productive and nutritious lawns (grazing lawns) can be created and used by a variety of grazers (J. Bennett et al., 2007). These often occur in areas of nutrient accumulation, particularly of nitrogen, for example fixed by *Vachellia* (*Acacia*) roots and around termite mounds, where grass is collected and deposited (O'Farrell *et al*., 2007). Areas of water run-off, such as contour ridges and roadside edges, also promote grass growth and are frequently grazed by livestock (O'Farrell *et al*., 2007). Hill slope seep wetlands are often considered valuable grazing resources for a variety of livestock, especially during dry seasons and drought (Libala, Palmer, & Odume, 2020). The carrying capacities of these areas are significantly higher than the surrounding rangelands (Libala et al., 2020).

If managed appropriately, grazing and burning can promote the biodiversity of grasses and sedges in these areas, highlighting the productive potential for grazing (Libala et al., 2020). Yet overstocking of vegetation resources can create a higher dependence on particular, more favourable vegetation types (Hoffman, 2003). Less palatable plants are overlooked by livestock and allowed to take root, altering the abundance of undesirable grasses, shrubs and trees (Hoffman, 2003).

In South Africa, there have been numerous efforts to use climatic conditions (annual mean temperature, precipitation, humidity) in order to model and predict expected vegetation types on the landscape (Barbosa, Pillar, Palmer, & Melo, 2013). These models can allow one to determine the likely vegetation that would exist without human-induced land use change and defoliation. For example, (Robertson & Palmer, 2002) used the South Africa Atlas of Climatology and Agro-Hydrology (Schulze et al., 2008) to predict the potential distribution of *Portulacaria afra* after degradation as a result of Angora goat farming, in order to prioritise areas of rehabilitation.

(Palmer & Van Staden, 1992) attempted to model the veld type present on the landscape using rainfall and elevation data, and this was then compared to a digitised version of (Acocks, 1953) classification of veld types in South Africa. These particular studies were somewhat limited by spatial resolution, inhibiting their ability to create local-scale models; but as satellite platforms and GIS software has improved, local-scale models of potential vegetation have become more feasible to attempt (Barbosa et al., 2013).

The aim of this research is to identify these key vegetation resources, determine their condition and annual production, and to ascertain the potential economic benefits that can arise from their conservation.

4.2.1 Research

Acquisition of very high resolution DigitalGlobe Imagery.

The very-high-resolution data (<1m per pixel) that are available from commercial satellites (e.g. Quickbird, IKONOS, Worldview) is extremely costly (~USD1,000 per scene) and was initially unaffordable for this project. However, the Digital Globe Foundation (DGF) offers data for experimental and non-commercial purposes free-of-charge based on the merit of the application. An application (Appendix 1) to DGF was prepared and was favourably received, and several scenes were selected and provided at no cost. The following scenes were selected and downloaded (Table 3). As the very high resolution of these data provides a better option for identifying small features on the ground, such as termite mounds and small trees, all further analysis of pattern in the clusters was carried out on these images.

Maps and histograms generated from cluster analysis

Without any prior knowledge of the land cover in the study area, an unsupervised classification was adopted (Richards, 2013) in which the analyst takes no part in an algorithm's learning process. Several methods are available for unsupervised classification but the most common uses clustering algorithms, which identifies pixels in an image that are spectrally similar.

Being freely available at high temporal resolution, Sentinel 2 satellite imagery was selected and downloaded from the United States Geological Society (USGS) using the Earth Explorer application (https://earthexplorer.usgs.gov/). Scene selection was based on cloud-free imagery during the growing season that corresponded with dates closest in advance of the planned field survey. Sentinel 2 provides 13 bands per downloaded image at varying resolution and spectral characteristics per band (Table 1). All data had been geometrically corrected to UTM projection using the Geodetic System WGS84. and represents top of the atmosphere (TOA) radiometric correction. Data were re-projected into a geographic projection to enable efficient field verification of location. Primary analysis was performed in IDRISI Terrset (Eastman, 2017). The green, red and near infra-red bands from the imagery were used in the cluster analysis function. This unsupervised classification procedure uses a histogram peak technique.

> "This defines peaks in a one-dimensional histogram, where a peak is defined as a value with a greater frequency than its neighbours on either side. Once the peaks have been identified, all possible values are assigned to the nearest peak and the divisions between classes fall at the midpoints between peaks. A peak is thus a class where the frequency is higher than all of its cardinal neighbours. The diagonal neighbours are omitted because of the correlation between bands." (Eastman, 2017).

The CLUSTER algorithm is modified from a histogram peak technique (Richards, 2013). A broad generalisation was chosen, the least significant clusters were dropped and clusters representing three cover classes not of interest in this study, namely wattle plantations, villages and severe gully degradation, were removed using a data mask and not used in further analysis. The remaining clusters were thought to represent the various rangeland conditions that may exist on the landscape and that would need further ground-truthing.

Table 3. Spectral characteristics and resolution of each band of Sentinel 2.

Band	Use	Wavelength	Resolution
B1	Aerosols	443nm	60m
B2	Blue	490nm	10m
B3	Green	560nm	10m
B4	Red	665nm	10m
B5	Red Edge 1	705nm	20m
B6	Red Edge 2	740nm	20m
B7	Red Edge 3	783nm	20m
B8	NIR	842nm	10m
B8a	Red Edge 4	865nm	20m
B9	Water vapour	940nm	60m
B10	Cirrus	1375nm	60m
B11	SWIR 1	1610nm	20m
B12	SWIR 2	2190nm	20m

Table 4: Spectral and resolution details of the Quickbird imagery that was provided free-of-charge by the Digital Globe Foundation.

Parameter	Panchromatic imagery	Band 1	Band 2	Band 3	Band 4
Spectral range(s)	0.45 - 0.90 µm, grayscale	0.45-0.52µm	0.52-0.60 µm	0.63-0.69 µm	0.76-0.90 µm
Spatial resolution, IFOV	0.61-0.72 m (GSD), 1.37 µrad	2.4-2.6m (GSD), 5.47 µrad	2.4-2.6m (GSD), 5.47 µrad	2.4-2.6m (GSD), 5.47 µrad	2.4-2.6m (GSD), 5.47 µrad
Scene ID	17APR28081619-M2AS-058533057010_01_P001				
Date Acquired	15/10/2018				

4.2.2 Results

Maps and histograms generated from cluster analysis

An initial map of the Tsitsa River Valley was composed of the blue, green and near infra-red Sentinel bands displaying the landscape in a visible spectrum for observation (**Error! Reference source not found.**). The river can be seen flowing through the middle from west to east. The surrounding landscape is highly heterogeneous, showing high levels of gully erosion in some areas, wattle plantations, homesteads, as well as large grasslands in between these. This image demonstrates the high levels of erosion that are present on this landscape and how erosion in this area directly impacts the landscape condition as well as river health in the catchment. However, areas of high vegetation growth can be clearly seen amongst these areas of degradation, showing the potential for rehabilitation in the landscape and the need to address these landscape condition factors in a more focused manner.

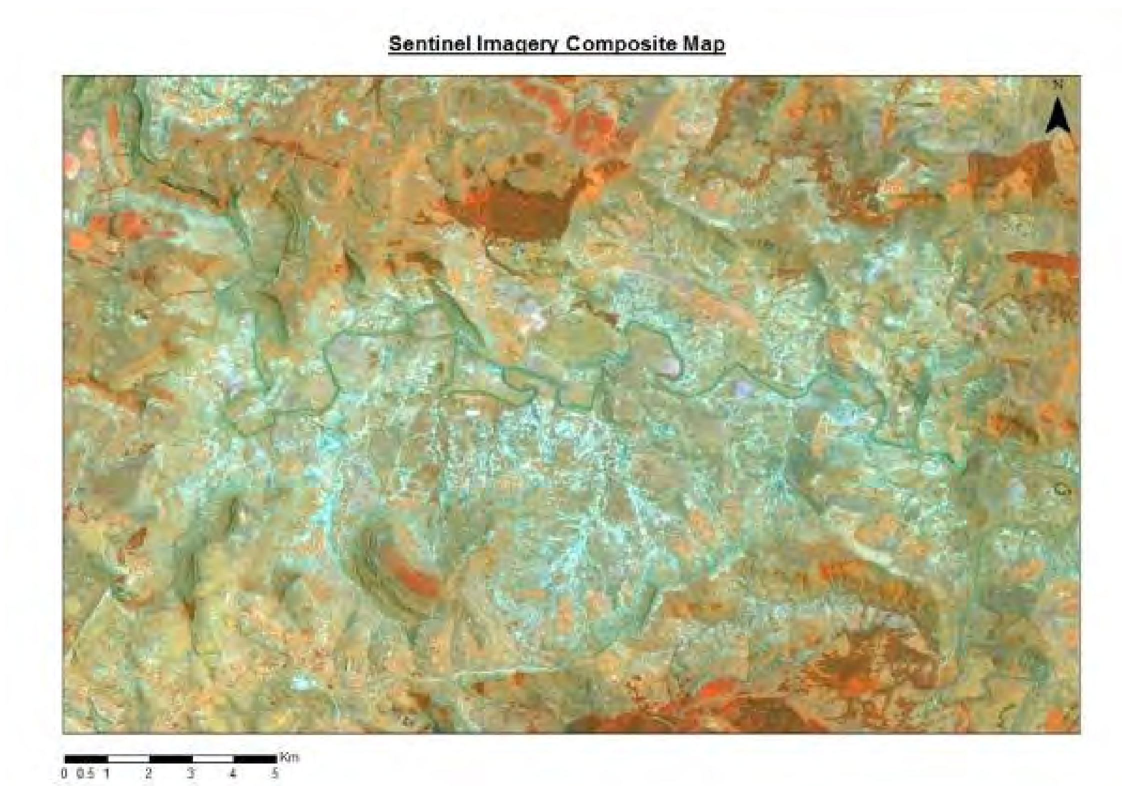

Figure 12: Three band colour composite of the study area (Sentinel 2 Date of image)

A cluster analysis was performed by IDRISI using four bands of Sentinel 2 imagery (Figure 13). This un-supervised classificaton created nine classes based on the characteristics seen in the landscape, but these were not all relevant for analysis of grassland patterns and production. Clusters 1, 2, 5 and 8 were identified as rangeland areas in which livestock could possibly be found and which were dominated by grass and tree cover. The other clusters include areas of wattle and pine plantations (3, 4, 9), as well as homestead areas, including home gardens and small areas of cultivation (<1ha)(6, 7).

Preliminary and general observations were made about the condition of each cluster, based on the areas which they overlie. For example, it was shown that cluster 9 fell over the large gully formations seen in Figure 7 indicating that it could represent the gully formations and the potential erosion present there, as well as also the potential vegetation rehabilitation occuring within the gullies.

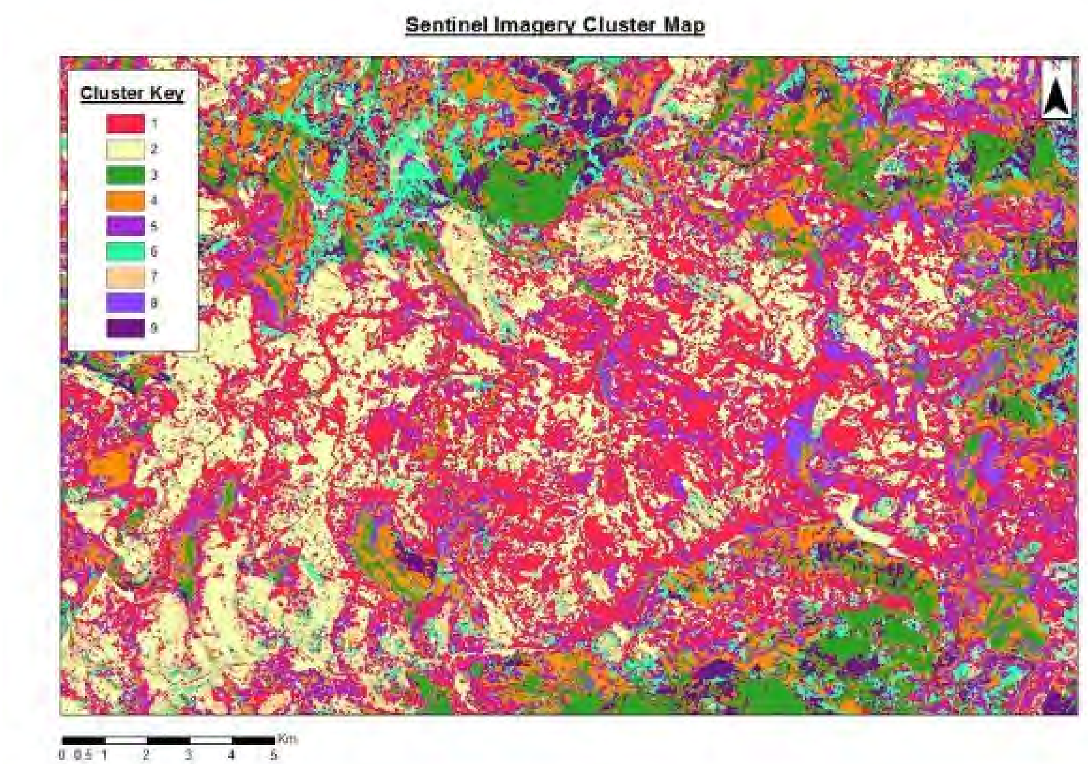

Figure 13. Cluster analysis of Sentinel 2 imagery

The recommended DAFF model showing the number of hectares needed to sustain each head of cattle in that location is shown in Figure 14. In the study area, 5 hectares of rangeland is needed on average to sustain a head of cattle (450kg large stock unit) due to the rangeland conditions present.

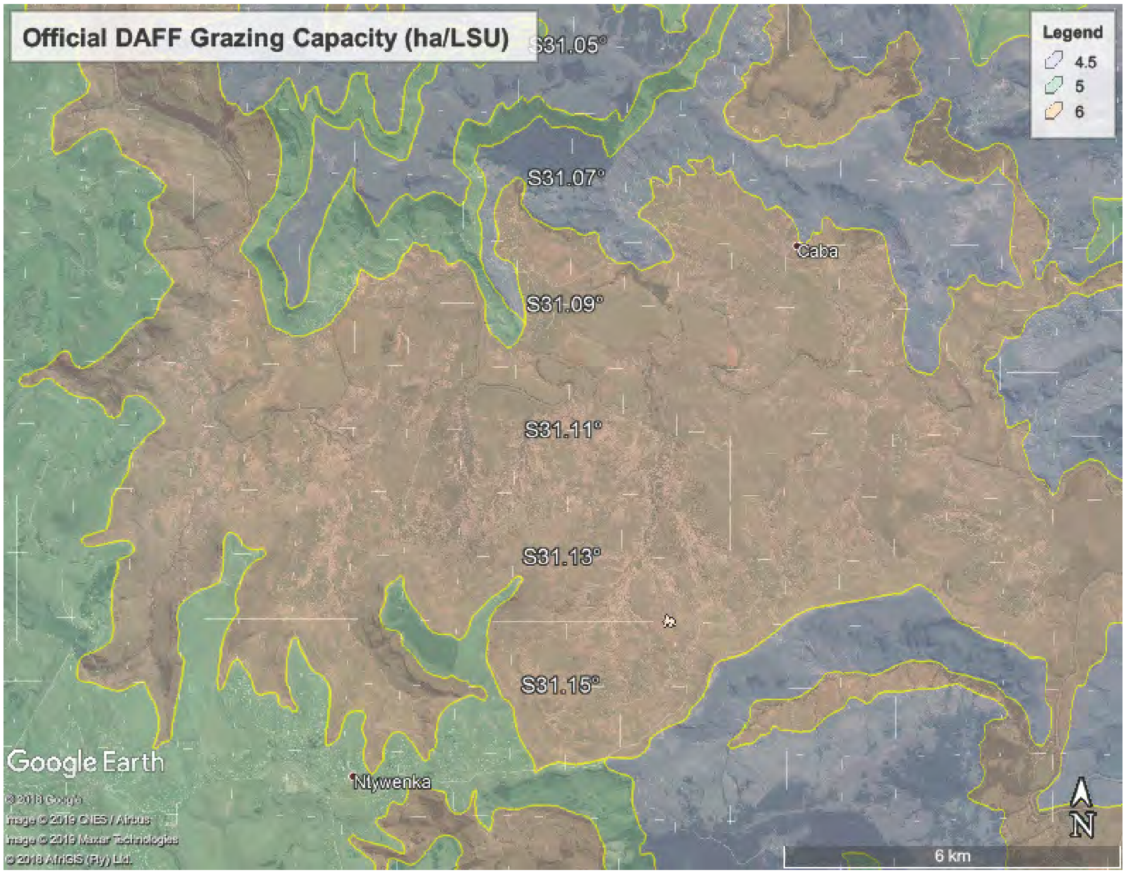

Figure 14: DAFF Map of Grazing Capacity (ha/LSU) of study area.

4.2.3 Discussion

The un-supervised classification of the Sentinel 2 data provided a suite of five clusters that showed important differences in the above-ground production and structure. This provided the first approximation to enable more detailed survey and analysis of the abandoned arable lands. Further description and analysis of patterns within each of these clusters was necessary to confirm the ecological and structural nature of these differences.

4.3 Current rangeland condition and production modelling

4.3.1 Field survey of current ecological status of clusters. line transects, cover, functional types, photographs, slope

Three field campaigns were arranged to collect data on the canopy cover (grass, herbs and trees), plant structural characteristics (growth form) and associated landscape features (presence of landscape engineers such as termites and mole rats).

GIS and RS data can be an extremely valuable tool and highly accurate, yet the remote nature of this data collection can often present limitations for the analysis of smaller landscape features. Simple errors as well as factors such as atmospheric distortions are examples that show the need for direct observation in order to make definitive knowledge claims and collection.

The IDRISI cluster function created nine classes based on the characteristics seen in the landscape. Of the clusters created within IDRISI, not all were relevant for grassland analysis due to the nature of vegetation observed remotely, as well as due to access by livsetock. These included areas of wattle and pine plantations (3, 4, 9), which were removed due to the difficulty in retrieving accurate GIS data below the tree canopy, and due to the lower amount of time spent by livestock in such locations due to lack of grass abundance and palatability. Homestead areas (6, 7) which have been recognised as highly productive livestock areas due the associated grazing lawns (Palmer and Fortescue 2004), were also not sampled in this project due to complex nature of the reflectance patterns and the intrusive nature of performing ground truthing experiments on private property. These locations are also highly heterogenous and intermixed with human activities and disturbances and so would have presented a overly-complex environment to sample systematically. The remaining clusters 1, 2, 5 and 8 were identified as rangeland areas in which free-ranging livestock had access, predominantly comprising valley bottom and lower slopes.

Once these clusters had been identified, random GPS points were generated in IDRISI and distributed across the cluster types. From these, 60 sample points were selected across the clusters in order to have adequate samples for each cluster. Finally, points were chosen based on their proximity to roads to offer easy access, as well as centrality within the measured cluster to ensure there was no overlap between points into neighbouring clusters.

Once at the site, 10m line transects were surveyed following (Flombaum & Sala, 2007) to describe the vegetation cover in the transect, including identifying the vegetation functional group, measure the cover, observe human disturbance, as well as animal and grazing activity, and to obtain photographic evidence. Data were captured using a custom-designed application in Kobo-collect using a hand-held Android device (Appendix 2). The percentage of canopy cover of each functional group was determined in each transect and the canopy cover (the plant area at the base, next to the ground) of each individual plant was measured. Specific species identification was not performed due to the limitations in identifiable features of the observed grasses present. Grasses had often been significantly grazed, predominantly leaving grass stubs that made specific identification difficult other than the basic functional groups, namely: prostrate perennial, erect perennial, stoloniferous perennial, forb, dwarf shrub, tree or bare soil. The total cover was measured for each functional group out of 10 metres and converted into a percentage value for further analysis.

Table 5. Description of the plant functional types used in this study.

Functional Type	Dominant species in the group	Grazing value	Leafiness
prostrate perennial grass	*Paspalum dilitatum*	High	High
erect perennial grass	*Themeda triandra, Heteropogon contortus, Digitaria eriantha, Eragrostis plana, E curvula*	High	High
stoloniferous perennial grass	*Cynodon dactylon, Pennesetum clandestinum*	Moderate	Low
forb		Low	Very low
dwarf shrub	*Chrysocoma ciliata, Felicia filifolia*	Moderate	Low
tree	*Vachellia karroo*	Moderate	High
bare soil			

The Department of Agriculture, Forestry and Fisheries (DAFF) has mapped the grazing capacity of South Africa, which is provided for the study area (Figure 14.) The recommended number of hectares per head of livestock (ha LSU^{-1}) is displayed, giving insight into the recommended stocking rates applicable for this area. This map was developed after a community-based assessment using expert knowledge and has not been validated against any production models (Palmer, personal communication.).

Estimates of production from cover v biomass regressions for each cluster. (Flombaum and Sala (2006), regression equations from Gwate (2016)).

Above ground biomass production - the total amount of biomass produced above ground by a plant within a year - has been used as one indicator for rangeland health. It directly translates into grass abundance, which has a direct impact on the stocking rates and presence of livestock in such locations. Regression equations have been successful at estimating the above-ground biomass of grass using the percentage of basal cover in a transect, such as the one provided by (Flombaum & Sala, 2007). These equations have been shown to be accurate in measuring the almost constant relationship between the basal cover of grass and its likely annual production of biomass. Gwate (2016) worked to modify this equation in order to obtain a regionally specific regression that can accurately represent the growth rates of grass within the sub-humid grasslands of the Eastern Cape, South Africa (Figure 9). Grass cover percentages were inserted into this equation in order to estimate the above ground biomass of each sample. This could later be compared to similar GIS and remote sensing estimates on the same sites.

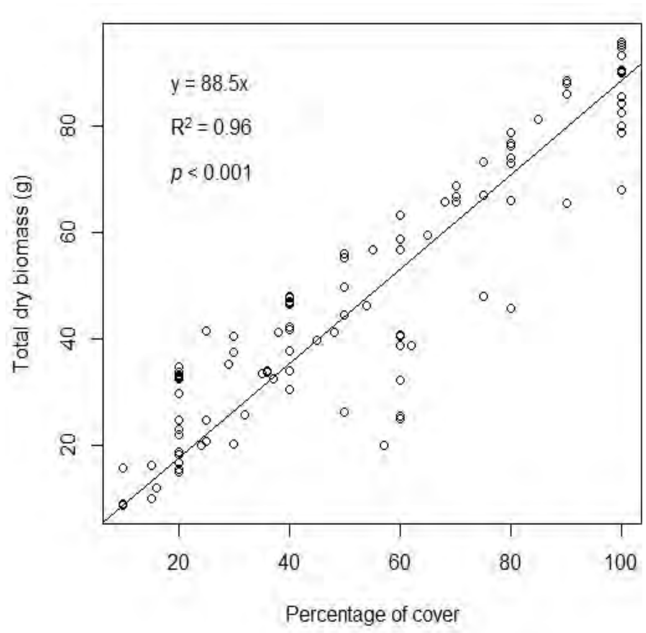

Figure 15. The relationship between grass canopy cover and production (from Gwate, 2016) that was used to predict annual production from line transect data.

Within Google Earth Engine (GEE) environment, the MODIS PsnNet product Photosynthesis Net Primary Production of each cluster type was examined in order to compare production with that determined from the line transect data. These were displayed graphically alongside the footprint areas. From these, the cluster characteristics were better interpreted in order to name and identify each cluster type.

Analysis of the spatial patterns in satellite imagery associated with each cluster. Textural analysis of all satellite bands.

Cluster characteristics were examined order to provide further perspective on the textural characteristics of these landscape units. High values of certain textural indices (e.g. patchiness, fragmentation, standard deviation) indicate degradation of a landscape, where resource control (flow of water and nutrients) is impaired, and water and nutrients are lost from the landscape (Palmer et al., 2001; Tongway & Hindley, 2004). Boxplot were prepared in R-console (R Development Core Team, 2015) to compare grass production and fragmentation for each band by cluster within the very high resolution (2.5 m resolution) Digital Globe imagery.

NDVI values were extracted from Digital Globe for each of the 60 sample points, and put into an Anova test using R-console. These NDVI values were also plotted against the grass production of each point in order to determine any possible relationships that may exist.

4.3.2 Results

Above ground production from cover v biomass regressions for each cluster.

Vegetation cover data and biomass estimates from Gwate (2016) were displayed in Figure 15. Many of the recorded transects had a high grass cover, indicating a high overall production of grass biomass within the study area. These preliminary results indicate that not all areas are highly degraded, and many areas provide substantial biomass production that can be used for grazing. There are still areas of low production, highlighting areas of potential degradation that may be in need of rehabilitation.

The photosynthesis net production (MODIS Psnnet) for each cluster footprint is shown in the figures 16-19. There are distinct differences within these observed areas, highlighting the diversity present in the landscape. Cluster 1 (Figure 16) is of poor condition due to its low grass cover, lowest above ground production (308 g DM m^{-2} yr^{-1}) and obvious evidence of recent cultivation. These grasslands have been subjected to human disturbance in the most recent past, indicated by the presence ploughing furrows in the landscape. There are signs of passive rehabilitation in this location, indicating potentially good use for livestock grazing. The contour banks are stable run-on areas with low grass production.

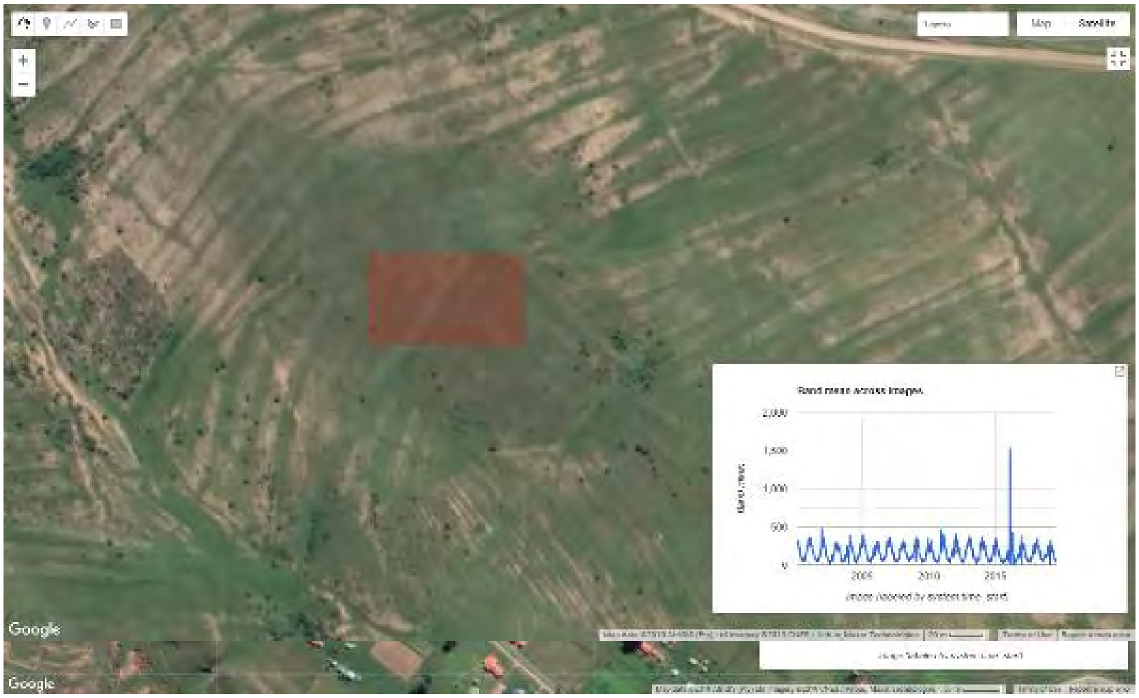

Figure 16. Footprint of portion of cluster 1 (red square) with the MODIS PSNnet time series (inset) showing that this is one of the least productive clusters, associated with the alluvial soils on abandoned cultivated land.

Cluster 2 appears to be less degraded than cluster 1 (Figure 17). There are signs of recent anthropogenic disturbances (e.g. ploughing and cropping activity), with contour created during Betterment less visible than in cluster 1. There are fewer trees present than in cluster 8, but they are beginning to appear on the landscape. These partially degraded rangelands show the need for adequate control and protection of vulnerable landscape elements, yet also of the resilience of these environments and current potential for productive grazing.

Figure 17. Footprint of portion of cluster 2 (red square) with the PSNnet time series (inset). Although this cluster is less productive than clusters 5 and 8, there is evidence of patchy growth areas and stabilization of post-cultivation erosion.

Cluster 5 (Figure 18) has the highest overall productivity (417 g DM m^{-2} yr^{-1}) and grass cover. This is shown by the rich green colour that can be seen in the observed footprint, as well as the relative homogeneity of the grass cover. These areas appear to be the result of seep runoff within the landscape, often caused by impermeable rock layers that force lateral water flow which reaches the surface as a hillslope seep. This change in runoff has a large effect on the grasses below this water source, often creating zones of high production where grass is palatable and highly abundant. There seems to be little anthropogenic disturbance, possibly resulting in the lower levels of erosion in such locations. These seep runoff areas are frequently small and hard to identify, especially through remote sensing, and so can be overlooked. However, they can provide a substantial amount of the grazing production in these landscapes and so are highly valuable to identify and analyse.

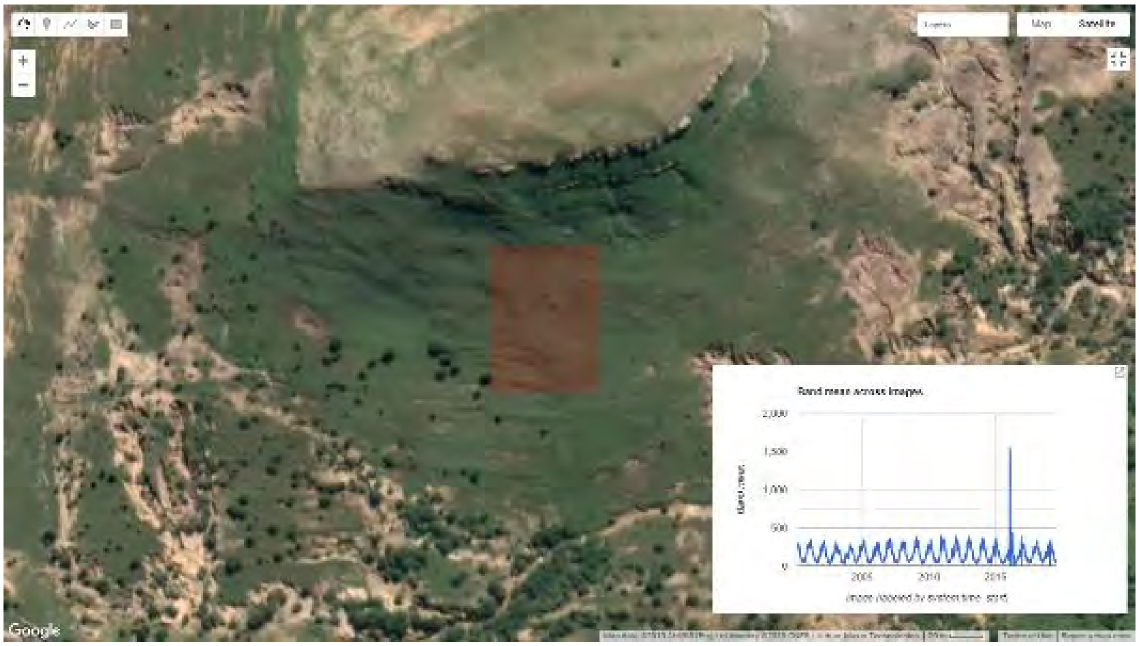

Figure 18. Footprint of portion of cluster 5 (red square) with the PSNnet time series (inset) providing darker green colour indicating that this is a more productive portion of the landscape than the adjacent abandoned eroded area. This is associated with the seep.

Cluster 8 (Figures 19 and 20) has moderate to high above ground production (374 g DM m^{-2} yr^{-1}) (Table 5) characterised by high level of grass cover and moderate tree cover, yet with differences in characteristics when compared to the other rangeland conditions. There are many more trees present on this landscape than on any of the other clusters. However, these trees can often be locations of nitrogen fixation, promoting the growth of palatable grasses and therefore increasing the grazing value of these landscapes. Cluster 8 is found on the lower hill slopes and rocky locations in the study area. These steep and rocky conditions may be less ideal locations for cattle grazing for example, but may still be highly valuable for smaller animals, including goats and sheep. The lack of erosion and general abundance of grass point to it being a high area of production. This was further confirmed in the analysis of the MODIS net primary production product (Figure 19).

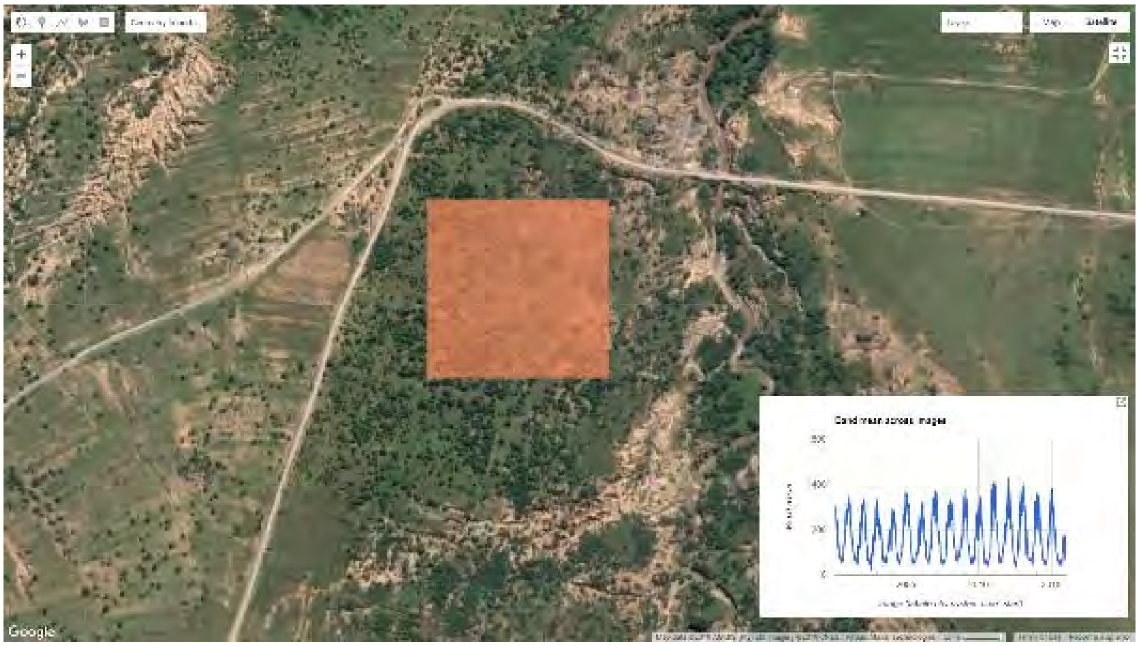

Figure 19. Footprint of portion of cluster 8 (orange square) with the PSNnet time series (inset) showing that this is the second most productive cluster, with high woody biomass, dominated by Vachellia karroo.

Figure 20. Lateral view of cluster 8, showing the establishment of V. karroo. These trees act as nutrient hotspots, providing shade during the hot months, and forage in the form of leaves and pods throughout the growing season. The termite mounds in the foreground are heavily grazed, whereas the tougher, less palatable grasses are un-grazed.

Figure 21. Cluster 9. Degraded erosion gully with very low vegetation cover, representing the dispersive quaternary alluvial soils. The centre of the MODIS pixel is located at the red dot.

The gullies (Figure 21) represent a fifth rangeland unit within the abandoned arable lands. A visual comparison between these areas using contemporary very-high resolution infra-red satellite imagery has revealed that their shape and size have not changed since the earliest aerial photographs captured in 1957 (Figures 6 & 7). Although not specifically sampled during this study using the line transect method of Flombaum and Sala (2007), they do represent an important contribution to the above-ground production of these rangelands. Livestock were seen to be using these areas during every field campaign conducted, suggesting that there is more work to be done on assessing the contribution of these areas to livestock productivity.

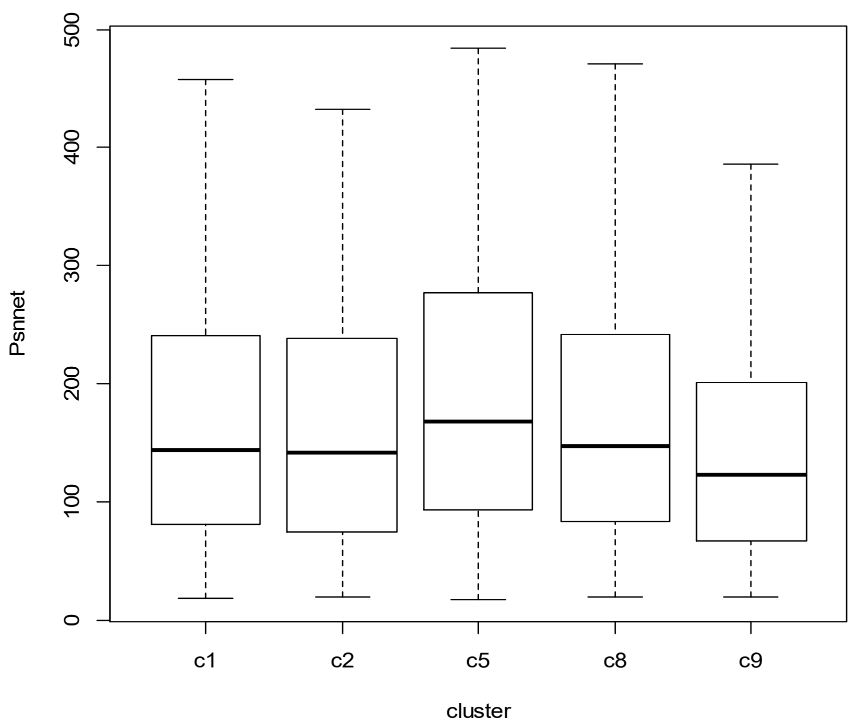

Figure 22. Boxplot of the differences between the mean MODIS PsnNet values of the five cluster classes used in this analysis. The degraded cluster (cluster 9) has been added to demonstrate the relatively small differences in net primary production between clusters with vastly different vegetation cover.

Analysis of the spatial patterns in satellite imagery associated with each cluster.

Textural analysis of all satellite bands

A boxplot is used to demonstrate the differences in net primary production observed by MODIS PsnNet between each cluster (Figure 22). Cluster 5 (seep runoff) was shown to have the highest overall production out of the clusters, followed by 8 (rocky grassland) and 2 (moderately degraded). Cluster 1 was shown to have the lowest average overall, showing a less desirable condition. Although cluster 2 was observed to fall over the gully formations, it is possible that vegetation growth within the gully could indicate potentially moderate grass production inside.

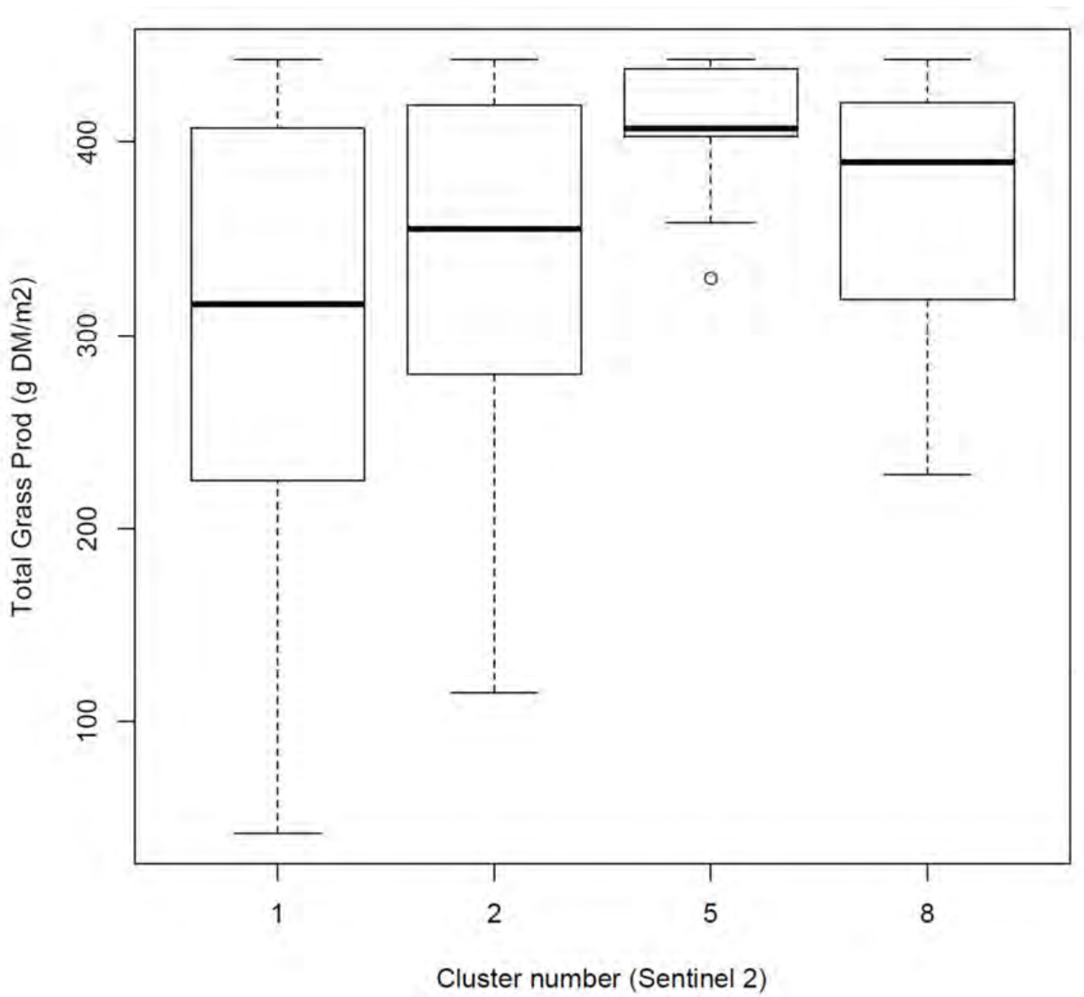

Figure 23. Grass production by cluster.

Table 6. Summary statistics of the total production for samples in each cluster based on Gwate (2016) and Flombaum and Sala (2007).

Cluster	**Mean** (g DM m^{-2} yr^{-1})	**Std dev**	**n**
1	308,6	116,0	19
2	343,1	89,2	20
5	417,5	30,6	13
8	373,9	75,6	8

Table 7. Predicted annual dry matter production (kg DM m^{-2} yr^{-1}) using canopy cover and DPM method.

Site	**Location**	***MAR (mm)**	****DPM method (Bransby and Tainton 1977)**	**Line intercept (Flombaum & Sala 2007)**
			++ANPP g +DM m^{-2} yr^{-1}	**++ANPP g +DM m^{-2} yr^{-1}**
Sinxaku Cluster 1 (this study)		610	N/A	308
Sinxaku Cluster 2 (this study)		610	N/A	343
Sinxaku Cluster 5 (this study)		610	N/A	417
Sinxaku Cluster 8 (this study)		610	N/A	373
Quaternary S50E (Gwate 2017)	31°40'41 S 27°35'12 E	772	324	314
Quaternary T12A (Gwate 2017)	31°31'25S 27°45'27E	655	270	283
Quaternary T35B (Gwate 2017)	31°04'05 S 28°17'34E	786	348	288
Combined (S50E, T12A & T35B)	(see above)		314	290
Danckwerts & Trollope (1980, grazed trial)	32°42'05 S 26°27'18E	409	252	N/A
O'Connor (2008, grazed commercial and communal rangelands)	29°45'01 S 29°33'07E	893	292	N/A
	29°49'01 S 29°37'57E	862	244	N/A
Everson & Everson (2016, biennial burnt)	28°56'17 S 29°157'41E	880	471	N/A
Ndovela (2014, un-grazed burning trial)	32°32'28 S 27°27'47E	680	254	N/A

*Mean annual rainfall, ******Disk pasture meter, +Dry matter, ++Aboveground primary net productivity

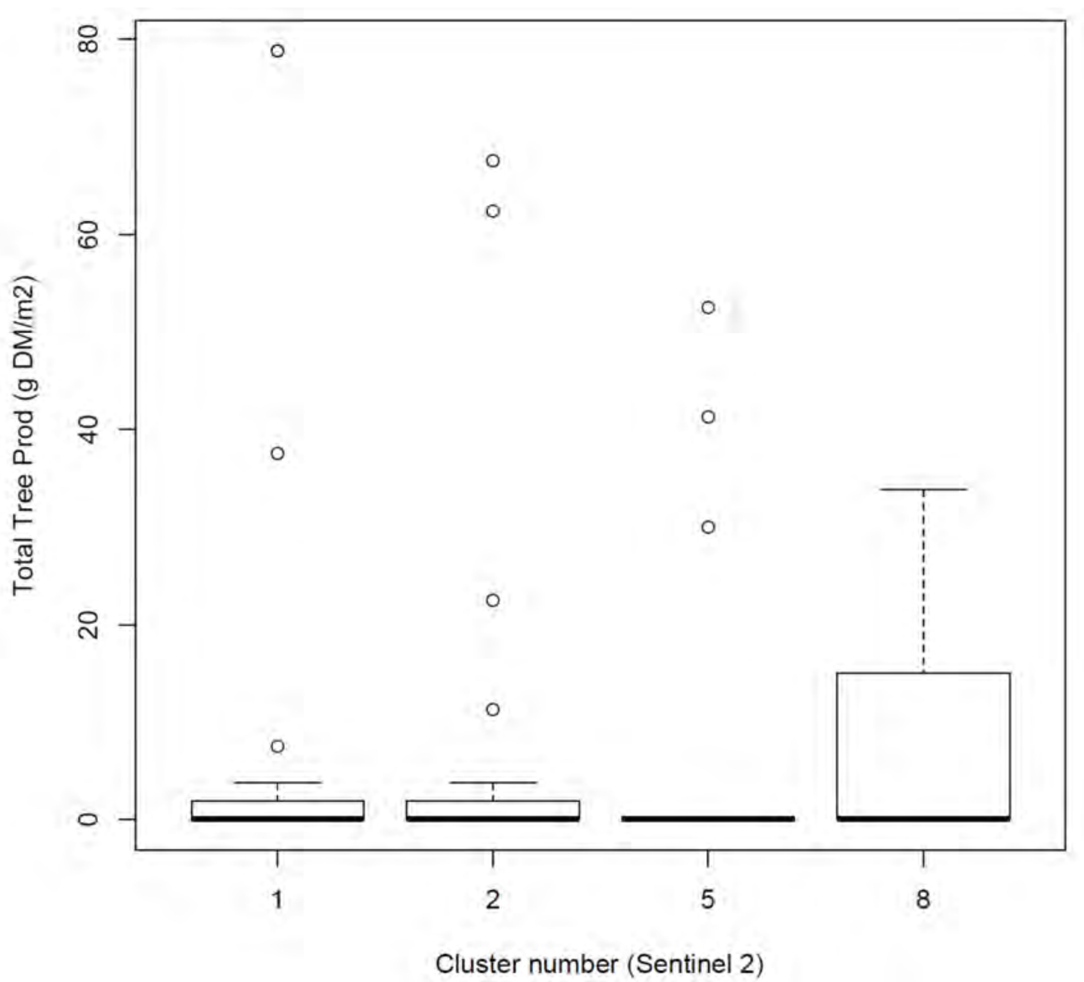

Figure 24. Tree production (g DM per m^{-2} yr^{-1}) by cluster.

Fragmentation of landscape

The differences in fragmentation for the Digital Globe (DG) blue band (band 1) imagery are provided (Figure 26). The degraded cultivated lands (cluster 1), seep areas (cluster 5) and rocky grassland (cluster 8) all showed relatively similar values for fragmentation, indicating relatively homogenous conditions. Yet the high fragmentation in previously moderately degraded rangeland (cluster 2) could be due to its inclusion of gully formations where soil colour is more variable due to the exposure of shales, which could have high heterogeneity as a result. This could be due to the mix of erosion and vegetation production that could occur in these locations.

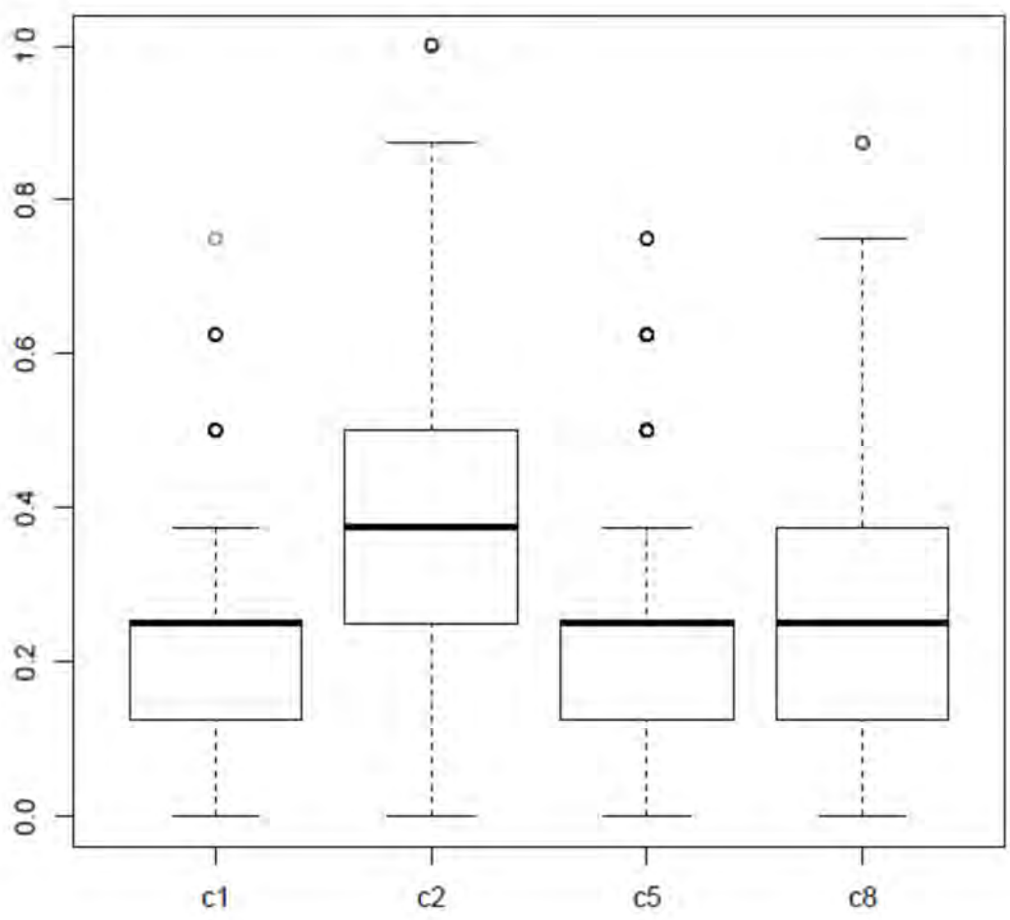

Figure 25.. Fragmentation by cluster of DG blue spectral band (band1)

The fragmentation of pixels in the DG green band (band 2) shows similar results (Figure 25), indicating that the previously degraded rangeland had the highest levels of fragmentation out of all the clusters. Again this could be due to the gully formations that are present within this cluster.

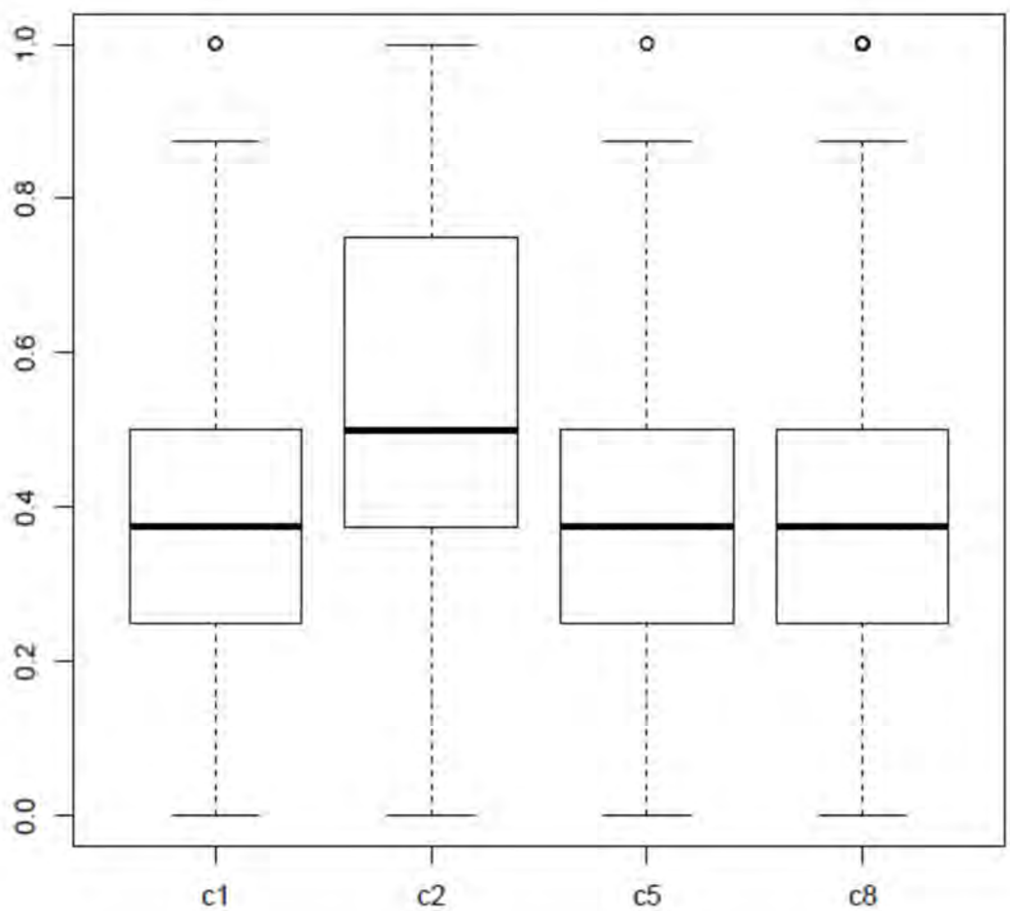

Figure 26. Fragmentation by cluster of DG green spectral band (band 2)

The fragmentation of band 3 also yields similar results, yet does show a lower overall fragmentation within the seep areas, shown in (Figure 27). This was also previously shown to have some of the highest levels of grass cover and production, indicating that, in this case, less fragmentation may mean more consistent grass cover. The previously degraded rangeland and rocky grasslands are shown to have similar fragmentation values, but the variability within rocky grassland is significantly higher showing large differences between sampled points.

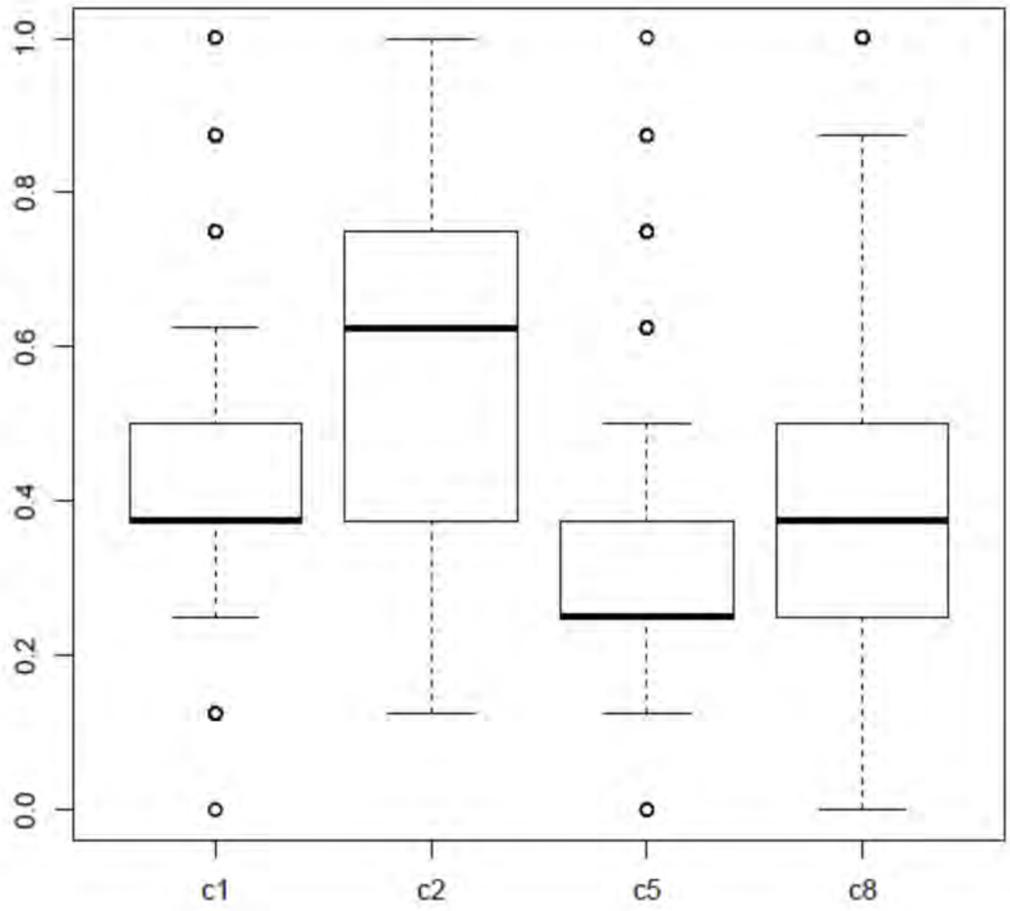

Figure 27. Fragmentation by cluster (band 3)

The fragmentation of band 4 (near infra-red) shows no differences in the values between each cluster type (Figure 28). The overall average for each cluster is the same, indicating homogenous conditions with regards to near-infrared reflectance.

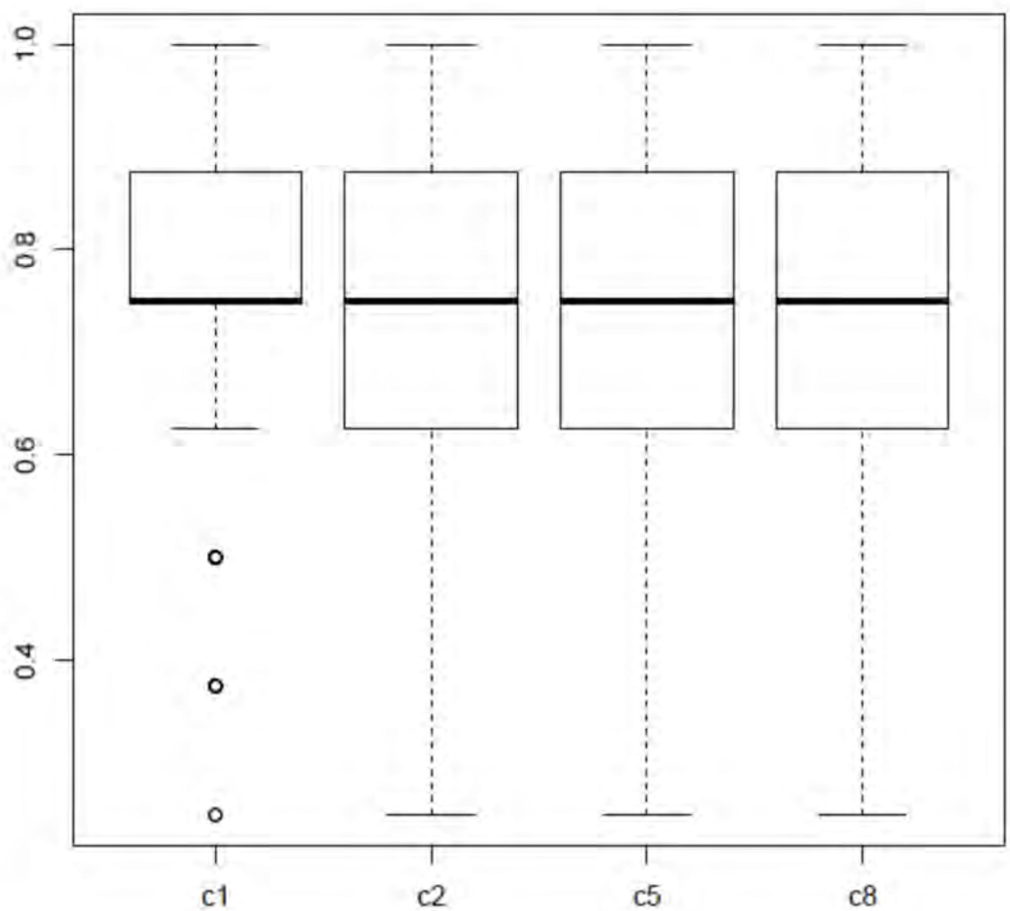

Figure 28. Fragmentation by cluster in DG near infra-red band (band 4).

The fragmentation of the NDVI values within each cluster were also measured (Figure 29), with the hill slope seeps areas having a higher overall fragmentation.

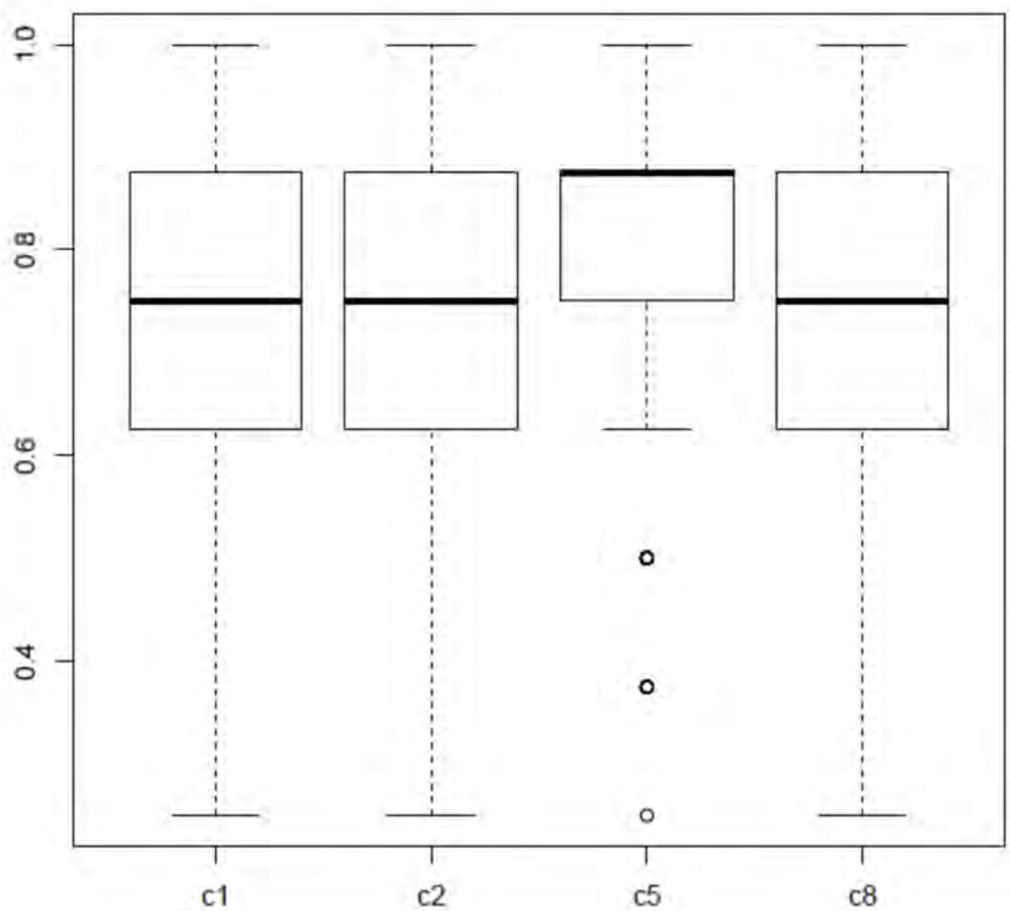

Figure 29. Fragmentation by cluster (NDVI)

The relationship between the observed grass cover and the NDVI of each transect was also plotted in Figure 30. It was thought that the highest cover would naturally have the highest NDVI values, yet this was often not the case and areas of lower grass cover still yielded high NDVI values.

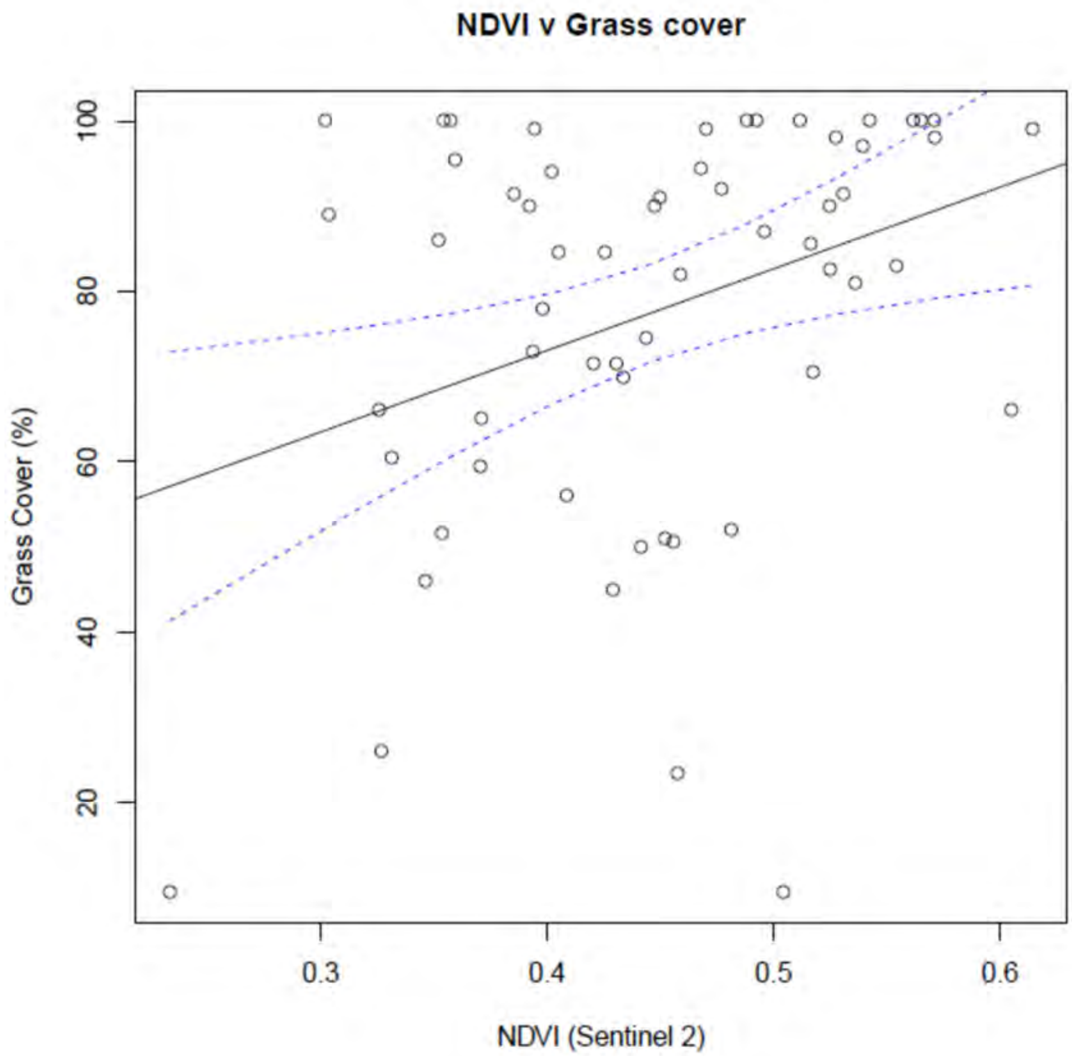

Figure 30. Relationship between observed grass cover and NDVI.

This same relationship was also graphed using a scatter plot diagram, shown in Figure 31. Again, this graph shows that the relationship between the grass cover and NDVI values is not always linear and straight forward, and that further insight into cluster characteristics is needed in order to explain this relationship.

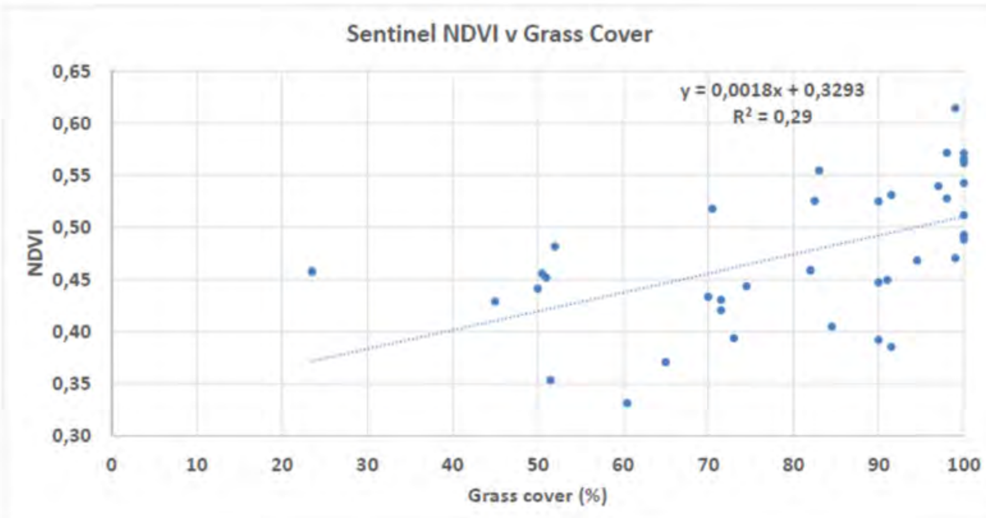

Figure 31. Scatter plot graph of grass cover vs NDVI.

CHAPTER FIVE: CONCLUDING DISCUSSION

The historical analysis of central government policies and their associated interventions undertaken during this study presents the case for a more nuanced understanding of current ecological conditions. Regional climate patterns, such as higher than expected rainfall in the 1930 and 1940s, elevated the expectations for rainfed crop production for the Tsitsa. This precipitated a notion that this region could produce cash crops under rainfed conditions that would support expanding human populations (Beinart, 2008). However, these elevated rainfall conditions did not persist and analysis of the rainfall data carried out in this study shows that mean annual rainfall has been steadily decreasing. The Betterment Planning intervention assumed that rainfed crop production would be the major driver of agricultural development within this catchment, but this did not transpire as there is evidence of extensive abandonment of cropping. There are several theories about why rainfed crops are less popular amongst farmers than expected and these include i) increasing risk of crop failure due to rainfall uncertainty, ii) limited access to short-term financing for cash crops, iii) a preference for livestock farming amongst local farmers, and iv) poor control over livestock that damage crops during the growing season. This study provides some evidence of the length of abandonment, with perennial grasses, trees and termitaria having become well established in these abandoned arable lands.

This study has resulted in the recognition of five “novel” rangeland types within the abandoned arable lands of the Tsitsa River’s alluvial plain. These rangeland types vary in several key environmental attributes, including their net primary productivity, their location on the landscape, their history of disturbance, the plant types that make up their composition and the spatial arrangement of photosynthetically active patches.

The hill-slope seeps (cluster 5) have the greatest overall productivity, combining good grass cover with the presence of woody shrubs such as *Vachellia karroo*. This rangeland occurs on the lower slopes of the mountains, where it receives additional moisture from phreatic water. Rehabilitation efforts should be directed to maintain and stabilize these seeps to preserve this productivity.

The riparian meadows, invaded by *Vachellia karroo* (cluster 8), are also important primary production areas for livestock. The grasslands have the second highest grass production, but have the added benefit of having the highest production from the scattered trees, which provide browsing for goats from leaves and seed pods.

The recently abandoned lands on alluvial soils (cluster 1) should be considered for further use in crop production, but efforts should be made to maintain all the contour banks associated these fields.

The use of the Flombaum and Sala (2007) technique for determining rangeland productivity has provided a robust alternative to other productivity assessment techniques which are used on commercial farms e.g. disk pasture meter (Bransby and Tainton (1977). Communal areas, that experience continuous, selective grazing from free-ranging animals do not permit conventional resting or spelling approaches to range management, as fences and gates are ignored by livestock owners bent on optimizing animal production. In addition, efforts to erect conventional grazing enclosures have met with limited success (Gusha 2018), as livestock disrupt any structure erected to prevent their accessing new plant growth. The technique described by Flombaum and Sala (2007) provides a method that should be used more widely to assess rangeland productivity in areas that experienced continuous high-intensity grazing. A comparison of the production estimates from several other studies with the current study (Table 5) reveals that the above-ground primary production for these abandoned arable lands is in line with that measured at other comparable sites.

The assessment of the fragmentation of the photosynthetic units within the four major clusters showed that there was little difference between the diversity of pixels in the four spectral bands in clusters 1, 5 and 8, but cluster 2 had higher fragmentation in the visible spectrum (blue, green and red bands). This points to a general evenness of texture in the visible range. This evenness is also reflected in the uniform texture seen in the imagery provided in Figures 6 and 8, which suggest that an enormous uniform "grazing lawn" (McNaughton, 1979) has been created by the continuous, high density herbivory. There was no difference between clusters in the near-infra red band, but when an NDVI was computed, cluster 5 had greater fragmentation. This could be attributable to the higher woody component of this cluster.

The comparison of erosion gullies using recent very high resolution near infra-red satellite imagery and earlier aerial photography has revealed that there is no change in the extent of these gullies since the early years of Betterment Planning (1958), showing that the causes of gully erosion, which contribute enormously to the visual impression that the area is severely degraded, pre-date current grazing practices of high stock densities.

This understanding of the difference between these five rangeland types provides management with the option of having different rehabilitation strategies for each type. Not all the abandoned lands should be treated equally when it comes to restoration. Those clusters (5 and 8) with greatest productivity and spatial diversity of photosynthesis (or active greenness) should be considered a priority for the focus of restoration efforts. These clusters represent units that offer greater livestock feed and resilience against forage shortages due to their diversity of growth forms and patchiness created by landscape engineers such as termites.

REFERENCES

Acocks, J. P. H. (1953). Veld types of South Africa 2nd edn. *Memoirs of the Botanical Survey of South Africa*, *28*, 1–192.

Barbosa, F. G., Pillar, V. D., Palmer, A. R., & Melo, A. S. (2013). Predicting the current distribution and potential spread of the exotic grass Eragrostis plana Nees in South America and identifying a bioclimatic niche shift during invasion. *Austral Ecology*, *38*(3), 260–267.

Bäse, F., Helmschrot, J., Schmied, H. M., & Flügel, W.-A. (2006). The impact of land use change on the hydrological dynamic of the semi arid Tsitsa catchment in South Africa. In *Proc. 2nd Göttingen GIS and Remote Sensing*.

Beinart, W. (2008). *The rise of conservation in South Africa : settlers, livestock, and the environment, 1770-1950*. Oxford University Press.

Belnap, J., Ludwig, J. A., Wilcox, B. P., Betancourt, J. L., Richard, W., Dean, J., … Milton, S. J. (2012). Big Questions Emerging from a Century of Rangeland Science and Management. *Source: Rangeland Ecology & Management*, *65*(6), 569–578.

Bennett, J., Lent, P. C., & Harris, P. J. C. (2007). Dry season foraging preferences of cattle and sheep in a communal area of South Africa. *African Journal of Range and Forage Science*, *24*(3), 109–121.

Bennett, James, & Barrett, H. (2007). Rangeland as a Common Property Resource: Contrasting Insights from Communal Areas of Central Eastern Cape Province, South Africa. *Source: Human Ecology*, *35*(1), 97–112.

Crist, E., Mora, C., & Engelman, R. (2017). The interaction of human population, food production, and biodiversity protection. *Science*, *356*(6335), 260–264.

Crookes, D. J., Blignaut, J. N., De Wit, M. P., Esler, K. J., Le Maitre, D. C., Milton, S. J., … Rebelo, A. (2013). *System dynamic modelling to assess economic viability and risk trade-offs for ecological restoration in South Africa*.

de Wet, C. (1989). Special Issue on The Politics of Conservation in Southern Africa. In *Source: Journal of Southern African Studies* (Vol. 15).

Dietz, T., Ostrom, E., & Stern, P. C. (2008). The struggle to govern the commons. *Urban Ecology: An International Perspective on the Interaction Between Humans and*

Nature, *1907*(2003), 611–622.

Dominguez, M. T., Madejón, E., López-Garrido, R., Marañón, T., & Murillo, J. M. (2016). Shrubs for the remediation of contaminated Mediterranean areas: Is the nurse effect mediated by increases in soil enzyme activities? *Ecological Engineering*, *97*, 577–581.

Eastman, J. R. (2017). *IDRISI Terrset. Source Code*. Worcester, Mass., USA: Clark University.

Fabricius, C., Biggs, H. C., & Powell, M. (2016). Research Investment Strategy: Ntabelanga and Laleni Ecological Infrastructure Project. *Department of Environmental Affairs*, 24pp.

Feinberg, H. M. (1993). The 1913 Natives Land Act in South Africa: Politics, Race, and Segregation in the Early 20th Century. *The International Journal of African Historical Studies*, *26*(1), 65.

Flombaum, P., & Sala, O. E. (2007). A non-destructive and rapid method to estimate biomass and aboveground net primary production in arid environments. *Journal of Arid Environments*, *69*(2), 352–358.

Gibson, L., Münch, Z., Palmer, A., & Mantel, S. (2018). Future land cover change scenarios in South African grasslands--implications of altered biophysical drivers on land management. *Heliyon*, *4*(7), e00693.

Gwate, O., Mantel, S. K., Palmer, A. R., Gibson, L. A., & Munch, Z. (2018). Measuring and modelling evapotranspiration in a South African grassland: Comparison of two improved Penman-Monteith formulations. *Water SA*, *44*(3), 482–494.

Hardin, G. (1968). *The Tragedy of the Commons* (Vol. 162).

Hobbs, R. J., Higgs, E., & Harris, J. A. (2009). Novel ecosystems: implications for conservation and restoration. *Trends in Ecology and Evolution*.

Hoffman, M. T. (2003). “Nature’s method of grazing”: Non-Selective Grazing (NSG) as a means of veld reclamation in South Africa. *South African Journal of Botany*, *69*(1), 92–98.

Lal, R. (2015). Restoring Soil Quality to Mitigate Soil Degradation. *Sustainability*, *7*(5), 5875–5895.

Libala, N., Palmer, C. G., & Odume, N. (2020). Using a trait-based approach for assessing the vulnerability and resilience of hillslope seep wetland vegetation cover to disturbances in the Tsitsa River catchment, Eastern Cape, South Africa. *Ecology and Evolution*, *10*, 277–291.

Milton, S. J., & Dean, W. R. J. (2010). Plant invasions in arid areas: Special problems and solutions: A South African perspective. *Biological Invasions*, *12*(12), 3935–3948.

Moyo, B., Dube, S., Lesoli, M., & Masika, P. J. (2010). Herbaceous biomass, species composition and soil properties of keygrazing patches in coastal forest thornveld and two grassland types of theEastern Cape province, South Africa Herbaceous biomass, species composition and soil properties of key grazing patc. *African Journal of Range & Forage Science*, *27*(3), 151–162.

Mucina, L., & Rutherford, M. C. (2006). Vegetation of South Africa, Lesotho and Swaziland. In *Strelitzia* (Vol. 19). Pretoria: South African National Biodiversity Institute.

Münch, Z., Okoye, P. I., Gibson, L., Mantel, S., Palmer, A. R., Munch, Z., … Palmer, A. R. (2017). Characterizing Degradation Gradients through Land Cover Change Analysis in Rural Eastern Cape, South Africa. *Geosciences*, *7*(1), 7.

O'Connor, T. G. (2008). Influence of land use on plant community composition and diversity in Highland Sourveld grassland in the southern Drakensberg, South Africa. *African Journal of Range and Forage Science*, *25*, 17–27.

O'Farrell, P. J., Donaldson, J. S., & Hoffman, M. T. (2007). The influence of ecosystem goods and services on livestock management practices on the Bokkeveld plateau, South Africa. *Agriculture, Ecosystems and Environment*, *122*(3), 312–324.

Oelofse, M., Birch-Thomsen, T., Magid, J., de Neergaard, A., van Deventer, R., Bruun, S., & Hill, T. (2015). The impact of black wattle encroachment of indigenous grasslands on soil carbon, Eastern Cape, South Africa. *Biological Invasions*, *18*(2), 1–12.

Palmer, A R, Short, A., & Yunusa, I. A. M. (2010). Biomass production and water use efficiency of grassland in KwaZulu-Natal, South Africa. *African Journal of Range & Forage Science*, *27*(3), 163–169.

Palmer, A R, & Van Staden, J. M. (1992). Predicting the distibution of plant communities using annual rainfall and elevation: an example from southern Africa. *Journal of Vegetation Science*, *3*, 261–266.

Palmer, Anthony R., & Bennett, J. E. (2013). Degradation of communal rangelands in South Africa: towards an improved understanding to inform policy. *African Journal of Range & Forage Science*, *30*(1–2), 57–63.

Palmer, AR R, Killer, F. J., Avis, A. M., & Tongway, D. (2001). Defining function in rangelands of the Peddie district, Eastern Cape, using Landscape Function Analysis. *Africa Journal of Range & Forage Science*, *18*(1), 53–58.

R Development Core Team. (2015). *R language*. Retrieved from http://cran.r-project.org/doc/manuals/R-lang.html

Ren, G., Wang, C., Dong, K., Zhu, H., Wang, Y., & Zhao, X. (2018). Effects of grazing exclusion on soil-vegetation relationships in a semiarid grassland on the Loess Plateau, China. *Land Degradation & Development*, *29*(11), 4071–4079.

Richards, J. (2013). *Remote Sensing Digital Image Analysis - An Introduction*. Berlin: Springer.

Robertson, M. P., & Palmer, A. R. (2002). Predicting the extent of succulent thicket under current and future climate scenarios. *African Journal of Range & Forage Science*, *18*, 21–28.

Rowntree, K. M. (2014). Reprint of: The evil of sluits: A re-assessment of soil erosion in the Karoo of South Africa as portrayed in century-old sources q. *Journal of Environmental Management*, *138*, 67–74.

Samuels, I., Cupido, C., Swarts, M. B. M. B., Palmer, A. R. A. R., & Paulse, J. W. J. W. (2016). Feeding ecology of four livestock species under different management in a semi-arid pastoral system in South Africa. *African Journal of Range & Forage Science*, *33*(1), 1–9.

Schulze, R. E., Maharaj, M., Warburton, M. L., Gers, C. J., Horan, M. J. C., Kunz, R. P., & Clark, D. J. (2008). South African atlas of climatology and agrohydrology. *Water Research Commission, Pretoria, RSA. WRC Report*.

Scorer, C., Mantel, S. K., & Palmer, A. R. (2019). Do abandoned farmlands promote spread of invasive alien plants? Change detection analysis of black wattle in montane grasslands of the Eastern Cape. *South African Geographical Journal*, *101*(1), 36–50.

Seastedt, T. R., Hobbs, R. J., & Suding, K. N. (2008, December). Management of novel ecosystems: Are novel approaches required? *Frontiers in Ecology and the Environment*, Vol. 6, pp. 547–553.

Sieben, E. J. J., Collins, N. B., Corry, F. T. J., Kotze, D. C., Job, N., Muasya, A. M., … Pretorius, L. (2016). The vegetation of grass lawn wetlands of floodplains and pans in semi-arid regions of South Africa: Description, classification and explanatory environmental factors. *South African Journal of Botany*, *104*, 215–224.

Stubbs, H. (2013). *LRC Working Paper Series A1/2013 2 BETTERMENT PLANNING AND RESTITUTION: CONSIDERING THE IMPLICATIONS OF THE DRAFT RESTITUTION BILL OF 2013*.

Tongway, D. J., & Hindley, N. L. (2004). Landscape Function Analysis: Procedures for Monitoring and Assessing Landscapes with Special Reference to Minesites and Rangelands. *CSIRO Sustainable Ecosystems*, 80.

Truitt, A. M., Granek, E. F., Duveneck, M. J., Goldsmith, K. A., Jordan, M. P., & Yazzie, K. C. (2015). What is Novel About Novel Ecosystems: Managing Change in an Ever-Changing World. *Environmental Management*, *55*(6), 1217–1226.

Tsalyuk, M., Kelly, M., & Getz, W. M. (2017). *Improving the prediction of African savanna vegetation variables using time series of MODIS products*.

Van Tol, J., Akpan, W., Kanuka, G., Ngesi, S., & Lange, D. (2016). Soil erosion and dam dividends: science facts and rural "fiction" around the Ntabelanga dam, Eastern Cape, South Africa. *South African Geographical Journal*, *98*(1), 169–181.

Vetter, S. (2009). Drought, change and resilience in south africa's arid and semi-arid rangelands. In *South African Journal of Science* (Vol. 105).

Walker, B., Holling, C. S., Carpenter, S. R., & Kinzig, A. (2004). Resilience, adaptability and transformability in social–ecological systems. *Ecology and Society*, *9*(2), 5.

APPENDICES

Appendix 1.

Vegetation Cover & Biomass production measured in each cluster using the line intercept method and regression model of Flombaum and Sala (2007).

Plot no.	Cluster No.	lat	long	Grass Cover (%)	Grass Production (kg/ha)	Tree Cover (%)	Tree Production (kg/ha)	Total Production (kg/ha)
1	1	-31.1228	28.6123	50.00	2212.50	0.00	0.00	2212.50
2	8	-31.1163	28.6123	90.00	3982.50	0.00	0.00	3982.50
3	2	-31.1118	28.6217	45.00	1991.25	0.00	0.00	1991.25
4	8	-31.1092	28.5970	59.50	2632.88	8.00	300.00	2932.88
5	1	-31.1143	28.6440	9.50	420.38	21.00	787.50	1207.88
6	5	-31.1155	28.5543	81.00	3584.25	14.00	525.00	4109.25
7	2	-31.1568	28.5678	99.00	4380.75	0.00	0.00	4380.75
8	1	-31.1472	28.5659	56.00	2478.00	1.00	37.50	2515.50
9	5	-31.1460	28.5623	100.00	4425.00	0.00	0.00	4425.00
10	5	-31.1509	28.6010	100.00	4425.00	0.00	0.00	4425.00
11	5	-31.1281	28.6089	91.00	4026.75	0.00	0.00	4026.75
12	2	-31.1145	28.5816	26.00	1150.50	24.38	623.93	1774.43
13	8	-31.1123	28.6064	86.00	3805.50	9.00	337.50	4143.00
14	2	-31.1094	28.6054	60.50	2677.13	0.00	0.00	2677.13
15	2	-31.1082	28.6044	89.00	3938.25	3.00	112.50	4050.75
16	2	-31.1160	28.5927	95.50	4225.88	0.00	0.00	4225.88
17	1	-31.1146	28.5781	51.00	2256.75	0.00	0.00	2256.75
18	2	-31.1104	28.5760	78.00	3451.50	18.00	675.00	4126.50
19	1	-31.1095	28.5662	87.00	3849.75	10.00	375.00	4224.75
20	5	-31.1062	28.5572	85.50	3783.38	11.00	412.50	4195.88
21	2	-31.1107	28.5528	46.00	2035.50	6.00	225.00	2260.50
22	2	-31.1146	28.5912	90.00	3982.50	0.00	0.00	3982.50
23	5	-31.1100	28.6031	92.00	4071.00	8.00	300.00	4371.00
24	1	-31.1116	28.6125	84.50	3739.13	2.00	75.00	3814.13
25	2	-31.0987	28.6397	100.00	4425.00	0.00	0.00	4425.00
26	2	-31.0943	28.6370	52.00	2301.00	0.00	0.00	2301.00
27	2	-31.0796	28.6069	94.00	4159.50	1.00	37.50	4197.00
28	5	-31.0839	28.6250	98.00	4336.50	0.00	0.00	4336.50
29	2	-31.0857	28.6351	100.00	4425.00	0.00	0.00	4425.00
30	1	-31.1623	28.5846	9.50	420.38	21.00	787.50	1207.88
31	8	-31.1189	28.6362	51.50	2278.88	0.00	0.00	2278.88
32	8	-31.1140	28.6363	100.00	4425.00	0.00	0.00	4425.00
33	1	-31.1260	28.5880	50.50	2234.63	0.00	0.00	2234.63
34	5	-31.1251	28.5920	74.50	3296.63	0.00	0.00	3296.63

35	1	-31.1147	28.6435	100.0 0	4425.00	0.00	0.00	4425.00
36	5	-31.1282	28.6624	91.50	4048.88	0.00	0.00	4048.88
37	1	-31.1277	28.6634	71.50	3163.88	0.00	0.00	3163.88
38	5	-31.1220	28.6478	100.0 0	4425.00	0.00	0.00	4425.00
39	8	-31.1039	28.6414	100.0 0	4425.00	0.00	0.00	4425.00
40	8	-31.0996	28.6446	90.00	3982.50	0.00	0.00	3982.50
41	2	-31.0874	28.6677	70.00	3097.50	0.00	0.00	3097.50
42	1	-31.0900	28.6642	23.50	1039.88	0.00	0.00	1039.88
43	2	-31.0925	28.6587	70.50	3119.63	0.00	0.00	3119.63
44	2	-31.0979	28.6554	82.50	3650.63	0.00	0.00	3650.63
45	8	-31.0987	28.6499	84.50	3739.13	0.00	0.00	3739.13
46	5	-31.0758	28.6213	99.00	4380.75	0.00	0.00	4380.75
47	5	-31.0630	28.6101	91.50	4048.88	0.00	0.00	4048.88
48	2	-31.0720	28.6039	66.00	2920.50	0.00	0.00	2920.50
49	1	-31.0792	28.6104	71.50	3163.88	0.00	0.00	3163.88
50	2	-31.0811	28.5878	100.0 0	4425.00	0.00	0.00	4425.00
51	2	-31.0783	28.5566	66.00	2920.50	0.00	0.00	2920.50
52	1	-31.0799	28.5733	100.0 0	4425.00	0.00	0.00	4425.00
53	1	-31.0974	28.5219	73.00	3230.25	0.00	0.00	3230.25
54	1	-31.0885	28.5425	98.00	4336.50	0.00	0.00	4336.50
55	5	-31.0886	28.5882	94.50	4181.63	0.00	0.00	4181.63
56	1	-31.0811	28.5958	97.00	4292.25	0.00	0.00	4292.25
57	2	-31.0856	28.6290	83.00	3672.75	0.00	0.00	3672.75
58	1	-31.1090	28.6309	65.00	2876.25	0.00	0.00	2876.25
59	1	-31.1382	28.5939	82.00	3628.50	0.00	0.00	3628.50
60	1	-31.1300	28.5998	99.00	4380.75	0.00	0.00	4380.75