Environmental change in Riemvasmaak, Northern Cape, South Africa twenty years after resettlement

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12 February 2016

Submitted in partial fulfillment of the requirements of the degree of Master of Science in Conservation Biology

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The financial assistance of Rotary International towards this research is hereby acknowledged.

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Abstract

The 75,000 ha area of Riemvasmaak, located north of the Orange River within the Northern Cape Province, is an important case study with regard to land restitution and livestock impacts upon arid rangelands hypothesized to be at disequilibrium. As part of a 'black spot' removal program during apartheid, about 1,500 people from Riemvasmaak were forcibly moved off their land in 1974. With many returning to the area in January 1995, Riemvasmaak represented the first successful land restitution case in post-apartheid South Africa. This study follows up on a long-term environmental monitoring project set up in 1995 and revisited in 2005 and early 2015 to determine the impact of the returnees on the vegetation and ecology of the region. It builds upon the repeat photography methodology utilized by Hoffman *et al.* (1995) and Hoffman and Todd (2010) in order to provide a robust and accessible measure of change in the herbaceous and woody components of the vegetation. The percentage cover of herbaceous and woody vegetation was visually estimated in repeat photographs from 27 photo stations for the years 1995, 2005, and 2015. The results of a linear mixed-effects model suggest that herbaceous vegetation decreased significantly from 1995 to 2005 ($p < 0.001$) and increased significantly from 2005 to 2015 ($p < 0.001$) while woody cover did not change significantly from 1995-2015. There was no difference in these trends between the three landform units assessed (rivers, sandy pediments and rocky slopes). Linear regressions utilizing size class and density of individuals for *Acacia erioloba* (*Vachellia erioloba*) indicated that there had been little recruitment over the period 1995-2015 in comparison to the period prior to the initial survey in 1995. Fifteen face-to-face interviews with livestock owners, herders, and the local Agricultural Collective in 2015 outlined the socioeconomic and cultural changes that had occurred in Riemvasmaak since 1995. One such change, a directive issued by the Riemvasmaak Municipality in 2009, that ownership of livestock would no longer be allowed within Municipality boundaries, resulted in the removal of livestock from Riemvasmaak in the years directly before 2015 and corresponded temporally with the rise in herbaceous cover seen in 2015. Livestock numbers recorded from 1995-2005 and in the years 2011 and 2015 revealed the highest number of grazers present in 2005, which correlated with the decline of herbaceous cover. The relative stability of woody cover despite the relatively high amount of browsers still present is likely primarily due to the ability of woody vegetation to compensate for the resultant loss of biomass. Trends in the amount of precipitation from 1990-2014 were not significant and finer scale calculations before the focal years do not match expected corresponding trends in vegetative change. It is likely that changes in herbaceous vegetation and *A. erioloba* recruitment were driven strongly by herbivory. This result is in contrast to this study's first hypothesis based upon systems at disequilibrium, which emphasises stochastic abiotic factors as a main driver of arid systems and drought-limited numbers of livestock having negligible feedback on vegetation. Although there were several consistencies reported by farmers that corroborated this study's analysis, perceptions of long-term environmental change varied widely, indicating differences in scale between their experiences and this study as well as the impact of factors such as their previous settlement in Riemvasmaak, time of return and mobility from site to site. Future directions for research within this area should focus upon species-level changes within the landforms, as well as emphasizing further engagement with the local community.

Key words: systems at disequilibrium, environmental change, repeat photography

Acknowledgements

I would first and foremost like to thank my supervisors. I am particularly indebted to Timm Hoffman for his support and guidance throughout the duration of this project. His insights into rangeland science and the case study of Riemvasmaak were invaluable. I am extremely grateful for his advice, his good humor and assistance in the field, his provision of the incredible long-term dataset analyzed within this study, and for the overall privilege of undertaking the thesis component of the Conservation Biology course under his supervision. I would also like to thank Simon Todd for his carefully considered suggestions, particularly concerning analysis. Thank you to individuals interviewed in Riemvasmaak and to Henry Basson and Lionel Mapanka of Riemvasmaak Tourism for their time during the field component of the project, as this project could not have happened without their kind assistance. I am also extremely grateful to Sam Jack, Desale Okubamichael, and James Puttick for their technical assistance, as well as the rest of the Plant Conservation Unit for their multiple perspectives and for making the PCU a home away from home. A heartfelt thank you to Vernon Visser, in the Statistics in Ecology, Environment and Conservation lab for the assistance I received in the form of R code and to both Vernon and Susan Cunningham for their time and advice concerning the statistical challenges I presented to them along the way. Thanks also go to Nick Lindenberg and Thomas Slingsby in the University of Cape Town GIS lab for their advice concerning the technicalities of the tested supervised classification technique.

A thank you especially to my course mates and friends in the Conservation Biology class of 2015 who helped me survive the year. Their friendship, support and camaraderie kept me going through stressful times and made this year incredibly special. Thank you in particular to Elke Visser for organizing our thesis writing retreat, to both Elke and Jennifer Angoh for their encouragement, to Christiaan Willem Brink and Kyle Lloyd for providing much-needed laughter, and *obrigada* to Wataru Tokura and Hermenegildo Matimele for always looking out for my well-being and for sharing their appreciation of all things botanical. I would like to thank my family for supporting my decision to go to graduate school in South Africa and friends Jaymie Krambeck, Michael Sterlacci and Chris Stepp for cheering me on. Finally, I would like to thank the bands Led Zeppelin, Lynyrd Skynyrd, Boston, Journey and Bad Company for providing the music that also helped keep me going through long hours in the lab.

Chapter 1 - Introduction and literature review

1.1. Introduction

1.1.1. Systems at equilibrium and disequilibrium

There has been much concern about the world's communally grazed rangelands and their sustainability due to the commonly held belief that communal rangelands are inherently unproductive and degraded (Hardin 1968; Vetter and Bond 2012). Degradation in this sense would not only include biophysical degradation, such as soil loss and vegetative change, but would also be considered as '…a reduction in the capacity of land to perform ecosystem functions and services that support society and development' (FAO 2010).

The scientific basis for this concern regarding land degradation has long been predicated upon the concept of rangeland carrying capacity. Rangeland carrying capacity is here defined and based on assumptions about the impact of livestock grazing on plant succession and is derived from Clementsian ideas regarding plant ecology (Behnke and Scoones 1993). This equilibrium model emphasizes the importance of biotic feedbacks of livestock grazing on vegetation cover productivity and composition and the density-dependent regulation of livestock numbers (Behnke and Scoones 1993; Illius and O'Connor 1999). It has also formed the basis of many regulatory interventions (Vetter 2005).

Traditional, equilibrium-based rangeland models do not take into consideration the inherent climatic variability and spatial heterogeneity of arid rangelands (Vetter and Bond 2012). Within highly stochastic environments, climate is important in determining the production of vegetation, which may then affect herbivore abundance. In light of this, the current thinking has shifted towards better determining the ways in which processes such as density-dependence would limit a population in areas that have high environmental variation (Bonenfant *et al.* 2009).

This requires examining the spatial and temporal contexts that interact with environmental variability in order to determine the impacts upon population trends of livestock. For example, variation in an environment has both spatial and temporal components, which vary in the patterning and degree of their heterogeneity. Temporal variation may increase herbivore density-dependence due to an increase in forage deficits per individual animal (Wang *et al.* 2013). However, spatial heterogeneity may buffer populations against temporal variability due to an increase in asynchronous plant phenology. This would allow herbivores better access to a larger amount of forage when it is most nutritious and would constrain their ability to deplete resources (Hempson *et al.* 2015).

This movement in rangeland science towards incorporating environmental variability in management practice is not particularly recent. In the 1990s, the so-called “new ecology” emerged and began to challenge equilibrium models and to explore the inherent flux and variability within arid and semi-arid rangeland systems in particular (Gillson and Hoffman 2007). Vegetative composition and biomass in these ‘systems at disequilibrium’ are hypothesized to be mainly driven by stochastic abiotic factors. These stochastic abiotic factors, such as highly variable rainfall, are hypothesized to drive changes in the vegetation rather than overgrazing, as animal numbers are theorized to be kept below equilibrium densities due to drought events (Cousins 1996; Ellis and Swift 1998; Sullivan and Rohde 2002).

However, arguments that propose the decoupling of consumers from their resource base often overlook that the adequacy of forage for a given population can only be assessed relative to that population’s size. Therefore, while environmental variation may impact the abundance of forage, any population response to it also is contingent on population size. Variation in essential resource availability due to environmental variation would continually redefine the equilibrium population size that would exist under conditions that were constant (Hempson *et al.* 2015). Within this context, high numbers of livestock can worsen already poor rangeland condition due to low rainfall as competition-mediated depletion of resources occurs. This in turn may lead to density-dependent decline in livestock if a certain threshold of livestock were to be reached (Owen-Smith 2006).

Due to the ability of livestock to impact rangelands, adaptive management by rangeland users is increasingly important for the utilization of rangelands in a sustainable manner (Campbell 2006; Vetter and Bond 2012). This is particularly relevant in southern African systems, such as within South Africa. High, constant stocking rates within these systems are often maintained through the utilization of off-farm income to purchase supplementary feed, the use of which would contribute to mitigating density-dependent effects on livestock populations. Communal area farmers are also often highly constrained within overcrowded rangelands where the ability to move over large distances to better pastures is seldom an option (Vetter 2005). Maintaining high and constant stocking rates during periods of drought through farming strategies, such as the use of supplementary feed, leads to increased grazing pressure. This and a lack of farmer mobility can lead to grazing induced degradation (Campbell 2006; Vetter 2005; Vetter and Bond 2012).

1.1.2. Land restitution within South Africa

Rangeland systems within South Africa are largely polarized between commercial and communal livestock farming. Commercial farming in this context refers mainly to livestock production on farms in what was historically white South Africa, where the raising of livestock is done primarily to sell at formal commercial markets. Although considerable variation exists within this sector, communal livestock production, comprising of mainly black South Africans, concerns the raising of livestock mainly for their own use or for sale in local markets (Bennet *et al.* 2012; Hoffman and Todd 2000).

In order to fully understand the spatial distributions and livelihood changes occurring within South African communal livestock systems and any resulting impacts upon the environment, it is vital to first understand the effects of land dispossession and restitution within South Africa. The genesis of the 'land question' occurred with the effects of colonial rule and national development before apartheid (Everingham and Jannecke 2006). The intervention of investors, prospectors, commercial farmers, public authorities and newly arrived missionaries and settlers helped redefine land rights within the country. Colonial and national authorities as well as white capitalists began to eliminate freeholders who depended upon their rights to their land and access to local markets to sustain their communities (Pityana 2015).

Apartheid laws only worsened class differences and the erosion of communities and kinships, weakening ties to land, and initiated further fragmentation and relocation. This was due not only to racial criteria but also due to the perceived usefulness of mineral resources, agricultural land and other properties that could be acquired (Levin and Weiner 1992). An example of influential apartheid legislation was the Bantu Homelands Citizenship Act of 1970. This Act prohibited black Africans from being South African citizens, forcing them instead to become citizens of tribal homelands. Not only were black Africans removed from the land they occupied and denied access to land elsewhere in South Africa, but their land was given to their white counterparts instead. These white farmers were also provided with subsidies to ensure the success of their agricultural enterprises, a form of systematic empowerment denied to those displaced (Pityana 2015).

However, with the end of apartheid in South Africa in 1994 came the shift of a subjugated population to legitimate citizenry. The success of the African National Congress (ANC) helped drive this transition as the ANC recognized that land restitution would serve as a useful tool to both allow community development and rural transformation (Everingham and Jannecke 2006). Restitution within this context aims to restore land to or compensate those dispossessed during the colonial and apartheid past, within a framework determined by law, passed by Parliament, and executed by the government (Pityana 2015).

The Restitution of Land Rights Act of 1994 was the first major piece of legislation passed in order to begin to redress these injustices of the apartheid era (Christopher 1995; Claassens 2015). This allowed for the creation of a Commission on the Restitution of Land Rights in order to examine any claims for the restoration of land ownership to dispossessed peoples relocated due to racially based laws. A Land Claim Court was also set up in order to mediate cases of dispute (African National Congress 1994).

In all, the government had forcibly moved at least 3.5 million people between 1960 and 1984 in accordance with racially-based policies, with many more individuals still impacted by moves initiated during the previous colonial (1652-1910) and segregationist governments (1910-48). Private land claims by communities were organized, aided occasionally by nongovernmental organizations, as many of the dispossessed were alive and resolute about returning to their land (Bernstein 2015). This caused significant difficulties, as much of land that was claimed was owned by the state, particularly by the South African Defence Force, which had gained large areas of land as part of its military buildup within the 1970s and 1980s (Christopher 1995).

Despite these difficulties, however, the post-apartheid government continued to be sympathetic to claimants, as evident in the fate of Riemvasmaak in the Northern Cape in South Africa. The community's initial application for restoration was rejected prior to 1994 under pressure from the South African Defence Force who had long utilized the area. However, immediately after the 1994 elections, the community had its land restored to them as the first successful land restitution case within post-apartheid South Africa (Cousins and Cousins 1998; Lund 1998; Surplus People Project 1993).

1.1.3. Riemvasmaak: case study of land restitution and environmental impacts

As the first successful land restitution case in post-apartheid South Africa, Riemvasmaak represents an important case study with regard to land restitution and resulting livestock impacts upon arid rangelands hypothesized to be at disequilibrium. As part of a 'black spot' removal program during apartheid, about 1,500 people from Riemvasmaak, the majority of which were engaged in communal livestock farming, were moved off their land in 1974 (Hoffman *et al*. 1995).

Those classified as Xhosa under apartheid laws were moved to Ciskei in the Eastern Cape, while those of Damara or Nama heritage were moved 1300 kilometers away to Khorixas in northern Namibia. Finally, those who were classified as Coloured remained in the small towns surrounding Riemvasmaak, such as Marchand, Augrabies, and Keimoes (Rural Development and Land Reform 2009). These forced relocations made way for a South African Defence Force military training camp, which also used the area to test their weaponry (Christopher 1995).

Under Proclamation 44 of 1982 and section 2 (2) (b) of the National Parks Act of 1976, a 4270 ha portion of Riemvasmaak known as Melkbosrand was also declared as part of Augrabies Falls National Park. When the original inhabitants of Riemvasmaak returned, the newly created Riemvasmaak Community Development Trust entered into an agreement with the National Parks Board that the National Parks Board should continue to manage 4137 ha of the area of Melkbosrand for a certain amount of yearly monetary compensation (Rural Development and Land Reform 2009).

From 1974 to January 1995, when the people from Riemvasmaak returned to their reclaimed land, the area was without grazing pressure from domestic livestock, although wild game such as kudu, gemsbok, springbok and klipspringer utilized the region, albeit in relatively low numbers (Hoffman *et al.* 1995). The National Botanical Institute (now called the South African National Biodiversity Institute) was approached in 1995 by the UK-based nongovernmental organization FARM-Africa to establish an environmental monitoring project (Hoffman *et al.* 1995). The objective was to determine the impact of the returnees on the vegetation and ecology of the region through the use of repeat photography and additional ecological surveys. Riemvasmaak was re-visited in early 2005 and again in early 2015 as part of this long-term monitoring project in order to access environmental change in the area over a ten and twenty years' time frame respectively. (Hoffman and Todd 2010). Livestock numbers were also recorded in 2005 and 2015 for the years 1995-2005, 2011 and 2015.

1.1.4. The use of repeat photography in documenting environmental change

Scientific photographic documentation, although having its roots in the survey of mountain glaciers in the Alps, has wide-ranging applications in various environments (Hattersly-Smith 1966). The versatility of the technique is illustrated in the use of previous research in Riemvasmaak focusing on changes in the environment across the region through the use of repeat photography (Hoffman and Todd 2010).

Repeat ground-based photography allows the comparison and interpretation between historical and current land-use patterns. Assessing human impacts on the environment is well-suited to the utilization of repeat photography (Zier and Baker 2006) and is particularly suited to use in rural communities that lack other sources of historical vegetative data. By pairing historical and modern photographs, a demonstration of human land-use change and the resulting effect on vegetation becomes evident. It also aids in predicting how similar areas may respond to future impacts (Vale 1987; Butler and DeChano 2001; Moseley 2006).

Repeat photography can be instrumental in both the detection and the resulting influence of environmental management strategies in areas vulnerable to human-driven change. For example, Chinese forest policies have been changed due to information gained from repeat photography (Moseley 2006), and in other areas of the world, repeat photography has been used to assess shorter-term changes in quickly progressing environmental safety concerns (Marck *et al.* 2006). Most relevant to this study includes work on rural landscape change within Pakistan (Nüsser 2001), Mexico (Works and Hadley 2000) and South Africa (Masubulele *et al.* 2013) that have used repeat photography as a methodology to highlight the impacts of economic change, population growth, herbivory, and climate on landscapes.

1.1.5. Challenges and benefits of repeat photography as a methodology

Despite its various uses, the utilization of repeat photography has both advantages and disadvantages. As opposed to the use of satellite based remote sensing or aerial photography, which provide unobstructed top-down views, repeat photography provides less comprehensive and more biased coverage of the landscape analyzed. Oblique photographs resulting from repeat photography exaggerate nearer things in size, which can often make areal quantification very difficult (Kull 2005; Webb *et al.* 2010).

A significant obstacle in the use of repeat photography is the inherent spatial biases concerning the selection of sites. Inherent spatial biases in the choice of photographed locations, such as along roads or areas more easily accessed, may invalidate the extrapolation of results to a larger area. A wide range of photo sites needs to be representative of the heterogeneity of an area in order to be able to more accurately gauge area-wide environmental change (Webb *et al.* 2010).

However, re-photography done in a systematic and thoughtful fashion can provide significant benefits in terms of time frame, detail, and cost. In terms of the latter, it can be much less costly than a remote sensing analysis and allow a deeper historical time frame in which to analyze change. Its greater level of detail can also provide a vital tool for environmental monitoring as their oblique perspective makes landscape features easier to recognize and understand by audiences not trained in aerial photograph interpretation (Kull 2005).

In addition, repeat photography additionally may allow for the analysis of details such as changes in growth form and in the abundance of individual species and avoids generalizations as seen in remote sensing pixels. Overall, the technique is particularly useful when more detailed, case-based information is required (Turner *et al.* 2003). However, it is rarely promoted as a useful quantitative tool for accessing landscape change, and much of its potential has yet to be explored (Hoffman and Todd 2010).

1.1.6. Aims, hypotheses, and conceptual framing of this study

The main goal of this study was to determine the major changes in the herbaceous (mainly perennial grasses and a small quantity of forbs) and woody components (trees and shrubs) of the vegetation of Riemvasmaak from 1995-2015. Another objective was to determine the major drivers of change (i.e. climatic factors or herbivory) and to assess which drivers may have influenced vegetation change the most, including those that may or may not have influenced the recruitment of a focal tree species, *Acacia erioloba*. A final objective of this study was to investigate how the local livestock owners and herders in Riemvasmaak perceived changes in climatic trends and vegetative cover over time, and if the results of this study are corroborated with those perceptions. All of these objectives are framed within a broader context of an examination of the potential impacts of land restitution upon an arid environment within South Africa, utilizing Riemvasmaak as a case study.

The research questions above were examined through the utilization of the repeat photography framework as set down by Hoffman *et al.* in 1995. However, this study utilized a more quantitative analytical methodology to determine vegetative change within the herbaceous and woody components of vegetation than was used in the 1995 and 2005 environmental evaluations of the repeat photographs. The use of face-to-face qualitative interviews, mainly with livestock owners within Riemvasmaak, was also employed to explore potential drivers of change in the region.

The changes observed in Riemvasmaak's arid rangelands have been interpreted within a general theoretical framework comprised of two potentially competing theories or models. The first of these concerns systems at disequilibrium theory, in which rainfall is considered the main driver of vegetative change in the region. Within this view, herbivory would have a relatively low impact upon vegetation due to the suppression of animal numbers below equilibrium densities due to drought events (Ellis and Swift 1988). If Riemvasmaak were a system at disequilibrium, it would be expected that vegetative condition would track rainfall. Herbaceous vegetation would likely be more variable than woody vegetation over the three time steps as it is more responsive to pulses in rainfall than woody cover, although woody cover may also be adversely affected to a lesser extent by drought events (Rich *et al.* 2008). Recruitment of *A. erioloba* would have likely been restricted to years with episodic good rainfall or rainfall that was evenly distributed over a season (Wilson and Witkowski 1998; Seymour 2008). Grazing from animals would not be a major limitation upon survival of seedlings because of drought-suppressed livestock numbers.

The second of these theories follows upon the work of Illius and O'Connor (1999, 2000) and Hempson *et al*. (2015), which represents a more recent rethinking of the systems at disequilibrium theory known as key resource theory. Within arid rangelands, although vegetative change is largely impacted by precipitation, it is hypothesized under this theory that herbivores would not necessarily be completely decoupled from their resource base. Under these conditions, herbivory would still have a significant impact upon the landscape. If key resource theory was applied to Riemvasmaak, woody cover would likely be more stable than herbaceous cover over time even assuming high numbers of browsers as well as grazers on the landscape. This reflects the greater ability of woody vegetation to tolerate a certain amount of herbivory than herbaceous vegetation (Oba and Post 1999). However, the greater ability of woody cover such as adult trees to tolerate browsing does not mean that recruitment of woody species would not be negatively affected by browsing pressure. While the germination of *A. erioloba* may be impacted by both frequency and amount of rainfall, the survival of seedlings after germination would likely be dependent upon the numbers of browsing livestock present (Moser-Nørgarrd and Denich 2011). If a threshold of animals were to be reached, it may be possible that competition-mediated density-dependent effects would occur (Owen-Smith 2006) and this should be evident both in the amount of herbaceous cover present as well as the size class distributions of *A. erioloba*.

The analysis of repeat photographs taken within Riemvasmaak in 1995, 2005, and 2015, as well as the analysis of size class distributions of *A. erioloba* surveyed in 1995 and 2015, and face-to-face interviews with farmers were undertaken in order to assess which of the two models mentioned above best explained the trends observed in the study area over time. The framing of this study within the context of these models incorporates previous thinking concerning the impact of herbivory and climate on arid rangelands.

Chapter 2 – The assessment of environmental change in Riemvasmaak

2.1. Study area

The original 75,000 hectare area of Riemvasmaak, in the Northern Cape of South Africa, lies between 28° 13' and 28° 32' S and between 20° 00' and 20° 25' E. It is bordered in the north and east by commercial farms, with the Orange River forming the southern border. The southeastern border of Riemvasmaak is bounded by the Augrabies Falls National Park, which is owned by the South African National Parks.

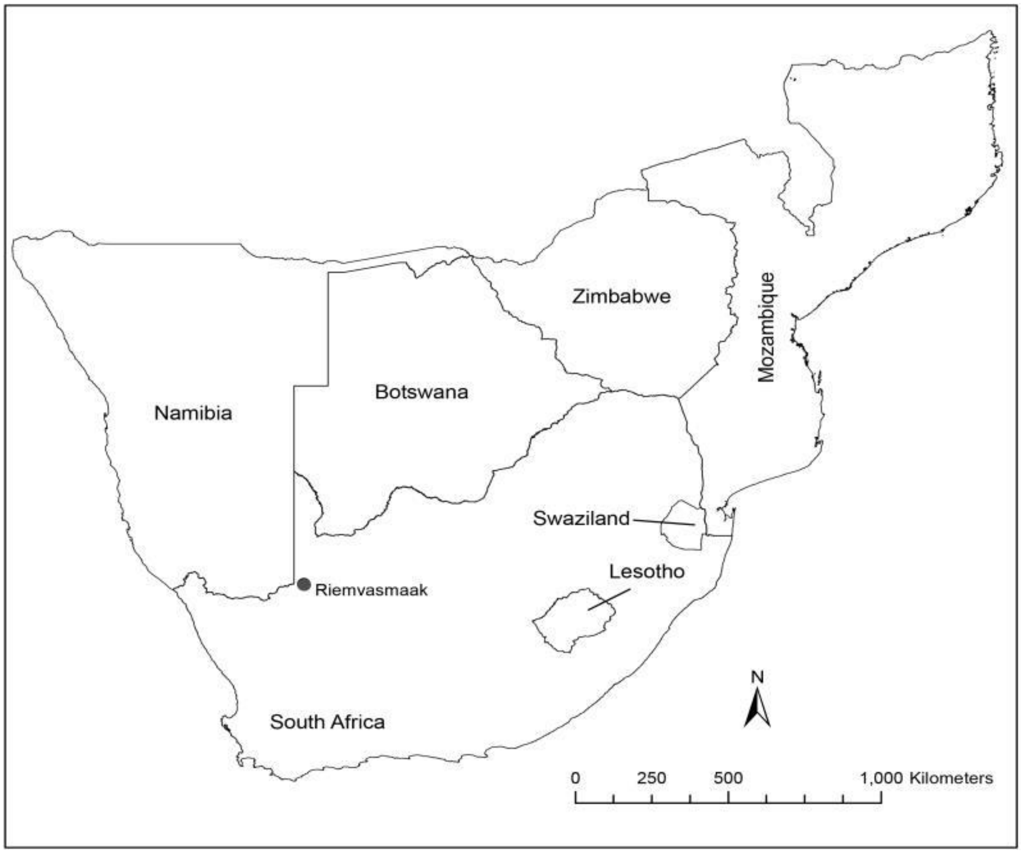


Figure 1: Location of Riemvasmaak in a southern African context

Since 2009, Riemvasmaak has acquired an additional 46,000 hectares of grazing and farming land. This area is comprised of 13 fenced and previously-white owned farms to the east and northeast of Riemvasmaak. The farms were bought by the government with the assistance of the Minister of Land Reform as part of an additional expansion program for Riemvasmaak (Ma/Hao Agricultural Collective pers. comm.). Under the auspices of the Department of Agriculture, this additional land has been subdivided into management units of about 2,000 hectares each. These translate into 23 farming units available for allocation to farmers that are legal claimants to this land. Each of the 2,000-hectare units can support 58 large livestock units or about 350 small livestock units (Agriculture, Land Reform, and Rural Development 2011).

A number of widely-dispersed permanent settlements existed within Riemvasmaak before 1974, with the largest still remaining as the Riemvasmaak Municipality itself, and smaller stockposts and settlements scattered throughout the area (Hoffman *et al.* 1995). The Riemvasmaak Municipality as contrasted to the 'greater' area of Riemvasmaak refers to the area of the village and its immediate surrounds, and unlike the greater area of Riemvasmaak, the Municipality does not include commonage and is only zoned as residential. A rudimentary road system exists within Riemvasmaak, but throughout the area it has largely degenerated to the extent that it is only accessible by off-road vehicles.

There are seventeen stock posts that were surveyed in September 2015 within greater Riemvasmaak. Although stock posts within Riemvasmaak are communal, one livestock owner will occasionally monopolize a single stock post. Some farmers also split their herds between keeping some of their livestock on the new farms and some within Riemvasmaak. There are three main types of farmers present in Riemvasmaak: 1) a livestock owner-herder, who both owns his livestock and herds them, 2) A livestock owner who lives within Riemvasmaak Municipality and pays a transient herder to herd his animals, and 3) A farmer who farms for his family, who in turn are expected to contribute to the running costs of the animals' care.

With a mean annual rainfall of 128 mm per year, Riemvasmaak is one of the most arid places within South Africa. Although rainfall is highly unpredictable (CV= 52.9%), trends from 1945-2015 from the Augrabies weather station (No. 02817601), nearby reveal that the highest rainfall occurs consistently between February and April, with a distinct peak in March.

The mean annual temperature is 21.6°C and although the mean daily maximum temperature for January, the warmest month, is 37.4 °C, summer temperatures often exceed 40°C. On a monthly basis, at no time during the year does water availability exceed evaporative demand and the area exists within a state of permanent drought (Hoffman *et al*. 1995).

Although the area is dry, three ephemeral river systems occurring within Riemvasmaak (the Bak, the Molopo, the Kourop) and one perennial (the Orange) serve as important water sources, and result in a combination of drought resistant and hydrous plant species within the area (Rural Department and Land Reform 2009). Common trees and shrubs within Riemvasmaak include *Euphorbia gregaria, Acacia mellifera (Senegalia mellifera), Rhigozum trichotomum, Boscia albitrunca, Acacia erioloba (Vachellia erioloba)*, while the perennial grass *Stipagrostis uniplumis* often dominates the plains (Hoffman *et al.* 1995; see Appendix D, Table D1)

2.2. Methods

2.2.1. Previous study design: 'landscape' approach

In order to analyze the area of Riemvasmaak, located within the Nama Karoo biome, Hoffman *et al.* (1995) adopted a landscape approach for the 1995 and 2005 surveys (Mucina and Rutherford 2006). Vegetation was described as associated with key landforms such as 'rocky slopes', 'sandy pediments' or 'riverbeds' rather than only with the identification and description of important plant communities (Werger and Coetzee 1977).

These different landforms are associated with the major geological groups in the area. The rocky slopes are diverse and are formed from the Namaqualand Mobile Belt, while sandy pediments are formed as a result of recent aeolian and alluvial sandy deposits within the broad river regions of Riemvasmaak. Dry riverbeds, although taking up less area than the other landform types, contribute disproportionally to the biomass and productive potential of the region (Hoffman *et al.* 1995)

The landforms originally delineated by Hoffman *et al.* (1995) were refined by transect walks at each photo station to determine species composition within the different landform units. A two-way matrix of species-by-sites was constructed and subjected to two-way indicator species (TWINSPAN) (Hill 1979) classification procedures in order to adjust landform classifications. TWINSPAN analysis groups samples (plots) with similar species composition and identifies 'communities' of species based on shared cover and composition.

2.2.2. Repeat photography methodology

Twenty-nine photo stations, selected for their landform and ecological representivity as well as ease of access, were established in January 1995 in Riemvasmaak (Hoffman *et al.* 1995; Fig. 2). The photo stations and their corresponding place names and GPS coordinates are described in Table E1 (see Appendix E). The photographs were re-taken in January 2005 and January 2015 from the same position as in 1995.

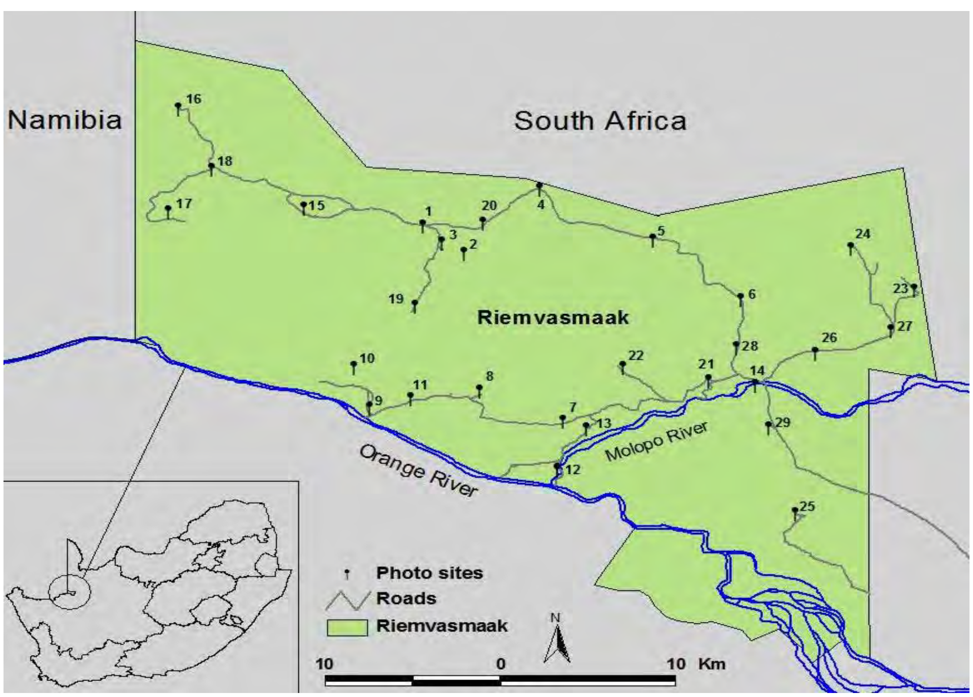


Figure 2: Location of photo stations within Riemvasmaak (Hoffman *et al.* 1995)

All photographs were taken on a tripod (*Bogen 3001*) with camera heights ranging from 138.5 cm to 160 cm. Four cameras were used at each photo station in 1995. A medium-format camera as well as a 35 mm single lens reflex (SLR) camera both containing black and white film were used first to capture the main image. Another 35 mm single-lens reflex (SLR) camera which contained slide film was used to record the main image only. Finally a Polaroid camera was used in 1995 only to provide an immediate record of the site. The location, camera height, photographic details, time of photograph and weather conditions were recorded. The camera station location and number were marked initially on a 1:50,000 topographic map and in later years captured with a Global Positioning System. The direction of the field of view of the medium-format black and white main image was also recorded with a compass (Hoffman and Todd 2010).

After photographing the main image, the field of view was swiveled at 30° increments to the left and the right, gaining as close to a 360° view as possible. Finally, the camera station itself was photographed from about 50 meters away and the spot directly below it marked with a rock cairn and metal dropper. The same cameras were utilized in 2005 and 2015, with a high-resolution digital image (using a Canon 6D) in RAW (image data unprocessed by the device) also recorded in 2015. All photographs were taken at the same locations at each photo station, the same time of year (first two weeks in January) and as close as possible to the same time of day as the original photograph (Hoffman and Todd 2010).

2.2.3. Lab data collection methodology: photographic analysis

The most commonly used and quickest estimation technique for vegetation abundance is the visual cover estimation method. It is considered reliable when using coarse class scales and categorizing different vegetation communities or when describing distinct gradients (Jukola-Sulonen and Salemaa 1985; Salemaa *et al.* 1999). The method of visual estimation was undertaken as a result of the suggestions and results of Dethier *et al.* (1993), who found visualization to be preferable to random-point analysis within quadrants, providing data that was repeatable among multiple observers.

The percentage cover of herbaceous and woody vegetation was estimated visually from the 1995, 2005 and 2015 photographs. Visual estimation of percentage cover occurred at twenty-seven photo stations, here termed sites. Site 5 was left out of the analysis, as it was of a single landform type insufficient for replication. Site 29 was also not used in this analysis as the image was taken from too high an elevation to accurately estimate percentage cover.

Photographs for 1995, 2005 and 2015 were available in black and white, and photographs from 2015 were additionally available as high-resolution digital color images (see

Appendix C). It was decided to use the digital color 2015 images rather than the black and white 2015 images as a clearer estimation of herbaceous cover could be made upon a color image due to the relative difficulty of perceiving tonally light herbaceous cover against tonally similar surroundings in the monochrome image. As the 1995-2005 photographs were only available in black and white, visual analysis was completed on them as is.

Photographs were analyzed within three different landform units (e.g. riverbeds, sandy pediments, and rocky slopes) within their respective sites. Visual estimation within these different landform units was undertaken in order to reflect change in different landform components due to grazing pressure. This was due to the observation that different landform units are utilized differently by different livestock types (e.g. cattle, sheep, and goats) and also respond differently to precipitation (Hoffman and Todd 2010). Landforms that were too distant or that comprised of more than 50% rock cover, making it difficult to determine cover visually and confidently, were left out of the analysis. The final number of landforms for the analysis totaled sixteen riverbeds and seventeen each for rocky slopes and sandy pediments. Although the majority of the twenty-seven sites contained multiple landforms, a minority of sites contained only one.

Using Adobe Photoshop CC 2015, all photographs were matched and landform units were delineated at each time step. Percentage cover estimates from the photographs were analyzed by growth form (e.g. tree, shrub, grass) in order to best detect change within the herbaceous and woody components of the landscape. An assumption for the dynamics of such groupings was that the between-group variability would exceed the within-group variability, as herbaceous and woody species of vegetation respond differently to grazing and precipitation (Austin 1985). Herbaceous vegetation included grasses and a small amount of forbs, while woody vegetation included shrubs and trees. A decision was made to use the conflated value of trees and shrubs (and term them 'woody'). This was because the two components were difficult to separate in the photographs and when initially analyzed reflected near-identical trends over time.

In order to reduce personal bias associated with this technique, three individuals with field-based ecological experience met upon two consecutive occasions to visualize the percentage cover of woody and herbaceous cover and a composite class of rock and bare ground termed 'ground' within each delineated landform. The black and white 1995, 2005 and digital color 2015 images were set up on three screens. Each analyst estimated percentage cover values individually, estimating percent cover of each class within each landform as a proportion of a whole as if scattered vegetation was 'pushed together', with all class estimations within a landform adding up to 1. The 2015 digital color image was analyzed prior to the black and white 1995 and 2005 images as the assumption was that it would be easier to estimate percentage cover from the color images. The black and white images were then analyzed by using the 2015 color images for comparative purposes.

After individually estimating percent coverage, these individual percent coverage estimations were discussed among the three analysts. In the event of a site where percent coverage of a growth form was difficult to distinguish, transect species data collected from 1995-2015 by Hoffman and Todd within those same landforms were consulted as a guide, demonstrating the importance of providing ancillary data (Hoffman and Cowling 1990; Hoffman *et al.* 1995; Hoffman and Todd 2010). A reduction or increase in growth form percentage cover was decided by area covered by growth form and included both new recruitment of plants and growth of existing individuals. Visual estimations by the three analysts were averaged for the final value (van Hees and Mead 2000).

2.2.4. Size class distributions of Acacia erioloba

The size class distributions of *Acacia erioloba* were re-measured in the field in September 2015, at the precise locations that were first surveyed in 1995 (see Appendix B; Table B1). Four line transects of *A. erioloba* were included because of its prevalence and importance as a valuable forage species for wild and domestic browsers and as a source of firewood in Riemvasmaak, despite its protected status (Anderson and Anderson 2001; Seymour and Milton 2003). Transect lengths varied but were usually 20 m wide (Hoffman *et al*. 1995; Table B1).

Three individuals, a GPS coordinate recorder, a height recorder and a research assistant operating a ranging rod walked along transects and measured all live *A. erioloba* individuals. The number of individuals present within 50 cm size class intervals was recorded. All individuals smaller than 1 m in height were lumped together in one size class because of the relatively high probability of missing individuals below 50 cm in height while walking the transect. Transects of *A. erioloba* had been measured in 1995 by Hoffman *et al.* and these transects were repeated. These repeated transects were located using site photographs, sketches and information on transect length and location recorded in the field in 1995.

At the start and end of each transect surveyed in 2015 and at each tree of interest GPS coordinates were recorded. The numbers of dead trees, dying trees, and resprouts were recorded, as well as the total number of individuals, any additional invasive species in the transect, and any notes on individual tree condition.

2.2.5. Stock numbers and interviews

Stock numbers were examined in terms of different stock types (e.g. cattle, sheep, goats and donkeys). Stock numbers of each animal type were gathered from all the major stockposts in the greater Riemvasmaak area in September 2015 either by asking stockpost owners or hired herders that were present at each site, or by counting animal numbers when the animals returned from grazing. Counting animal numbers when the animals returned from grazing was expected to be more accurate than relying solely on numbers reported by stockpost owners or hired herders. Stock data from 1995-2005 were derived from Mr. Herman Festus who was working with FARM-Africa (a UK-based NGO assisting the Riemvasmaak community with their development) at the time on a range of agricultural projects.

Stock numbers within Riemvasmaak Municipality were obtained in September 2015 by asking all livestock owners within the area. Stock numbers from 2011 were obtained from the Ma/Hao Agricultural Collective, a farmer's council whose main responsibility had been to look after animal health through the organization of dips and inoculations at which animal numbers would be recorded. It was not possible to collect data for the entire period of 2005-2015 for either the greater Riemvasmaak area or the Municipality.

From 3-9 September 2015, fifteen semi-structured interviews were carried out in Afrikaans with the aid of the research assistant and translator. Although some unavoidable bias may have occurred due to the interviewer's gender and background outside the community, much of these effects were likely to have been mitigated by the aid of the research assistant and translator who is a respected community member of Riemvasmaak as well as by the project supervisor who is male, speaks Afrikaans, and has a long association with the study area. Interview subjects included stockpost owners, hired livestock herders, the Ma/Hao Agricultural Collective and livestock owners within the Riemvasmaak Municipality itself. These interview subjects were of a variety of ages, with many born in Namibia and returning to Riemvasmaak after reclaiming their land in 1995, and several that had lived in Riemvasmaak prior to 1974 and had been removed and returned after 1995.

Interview questions comprised of personal information related to the informant's previous or current experience within Riemvasmaak. Other questions addressed current livestock holdings, sales and production, and infrastructure and mobility. Questions were also asked about perceived changes in rainfall, from before 1974 to the present, and from 1995-2015. Finally, questions were asked relating to impressions concerning changes in vegetation from 1995-2015, potential causative factors, and adaptations to farming as a result of any changes (see Appendix A).

Ethical clearance from the University of Cape Town's Faculty of Science Research Ethics Committee (approval code: FSREC 36-2015) was obtained prior to the commencement of fieldwork (see Appendix A). Prior to being interviewed, all interview subjects were provided with a copy of a consent form translated into Afrikaans indicating the purpose of the study and the guarantee of anonymity for their responses. All responses to interview questions were kept anonymous, except for those of the research assistant and professional guide Lionel Mapanka, who gave written permission for his name to be used.

2.2.6. Mixed-effects model analysis of vegetative cover

To discern changes in plant cover over time, a linear mixed-effects model (LME) in the R (R Core Team 2015) package *nlme* was used (Pinheiro *et al.* 2015). A mixed-effects model was chosen so that site and landform could be included as random effects and their variance accounted for (Pinheiro and Bates 2000). Landform here is defined as rocky slopes, sandy pediments, or riverbeds located at the 27 photo sites.

Plant cover was defined as the proportional cover of herbaceous plants, woody plants and bare ground. Woody cover incorporated both shrubs and trees while the herbaceous component incorporated mostly grasses. Bare ground was not included in the response variable because cover types represented proportions and the inclusion of all three cover types would have summed to one. Plant cover was log transformed to approximate normality. Cover type (herbaceous or woody) and year and their interaction were entered into the model as fixed effects, while site and landform were entered as random effects. Several differing autocorrelation structures were tested in order to correct for non-independence of longitudinal (temporal) data and a corARMA structure was found to provide the best model fit using Akaike's information criterion. *Post-hoc* Z tests using the R package *multcomp* (Hothorn *et al.* 2008) were then used to identify changes between herbaceous and woody cover between each time period.

An additional mixed-effects model was developed, the same as above, but incorporating landform as a fixed rather than a random effect. This was done to test for an effect of landform on cover. Interactions that were also tested were landform and cover type, landform and year, and the three-way interaction of cover type, landform, and year.

2.2.7. Size class distribution linear regressions for *Acacia erioloba*

The method for inferring recruitment status of different plant species followed Shackleton *et al.* (1993). Recruitment statuses of each species of interest were determined by analyzing the slope of a linear regression of the 50-cm interval height size classes (h) and density of individual trees within each size class (Ni). The height size classes were used as the independent variable, while density of individuals served as the dependent variable. Ni was transformed by ln (Ni +1), as some classes had zero individuals. The regression was then done using ln (Ni+1) and ln (h+1) within Excel (Venter and Witkowski 2010; Tsheboeng and Murray-Hudson 2013). Negative slopes indicated ongoing recruitment with more individuals in the smaller size classes than in the larger size classes while positive slopes indicated little or episodic recruitment (Helm and Witkowski 2012). Statistical significance of the linear regression was determined by regression analysis within Excel.

2.2.8. Precipitation change (1990-2014) linear regression

Rainfall data was obtained from the South African Weather Service (SAWS) Augrabies weather station (No. 02817601) located at 28° 40” S and 20° 26” E, with monthly rainfall data (mm) available from 1990 to 2015. This dataset was chosen as, although it is not the closest weather station to Riemvasmaak and is 11.7 kilometers from the closest station of Augrabies Falls National Park, Augrabies Falls and nearby Augrabies Waterval weather stations had many incomplete or unreliable rainfall values. This rainfall station, for similar reasons, was chosen for the precipitation analysis in Hoffman *et al.*’s 1995 study. It was also chosen as it allowed direct comparisons between recent rainfall patterns with before 1974 (see Appendix D; Fig. D1). Monthly rainfall data was totaled for 1990-2014 as the 2015 survey was undertaken in the first two weeks of the year. It was decided to total rainfall data for the analysis from January to December because that included the period immediately prior to when each of the photographs was taken in Jan. 1995, Jan. 2005, and Jan. 2015. The trend of rainfall data over time was determined by analyzing the slope of a linear regression of year and the rainfall value (mm). A linear regression was chosen in order to best avoid inter-annual fluctuations in rainfall. This approach has been used elsewhere, an example of which is in Kephe *et al*. (2015) in Theoretical and Applied Climatology. Statistical significance of the linear regression was determined by regression analysis within Excel.

2.2.9. Finer scale precipitation change

The sum of the total yearly amount of rainfall (mm) from the Augrabies weather station was calculated within Excel three, two, and one year before each of the dates that the photographs and surveys were taken (1995, 2005, 2015). This was done in order to gain a comparative idea of change in precipitation on a shorter time scale than the previous precipitation analysis, to further clarify rainfall patterns, and how these patterns may have affected changes observed in herbaceous cover.

2.3. Results

2.3.1. Analysis of vegetative cover

Changes in the cover of herbaceous and woody growth forms and total cover (sum of herbaceous and woody cover) for the three time steps (1995, 2005, and 2015) are shown in Table 1. Results indicate that there was a drop in total cover from 1995-2005, and an increase in 2015 to near 1995 cover levels. Herbaceous vegetation decreased from 1995-2005 and returned to near 1995 cover levels in 2015, while woody cover remained relatively stable over the three time steps (1995, 2005, 2015). Trends in total cover, herbaceous cover and woody cover were consistent within all landform types (rocky slopes, sandy pediments, and riverbeds). However, certain landforms contained higher percentages of total cover or herbaceous or woody vegetation.

Table 1: Mean % cover values (± std dev) for overall cover (sum of herbaceous and woody cover), herbaceous cover and woody cover for each of the landform types analyzed from repeat photographs from 1995, 2005, and 2015.

	Landform		
Growth Form	Rocky Slopes (n = 17)	Sandy Pediments (n= 17)	Riverbeds (n=16)
Herbaceous			
1995	11 ± 9	21 ± 16	9 ± 5
2005	3 ± 4	9 ± 13	4 ± 3
2015	16 ± 14	23 ± 17	13 ± 12
Woody			
1995	22 ± 12	20 ± 6	49 ± 24
2005	21 ± 10	19 ± 7	49 ± 26
2015	25 ± 13	22 ± 11	48 ± 24
Total Cover			
1995	33 ± 15	41 ± 15	58 ± 21
2005	24 ± 11	28 ± 13	52 ± 26
2015	41 ± 18	45 ± 16	61 ± 21

The results of the best-fit mixed-effects model indicated total cover (sum of herbaceous and woody cover) differed significantly ($F=19.88$, $p< 0.001$) over the three time steps (1995, 2005, 2015). Total cover was found to be higher in 1995 and 2015 than it was in 2005 (Table 2).

Table 2: Summary initial and re-leveled results of mixed-effects analysis with a corARMA autocorrelation structure with cover as response and cover type and year as fixed effects. Cover type reference is herbaceous and year references are 1995 and 2005.

Predictors	Value	95% CI	DF	t-value	*p*-value
Cover Type (ref = Herbaceous)					
Cover Type Woody	0.32	0.20 - 0.44	245	5.81	<0.001
Year (ref =1995)					
Year 2005	-0.22	-0.30 - -0.14	245	-5.31	<0.001
Year 2015	0.07	-0.03-0.17	245	1.29	0.20
Year (ref = 2005)					
Year 1995	0.22	0.14 -0.30	245	5.31	<0.001
Year 2015	0.29	0.21 -0.37	245	6.88	<0.001

Woody cover was higher than herbaceous cover in Riemvasmaak (β =0.32, p< 0.001; Table 2). Importantly, the interaction between cover type and year was significant (F=11.48, p< 0.001), indicating that changes in cover type occurred over the three time steps (1995, 2005, 2015). Herbaceous cover decreased significantly from 1995 to 2005 (p< 0.001) but increased significantly from 2005 to 2015 (p< 0.001), returning to similar cover levels in 2015 as in 1995. There was no significant change in herbaceous cover when comparing 1995 to 2015. Woody cover did not change significantly over the three time steps (Fig. 3; See Appendix C; Table C1).

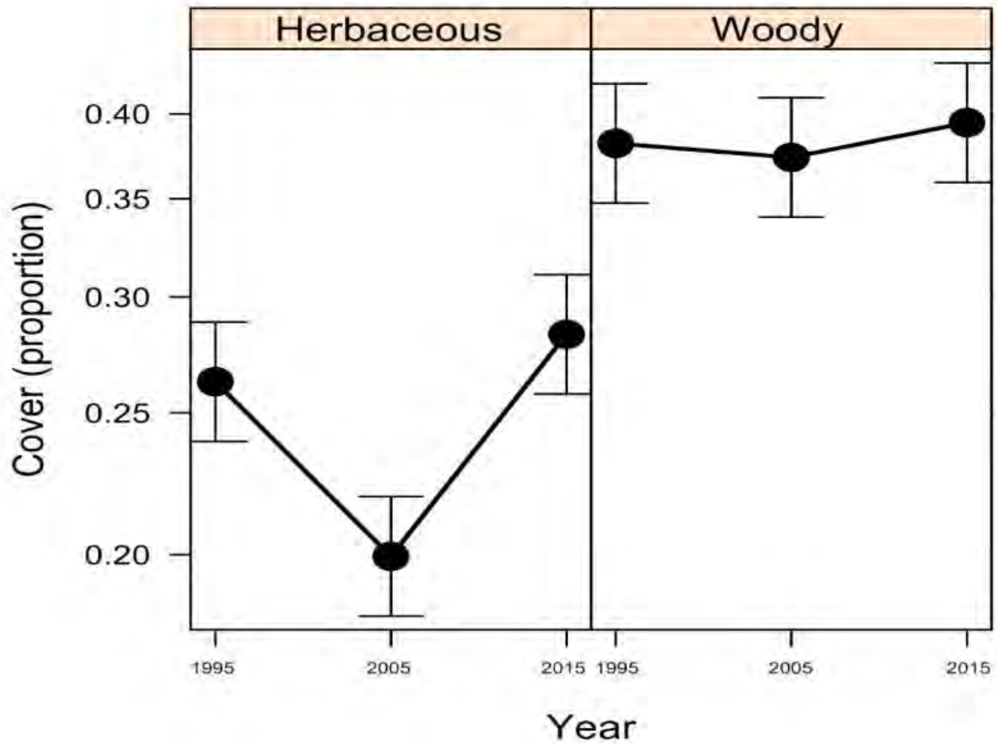


Figure 3: Predicted changes in cover of herbaceous and woody vegetation from 1995 to 2005 and to 2015. Predicted values are derived from a linear mixed-effects model that controls for differences between sites, landforms, and the interaction between cover type and year, and temporal autocorrelation. Points represent predicted means and bars are 95% confidence intervals.


1995

2005

Figure 4: Initial herbaceous cover, reduction and increase and relative stability of woody cover from 1995, 2005, and 2015 at Site 22, Droeputs, Riemvasmaak

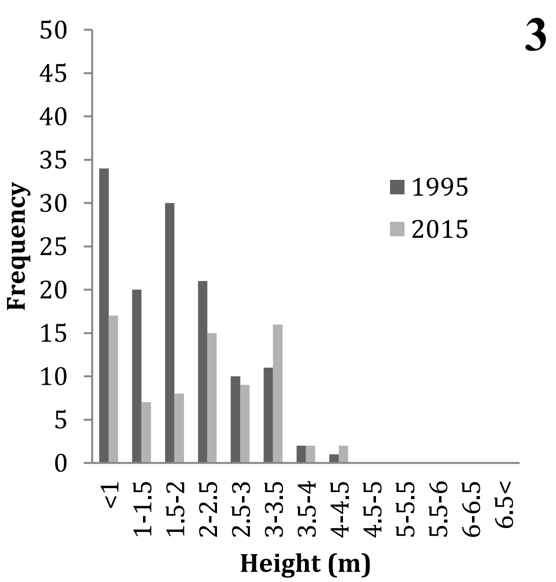
The mixed-effects model performed with landform as a fixed effect rather than a random effect showed total cover to differ significantly between types of landforms (F=5.48, $p = 0.007$). Riverbeds had the highest total cover relative to rocky slopes or sandy pediments. There were no significant interactions between landform and year or cover type, year and landform. However, the interaction of cover type and landform was significant (F=37.86, $p < 0.001$) with woody and herbaceous vegetation each having higher cover on particular types of landforms (Table 3).

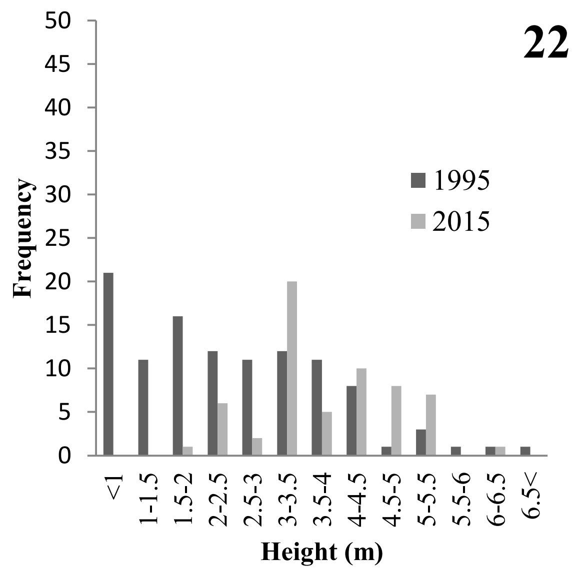
Table 3: Analysis of variance results of mixed-effects analysis with a corARMA autocorrelation structure, with cover as response and cover type, year and landform as fixed effects.

Predictors	numDF	F-value	*p*-value
Landform	2	5.48	0.007
Cover Type: Landform	2	37.86	<0.001
Year: Landform	4	0.55	0.70
Cover Type: Year: Landform	4	0.16	0.96

2.3.2. Size class distribution linear regressions for *Acacia erioloba*

There is evidence that there has been a general decline from 1995-2015 in the number of live individuals of *Acacia erioloba* across all sites surveyed (Appendix B; Table B1). Changes over time in the number of *Acacia erioloba* individuals within each 50-cm size class, surveyed in 1995 and re-surveyed in 2015, are shown in Figure 5 for four sites. Results showed there were more individuals in the smaller size classes in 1995 (<2 m) than in 2015. In 2015, however, there were more individuals scattered throughout the larger size classes.





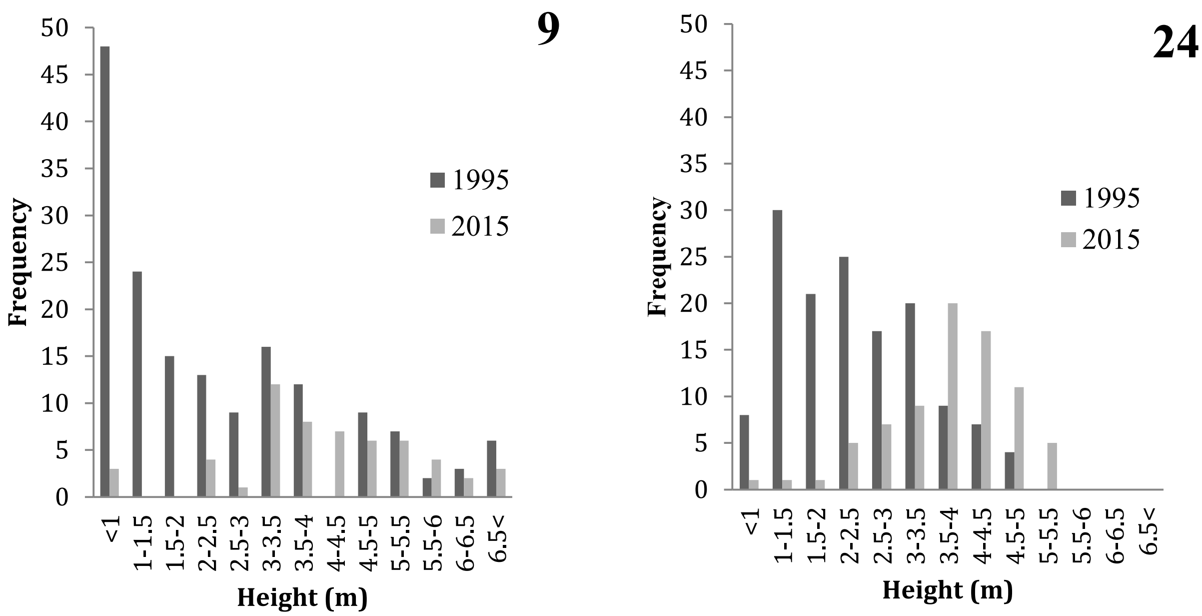


Figure 5: Size class distribution histograms (1995 and 2015) of *Acacia erioloba* at Site 3, Site 9, Site 22, and Site 24, Riemvasmaak

Much of the 1995 *Acacia erioloba* transect data had good fit within the linear regressions with the exception of Site 24 (Table 4). Site 24 in 1995 only displayed good fit (R^2 =0.86) within the linear regression with the removal of the <1 m size class. R^2 values of 1995 transects ranged from 0.15 to 0.83. In contrast, the transect data collected in 2015 showed comparatively poorer fit with a high variability of densities scattered within the different height size classes. R^2 values ranged from 0.08 to 0.45.

The frequency by height size class distribution data for three transects out of four surveyed in 1995 showed a significant negative relationship between height size classes and density of individual trees in each size class (Table 4). This indicates more individuals in the smaller size classes and a stable population in 1995 (Fig.5; Table 4). Site 9 and Site 22 displayed the most significant negative relationship between height size class and density of individual trees in each size class (p< 0.001)

The frequency by height size class distribution data for one transect out of four surveyed in 2015 showed a significant positive relationship at Site 24 (p = 0.03) (Fig 5; Table 4). This indicates more individuals in the larger size classes and limited recruitment. All other transects surveyed in 2015 were non-significant.

Table 4: Regression analysis height size class and density relationships results for *Acacia erioloba* in 1995 and 2015 at various sites.

Site	Year	df	F	*p*	Coef	R^2
3	1995	7	27.61	0.002	-0.009	0.82
3	2015	7	2.43	0.17	-0.003	0.29
9	1995	12	36.92	< 0.001	-0.003	0.77
9	2015	12	1.22	0.29	0.000	0.1
22	1995	12	55.46	< 0.001	-0.003	0.83
22	2015	11	0.81	0.39	0.000	0.08
24	1995	8	1.23	0.30	-0.004	0.15
24	2015	9	6.64	0.03	0.005	0.45

2.3.3. Precipitation change (1990-2014) linear regression

The trend of total yearly rainfall (mm) from 1990-2014 was non-significant (p=0.34) (Fig. 6). The analysis had poor fit with an R^2 of 0.04.

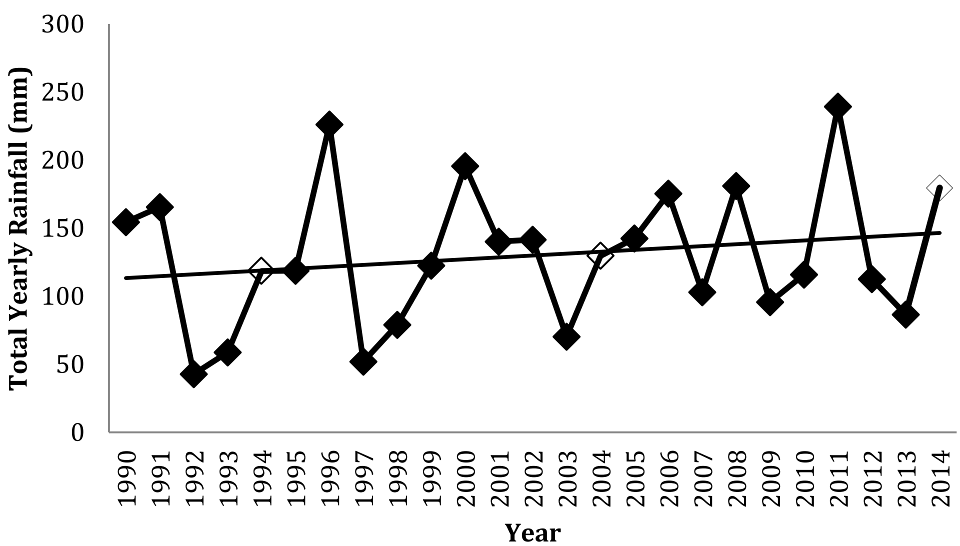


Figure 6: Line graph displaying trend of total yearly rainfall from Augrabies weather station from 1990-2014. Line shows the trend over the 25 years ($y = 1.3873x + 111.77$; R^2 0.03888). Open symbols indicate the year immediately prior to the sampling date, which took place in the first two weeks of January the following year.

2.3.4. Finer scale precipitation change

The total yearly amount of rainfall (mm) from the Augrabies weather station displayed a consistent increasing trend whether it was calculated three years, two years or a year before the focal years of 1995, 2005, and 2015 (Table 5). The lowest values for rainfall was consistently before 1995, the intermediate before 2005, and the highest before 2015. All rainfall values calculated one-year prior to each focal observation year exceeded the mean annual rainfall figure of 128 mm save for one year prior to 1995 (119 mm).

Table 5: Total amount of rainfall (mm) calculated three years, two years and one year before the focal observation years of 1995, 2005, and 2015. Mean annual rainfall for Riemvasmaak is 128 mm.

	Three years	
1995	2005	2015
220	341	379
	Two years	
1995	2005	2015
177	200	266
	One year	
1995	2005	2015
119	130	180

2.3.5. Recruitment of Prosopis spp. 1995-2015

An increase in the number of invasive *Prosopis* spp. occurred during 1995-2015 at Site 16 and Site 23. At Site 16 in 1995, Hoffman *et al*. (1995) recorded 11 live individuals, and in 2015, the number of live individual trees had increased to 48. At Site 23, the population of *Prosopis* spp. increased from no live individuals recorded in 1995 to 60 recorded live individuals in 2015.

2.3.6. Stock numbers and interviews

Within the area of Greater Riemvasmaak stock numbers increased continuously in each of the four main categories (cattle, sheep, goats and donkeys) from 1995-2005 (Fig.7). Data for stock numbers in September 2015 showed that the numbers of cattle, sheep, and donkeys had all declined from 2005 numbers with cattle showing the largest decline (73%) from 2005, while donkeys (67%) and sheep (34%) displayed a lesser but still notable decline. In contrast, goats had increased from 2005 (79%).

From 2011, cattle showed a lesser decrease (65%) in 2015 than from 2005, while sheep displayed a marked decrease (69%). Donkeys experienced an increase (83%) in 2015 from their 2011 numbers, but still remained well below their numbers in 2005. Goats, although still high above their 2005 numbers, had decreased (26%) since 2011.

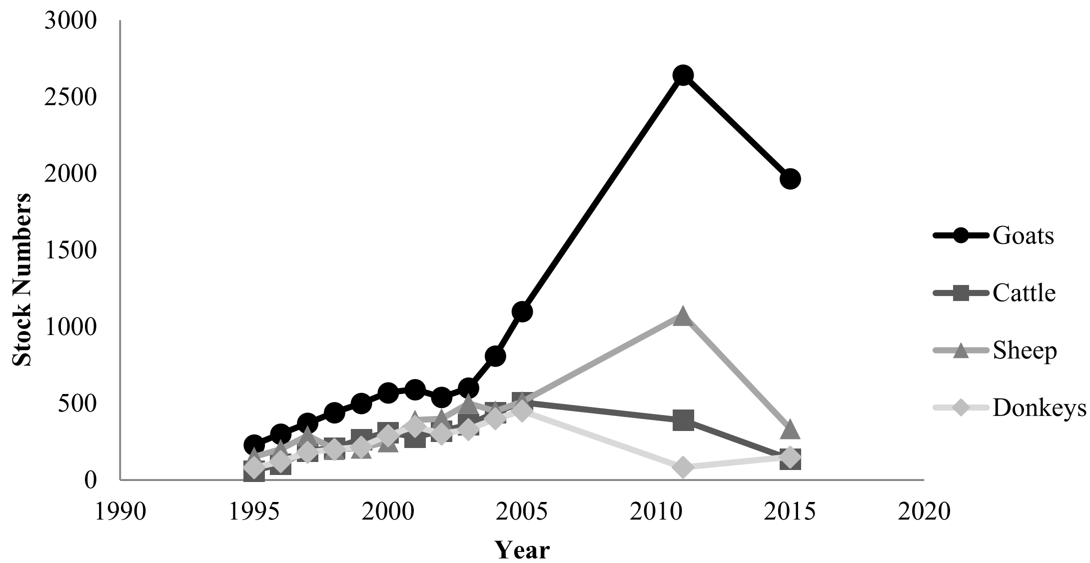


Figure 7: Trend of total stock numbers of goats, sheep, cattle, and donkeys in Riemvasmaak from 1995-2005, 2011, and 2015.

Rain was constantly reported as making a large difference to the condition of the vegetation within Riemvasmaak. Although there was a wide range in the amount of recent rainfall reported by interviewees as compared to before 1974 and since 1995, the majority indicated that there had been an increase in the variability of rainfall in the area, particularly within the last few years, with a shorter rainfall season. Several individuals reported good rainfall in the early to mid-1970s. A disastrous drought was also reported by several interviewees to have occurred in 1997 (see Fig. 6), requiring the intervention of the Department of Agriculture. The amount of rainfall between sites was also reported by many interviewees as being highly variable.

The condition of the veld was generally considered by most of the interviewees who returned in or directly after 1995 as very good at the time of their return, and several reported a decline in quality in the mid-2000s. However, reports of the current condition of the veld were highly variable depending on the individual interviewed and the site where they were located. Sites were reported to have varying conditions, with some such as Site 19, Site 12, and Site 22 seen as currently favorable in terms of supporting animals, and others, such as Site 18, Site 7, or Site 6 reported as overgrazed or impacted by military activities of the past. Individuals located at these favorable sites, or individuals located near the mountains, were more likely to report good condition veld than individuals located in the lowlands or at unfavorable sites. Indicators of veld quality that respondents provided were correlated with suitability of grazing, such as “enough grass or more grass” as a positive indicator, and “not enough grass or less grass” as a negative indicator. Reported decline in tree condition and a later flowering time for species such as *Acacia mellifera* was also cited as indicators of poor veld condition.

The Ma/Hao Agricultural Collective and several other individuals indicated a general improvement in the condition of the veld because of the movement of many animals (especially cattle) to the new rotational grazing farms off Riemvasmaak, which started in 2009. Other drivers cited by interviewees included a recent preference for browsers such as goats over grazers such as sheep and cattle due to their less time-intensive nature, a disinterest in livestock farming by youth and an incentive to reduce livestock farming activities due to high levels of stock theft. Although there were a variety of responses concerning the amount of herbaceous cover and woody cover over the period from 1995-2015, four individuals reported no new recruitment of trees, with two also reporting a worsening in the condition of adult *Acacia mellifera* trees.

2.4. Discussion

The mixed-effects model performed with landform as a fixed effect displayed no significant interaction between changes in cover over the years due to landform type. The best-fit mixed-effects model performed without landform as a fixed effect showed total cover to differ significantly ($p < 0.001$) over the three time steps (1995, 2005, 2015) (Fig. 3; see Appendix C; Table C1). This indicated that changes in total cover occurred over the wider area of Riemvasmaak, and were likely driven by either climate or livestock grazing. Additionally, as the interaction in the best-fit model between cover type and year was significant ($F=11.48$, $p < 0.001$), this indicated a clear difference in the amount of change seen when comparing herbaceous and woody vegetation.

2.4.1. Drivers of change within herbaceous and woody vegetation (1995-2015)

Although total vegetation (both herbaceous and woody) in 2005 was much lower than in 1995 or 2015, herbaceous and woody vegetation displayed different responses over the three time steps. Herbaceous vegetation was more variable, declining significantly from 1995 to 2005 ($p < 0.001$) and increasing significantly ($p < 0.001$) from 2005 to 2015 to similar cover levels as 1995. In contrast, woody cover did not change significantly from 1995-2015 (Fig. 3; see Appendix C; Table C1). These results are discussed below in terms of the influence of rainfall and herbivory on vegetation cover in arid and semi-arid rangelands.

Woody and herbaceous vegetation respond differentially to precipitation. In comparison with woody species, herbaceous species tend to be more responsive to short-term climatic fluctuations (Rich *et al.* 2008), and the amount of precipitation can cause a strong response in seasonal peak herbaceous biomass (O'Connor and Roux 1995; Fynn and O'Connor 2000). However, there was no significant trend in the amount of rainfall (mm) from 1990-2014 (Fig. 6), indicating an arid system with rainfall that is extremely variable in the amount of precipitation per year (Thomey *et al.* 2011). Calculating the amount of rainfall three, two, and one year before each focal year (1995, 2005, 2015) further clarified patterns (Table 5).

The lowest values for rainfall, whether three, two or one year before, occurred before 1995. This was due to the very low rainfall years of 1992 (43 mm), 1993 (59 mm) and 1994 (119 mm), which were all below Riemvasmaak's mean annual rainfall figure of 128 mm. The highest amount of rainfall consistently occurred before 2015, mainly due to the high rainfall year of 2014 (180 mm), while 2013 and 2012 were comparatively low rainfall years (87 mm and 113 mm respectively). Due to the extremes in high and low rainfall, variability in rainfall was also highest prior to 2015 (Fig. 6; Table 5).

Despite low rainfall before 1995 and high rainfall in 2014, the mixed-effects model analysis found that 1995 did not have significantly different herbaceous cover than in 2015 (Fig. 3; see Appendix C; Table C1). This finding contrasts with the hypothesis of systems at disequilibrium theory which suggests that climatic conditions would be the main driver of change in Riemvasmaak's arid rangelands (Gillson and Hoffman 2007). As trends in amount and variability of precipitation do not match expected corresponding trends in vegetative cover, it is probable that other factors such as herbivory are interacting with precipitation and driving the resultant changes.

The numbers of different livestock types present on the landscape may help to explain the significant differences in changes between herbaceous and woody vegetation, as impacts on vegetation by livestock are not homogenous (Rook *et al.* 2004). For example, cattle are preferentially grazers and their intake of woody plants is more limited than small ruminants (Celaya *et al.* 2007). Higher dietary overlap between cattle and sheep than cattle and goats, which are preferentially browsers (Pande *et al.* 2002, see Appendix B), also agrees with multiple studies in widely different environments such as in the Sahel (Sanon *et al.* 2005) and in the Pyrenees mountains (Aldezabal 2001). Donkeys, in contrast, are opportunistic in their dietary preferences and exhibit both grazing and browsing behavior (Gartzia *et al.* 2009). This heterogeneity in livestock dietary preferences becomes particularly relevant, as within Riemvasmaak livestock numbers and types changed substantially over the study period. There was a large drop in grazers (cattle, sheep, and donkeys) from 2005 to 2015, while browsers (goats) increased from their 2005 numbers (Fig. 7).

It is likely that a reduction of grazing livestock (especially cattle) on the landscape after 2011 benefited herbaceous cover and that the relatively high cover of herbaceous vegetation observed in 2015 occurred as a direct result of the reduction in grazers. This reduction, however, did not occur as a result of a major drought or decline in rainfall in the region but instead was strongly influenced by factors that were cultural and socioeconomic in nature. For example, several interviewees reported a disinterest in livestock farming by the youth and a preference for keeping less time-intensive livestock such as goats rather than sheep. The reduction in the number of donkeys in 2015 in comparison with 2005 may be due to the rise in available vehicles in the community. Many former transport animals were reportedly used for their meat, as the Damara people, who are a majority group in Riemvasmaak, are large consumers of donkey meat (Lionel Mapanka pers. comm.). Overall livestock numbers may also be dropping in response to high levels of stock theft, as individuals become less willing to invest in full-time small-scale livestock farming. The police within Riemvasmaak are widely seen by interviewees to be incompetent at stopping the problem of livestock theft. As one long-term livestock owner eloquently stated: "The policemen are useless. You can take the policeman to where your goat was stolen, show him the man who stole your goat roasting it over a fire, only for the thief to convince the policeman the goat is actually his and the policeman to leave!"

Giannecchini *et al.*'s (2007) study of the linkages between environmental change and socio-economic factors in communal rangelands in a former Bantustan region in Limpopo Province, South Africa corroborated many of this study's findings. In the study areas within Limpopo Province there was an increase in goat ownership, which Giannecchini *et al.* (2007) attributed to the physiological traits of goats, such as a higher birth rate and higher resilience to food shortages than cattle. These morphological traits of goats are advantageous for opportunistic livestock farming, although Giannecchini *et al.* (2007) acknowledged that their rainfall data did not suggest a worsening in severity or frequency of droughts. With regard to the impact of stock theft, Ntshona and Turner (2002) in the communal rangelands of the Maluti district in the Eastern Cape found high instances of stock theft and that these levels of stock theft were a growing disincentive for livestock production.

However, the removal of such large numbers of livestock, particularly cattle, from Riemvasmaak to the new commercial farms, can be traced back to a directive issued by the Riemvasmaak Municipality in 2009 that livestock would no longer be allowed within the Municipality (i.e. village) boundaries. The directive was issued because of noise as well as hygiene concerns as overall livestock numbers within the Municipality continued to rise after 2005. Preparations to move out of the Riemvasmaak Municipality began in 2009 and the majority of farmers completed the move in 2013 when the directive became effective because of the availability of additional land (Ma/Hao Agricultural Collective pers. comm.).

A reduction in woody plant growth and general degradation of rangelands has previously been attributed to browsing by free ranging goats (Oba 1998; Pande *et al.* 2002). Much of this potential to contribute to degradation has been attributed to the morphological traits which goats possess, such as narrow muzzles and prehensile tongues that allow them to efficiently remove leaves and shoots from thorny plants. Limited bipedal posture additionally allows goats to use browse up to 1.5 m (Oba 1998). However, woody cover, in this case referring to adult individuals, was stable from 1995-2015, despite the relatively high numbers of browsers that utilized the landscape (Fig. 7) and as evidenced by the distinct browse line observed on many individual trees in the field in 2015.

Although undoubtedly important, herbivore selectivity and behavior are not the only factors to consider when determining why herbaceous cover was more variable than woody cover over the period from 1995-2015. Other factors may include the physical characteristics due to generalized differences between woody and herbaceous vegetation which would result in different adaptive strategies and tolerances to herbivory. Tolerance is defined within this context as comprising of both the ability to temporarily cope with a reduction in biomass, and an ability to recover through regrowth (Krause and Raffa 1996). Multiple studies confirm that many woody plants are able to effectively compensate or overcompensate for biomass lost due to herbivory (Dangerfield and Modukanele 1996; Hjältén 1999; Vanderklein and Reich 1999; Lehtilä *et al.* 2000). Particularly relevant for this study is Oba and Post's (1999) experimental results in an arid zone in Kenya, which provided evidence that browsing has an effect on twig growth of *Acacia tortilis.* Their results indicated that browsed twigs sustained greater net growth than unbrowsed twigs, implying that goat browsing stimulated twig production.

Grasses have some traits in common with woody plants, such as the presence of physiologically independent components (tillers). However, unlike most woody plants, grass growth and regrowth tends to not take place from terminal buds, but from basal meristems protected by leaf sheaths. Although grass tussocks may be affected by heavy grazing, most grazing of grass swards does not damage the protected meristems. Because of this, growth after damage can occur quickly once grazing pressure is removed (Haukioja and Koricheva 2000). Grasses are also considerably tolerant of herbivory over time in that they have a high seed bank that is long-lived in the soil and thus have the ability to bounce back quickly if allowed to rest and if there had been adequate precipitation (Hoffman and Todd 2010). Herbaceous vegetation was under grazing pressure from livestock from 1995, suffering the highest pressure in 2005, but was largely relieved of livestock grazing pressure from 2013. This would have a beneficial effect upon herbaceous cover, and may have allowed it to recover quickly to similar levels as were seen in 1995.

2.4.2. Drivers of change in size class distributions of *Acacia erioloba*

While adult woody vegetation appears not to be negatively affected by browsing, recruitment of tree species may be affected as was voiced as a concern by several interviewees. The relatively long-lived nature of trees, however, may mean that any impacts of browsing are likely only to become evident after adult trees die and are not replaced.

Within the size class distributions of *Acacia erioloba,* the slope of the linear regression of the height size classes and density of individual trees within each size class displayed a negative and significant trend in 1995 with the exception of Site 24. It was clear, therefore, that there was a great deal of recruitment in these trees prior to 1995. Such high levels of recruitment were distinctly lacking in transects surveyed in 2015 (Fig.5; Table 4). Under the systems at disequilibrium theory, it might have been expected that recruitment of *A. erioloba* would have taken place prior to 2015 provided that the amount and frequency of precipitation allowed for germination and establishment. However, results of the 2015 surveys showed a distinct lack of individuals <1.5 m in height at most sites.

Several studies have found the successful establishment of *A. erioloba* to be restricted mostly to years in which rainfall is evenly distributed over a season or during episodic good rainfall (Wilson and Witkowski 1998; Barnes 1999, 2001b; Wiegand *et al.* 2005; Seymour 2008). For example, the prevalence of a considerable population of young *A. erioloba* individuals <2 m in height recorded in Riemvasmaak in 1995 by Hoffman *et al.,* was attributed in that study to very high rainfall conditions present between 1974-1976 (see Appendix D; Fig. D1). As *A.erioloba* is very slow-growing, with a growth rate only about 65 mm a year (van Rooyen *et al.* 1994), it may be that rainfall several years prior to 1995 (Fig. D1) might have been sufficient in frequency and quantity to allow for the germination and establishment of new recruits in an environment relatively free of herbivores.

Although saplings in species such as *A. erioloba* are vulnerable to severe drought, they also have deep rooting systems that may be deep enough to allow them to escape moderately dry periods (Holdo and Timberlake 2008). This possibility is supported by the findings of van Rooyen *et al.* (1984) in the Kgalagadi Transfronteir Park. Above-average quantities of rainfall during the period of 1974-1976, followed by eight years of average to below-average rainfall, had little effect on the population dynamics of trees such as *A. erioloba* in their study area.

However, it is also important to consider that the absence of livestock in the years prior to 1995 enabled the survival of seedlings which had emerged after the high 1974-1976 rainfall event in the region. Between 1995 and 2015 browsing pressure increased significantly and any seedlings which might have germinated over this period would have been heavily browsed by livestock. Such evidence contradicts the ideas proposed in the systems at disequilibrium theory which suggest that herbivory is rarely limiting as livestock numbers would be kept low due to drought events. However, as suggested by key resource theory (Illius and O'Connor 1999, 2000, Hempson *et al*. 2015) herbivory may be an important driver of recruitment and survival. By restricting saplings to <1 m, herbivores leave saplings susceptible to further herbivory, and often, the impacts of even small herbivores on recruitment can be notable. Augustine and McNaughton (2004) found the impacts of small browsers to be equivalent to a 6-fold reduction in shrub recruitment in the 0.5-1.5 m height class, which has important implications for the role of browsing in keeping down the heights of tree saplings.

Domestic goats in particular are often implicated in preventing tree regeneration around settlements due to their ability to exploit patchy browse resources. It is believed that goats hinder recruitment of many tree species such as *A. erioloba* by consuming seedlings or removing the shoots of the current season (Oba 1998). For example, utilizing three monitoring sites in an arid system in Namibia, Moser-Nørgarrd and Denich (2011) examined the survival of protected and unprotected seedlings of two arid species of trees, one being *A. erioloba.* They found that in areas of high livestock numbers, no or few unprotected seedlings survived. Direct observations in the field from this same study additionally confirmed frequent occurrences of goats eating freshly emerged seedlings. Moser-Nørgarrd and Denich's (2011) results are particularly relevant to this study as although numbers of grazing livestock declined over the period 2005-2015, the numbers of goats still remained high within Riemvasmaak. Therefore, goat browsing may have had a particularly strong effect on the recruitment of *A. erioloba* for those individuals able to germinate prior to 2015 as well as for individuals <1.5 m which were present in 1995.

2.4.3. Corroborations of farmer perceptions with results

Although perceptions of the interviewees varied from person to person, there were several important consistencies within the interviews. Recent variability of rainfall was reported across a wide range of sites and by several different people. When examining the precipitation data provided by the South African Weather Service (SAWS) from the Augrabies weather station (No. 02817601), trends of variation before 2015 corroborate the general perception of recent high variability in rainfall (Fig. 6).

Although there were differing opinions concerning changes in rainfall compared to before 1974 and trends in rainfall from 1995-2015, extreme precipitation events were consistently voiced by interviewees. The drought disaster in 1997 and the high rainfall reported in the period 1974-1976 corroborated the Augrabies precipitation data (see Fig. 6 in results and

Fig.D1 in Appendix D).

The condition of the veld was universally reported to have been ‘good’ by those returning in 1995. A high level of herbaceous cover seen within the 1995 photographs agrees with this reported ‘good’ condition of the veld. In contrast several interviewees reported veld condition to be declining in quality in the mid-2000s. This was likewise in agreement with the significant drop of herbaceous cover in 2005 found in this study’s analysis. A lack of new recruitment of trees consistently voiced by interviewees also agrees with the lack of recruitment of a focal tree species (*Acacia erioloba*) found within this study.

The perceptions of the current condition of the veld as compared to before 1974 and from 1995 were much more variable. Some interviewees reported more herbaceous cover in 2015 than in 1995, and some reported less. However, every interviewee indicated that they only used supplemental feed during extremely dry conditions or for sick, pregnant, or young animals. This may be potentially a reflection of the current acceptability of the veld for the number of animals utilizing it.

More consistent reporting of extremes in precipitation and veld condition agreed with the results from other studies (Ovuka and Lindqvist 2000; Mertz *et al*. 2009) that overall, long-term trends reported would be variable but that particular extremes in environmental change would be more consistent among multiple interviewees.

Importantly, individual perceptions seemed to be consistent across multiple interviews concerning the overall numbers of livestock, and corroborated the livestock data obtained for this study. As reported by interviewee No.12, “so many people were there before 2013, you had to choose a direction to graze. Now, you can graze in any direction.” Whether or not they believed current herbaceous cover was superior or inferior to 1995, most interviewees who mentioned drivers of vegetative change noted that the removal of the majority of grazers from Riemvasmaak by 2013 was in general beneficial for the condition of the rangeland, although several believed there were still too many animals present on the landscape.

Chapter 3 – Study Review

3.1. Conclusions in relation to the conceptual framing of the study

Due to the lack of correlation between precipitation trends and trends in herbaceous vegetation, it is unlikely that precipitation is the sole driver within this system as suggested by disequilibrium theory and the 'new thinking' in range ecology (Ellis and Swift 1988). In contrast, it is likely that herbivory, and thus the return of livestock owners in 1995, has had a significant impact upon this arid rangeland. Importantly, a carry-over effect of impacts between time steps probably occurred and was assumed within this study's analysis (Fynn and O'Connor 2000). The impacts of rainfall and herbivory in the years prior to each focal year of 1995, 2005, and 2015 likely influenced the changes in cover witnessed in those three time steps. For instance, a total release from livestock grazing pressure, which occurred in 1974-1994, may have interacted with comparatively poor rainfall prior to 1995 in order to nevertheless produce a notable cover of herbaceous vegetation. This, and the resurgence of herbaceous cover in 2015 within Riemvasmaak, reflects a certain resilience of the landscape.

In their important contribution to the debate on the dynamics of arid and semi rangelands, Illius and O'Connor (1999, 2000) and Hempson *et al.* (2015) suggest that although vegetative change may be initially driven by precipitation, herbivores would not necessarily be completely decoupled from their resource base, and therefore also have a strong impact upon the landscape. They also argue that competition-mediated density-dependent effects upon herbivores may occur if a certain threshold of livestock numbers are reached and takes into consideration the inherent tolerance of different vegetation types to herbivory. However, what is often not taken into consideration in studies of arid rangeland dynamics is the inherent heterogeneity of an area such as Riemvasmaak. Riemvasmaak is not only spatially heterogeneous, including the presence of the perennial Orange River, but is comprised of different types of vegetation (i.e. herbaceous and woody) located in different abundances within different landforms (rivers, sandy pediments, and rocky slopes). Herds are comprised of multiple livestock types (cattle, sheep, goats and donkeys) with different dietary requirements. Changes in overall livestock numbers and types and their resulting impacts upon vegetation are primarily driven by socioeconomic and cultural factors as found from the interviews, which were important in further postulating drivers of vegetative change.

Importantly, in contrast to Hempson *et al.*'s (2015) study area in the Richtersveld National Park, Riemvasmaak is a developmental project located near an urban center (Kakamas). As a developmental project, the people living in Riemvasmaak have many additional inputs and options available to them, which change over time and influence their livestock enterprises. These include access to available farms located some distance from Riemvasmaak and the provision of governmental pensions and off-farm income that could be used to purchase supplemental feed during times of drought. These additional inputs might have mitigated any density-dependent effects that could have occurred with grazing livestock in response to poor rangeland condition in the mid-2000s. This would have allowed an artificially high number of grazers and potentially have led to increased degradation of the landscape (Vetter and Bond 2012). Both the heterogeneity of Riemvasmaak and the availability of additional inputs into the system indicate that neither a systems at disequilibrium nor a key resource theory framework is an adequate fit for this system. Treating the landscape as a linked socio-ecological system is the most effective way of understanding change within Riemvasmaak.

As an additional example, although goat numbers seem to track rainfall, reducing slightly from 2011 to 2015 (Fig. 7), cultural and socioeconomic factors such as an increase in stock theft and the movement of a certain amount of goats as well as cattle off Riemvasmaak in 2013 may also be in operation. Therefore, it is important to be cautious in examining all factors that may be affecting drivers before conclusions can be postulated concerning any potential density-dependent regulation of livestock numbers.

3.1.1. Limitations of this study

Conclusions of interviewees' perceptions were based upon a sample size of fifteen interviews. Selection of interviewees was limited by which individuals were available and willing to be interviewed. Importantly, although most interviewees lived in Riemvasmaak prior to 1974, many, whether they lived in Riemvasmaak previously or not, did not come to Riemvasmaak directly after 1995. Dates of settling in Riemvasmaak varied for interviewees from between 1995 to 2007.

Due to the fact that questions were asked on changes over a significant time period, extremes in precipitation or vegetative change were more likely to be recalled than overall trends in long-term change. As a result of this, many perceptions of change of veld condition and rainfall from before 1974 and from 1995-2015 must be examined with this in mind as well as the tendency of many farmers outside the Municipality to move to different sites after settling at one for several years.

Another limitation is that photographs were only taken in 1995, 2005, and 2015, which precluded examining vegetative change at a finer temporal scale. Conclusions of an overall trend in vegetative change from 1995-2015 were based upon 27 sites and three landform types comprising of seventeen rocky slopes, seventeen sandy pediments and sixteen riverbeds. Due to the nature of the broad-scale questions posed, as a large area such as

Riemvasmaak contains implicit heterogeneity and complexity, there may be additional competing explanations to the causal factors proposed.

The heterogeneity of the study area likely impacted interviewee perceptions, as the scale of this study's analysis concerning overall change may be significantly different from what an individual might experience at a single site. It is certainly possible that an individual's perceptions of veld condition might vary significantly between sites. For example, interviewees in less utilized sites such as mountainous areas reported better veld condition than interviewees in areas that were or are commonly grazed. Heterogeneity in amount of rainfall from site to site also was mentioned within interviews, which, if accurate, may have also influenced interviewee opinions of changing rainfall patterns and their impacts.

Detailed analysis of drivers of vegetative change was limited by data available concerning Riemvasmaak. For example, analysis of precipitation as a driver was limited to the availability of suitable rainfall data. The closest weather station that possessed a complete rainfall record was located 11.7 k from the rainfall station of Augrabies Falls on the southeastern border of Riemvasmaak. Potential heterogeneity in rainfall between different sites would not be reflected in the precipitation data obtained from the SAWS Augrabies weather station.

Conclusions of herbivory as a driver were based upon what livestock data was available, which may not reflect exact numbers of each livestock type present in Riemvasmaak. Livestock data was only available for the entirety of Riemvasmaak from 1995-2005 and 2011, and were not differentiated into different ages or sexes of animals during those years. This prohibited the calculation of Large Stock Units in accordance with guidelines set out in the Conservation of Agricultural Resources Act (Act 43 of 1983).

Livestock data was sourced from both unpublished records provided to Hoffman and Todd (2010) and from the Ma/Hao Agricultural Collective, the latter of which had ceased to collect livestock data in 2011 due to the cessation of their animal dip program. Values for 2015 were by necessity obtained during this study by brief interviews with stockpost owners or livestock herders at each site, including the Municipality, or by counting numbers of animals returning from grazing. It can be expected that there may be some inaccuracy in knowledge of animal numbers when interviewing individuals, particularly those with larger herds or when interviewing hired herders.

In terms of overall availability of data, lack of site-by-site rainfall and livestock number data for 1995-2015 prohibited the examination of the impacts of rainfall and livestock numbers on a finer spatial scale. This would have likely been more comparable to individual interviewees' perceptions. Conclusions with respect to key resource theory were also limited by the fact that this study lacked the data to fully explore seasonal variation on resource use and the role of the Orange River riparian zone as a key resource.

3.1.2. Future research and recommendations

There are three major issues that should be addressed in the context of examining detailed environmental change within Riemvasmaak. These issues are; species-level compositional change within landforms, type and timing of repeat photographs, and in addition to more intensive data collection by researchers, engagement with the local community to allow both more frequent collection of data and the monitoring of invasive species.

A broad-scale analysis such as examining differences in the herbaceous and woody component of the vegetation is valuable as a pilot study. However, the analysis of changes in species composition within Riemvasmaak is beyond the scope of this study due to the difficulty in discerning species-level estimates from the repeat photographs. However, goat dietary observations within this study confirmed that different species of plants within Riemvasmaak are differentially utilized by domestic ungulates (see Appendix B). Additionally, as interviewees did not fully define the comparative meaning of ‘good’ as opposed to ‘bad’ veld, it is possible that changes occurring in species composition not addressed in this analysis may have further influenced opinions of veld quality.

An analysis of species-level compositional change would provide a more refined understanding of what is occurring within the area. For example, intense grazing can lead to removal of the most palatable species such as perennial grasses, which may then open space for less palatable and faster establishing annual grasses (Thomas and Twyman 2004). Different species of plants within the area, as well as having different palatablities may also respond differently to climatic conditions and have different tolerances to disturbance. This would affect compositional change in response (Jauffret and Lavorel 2003).

Any changes in composition found from further examination may point in more detail to the state of the rangeland over time, including its diversity, capacity to support livestock, and the importance of various drivers. Further analyses utilizing species-level transect data, such as that collected by Hoffman *et al.* in 1995 and Hoffman and Todd in 2005 and 2015 within each landform at each site could prove useful in examining changes in vegetative composition from 1995-2015.

The results of the mixed-effects model performed with landform as a fixed effect displayed no significant interaction between changes in herbaceous and woody cover over the years due to landform type. However, there may be subtler changes within species composition occurring within landforms in accordance to Hoffman *et al.*‘s (1995) original classification of landform units due to species composition.

This potentiality is also supported by the significance of cover type by landform (p< 0.001), indicating that different landforms had different quantities of herbaceous and woody vegetation (Table 3). Changes between different species within landforms from 1995-2015 should be further examined within the context of this study's design, and if found to be insignificant, additional methodology should be constructed for accessing overall change in species composition if further studies are to be carried out.

If further research is to take place in Riemvasmaak utilizing repeat photography, it is recommended, that in lieu of black and white photographs, researchers should use digital color photographs. This is due to the difficulty of accurately accessing vegetative cover, particularly herbaceous cover, from black and white photographs (see Methods). Within this study, although photographs for each site for 1995 and 2005 were only available in black and white, it was found to be easier to estimate percentage cover within those photographs when using the available digital color photographs from 2015. Alternate techniques for analysis of repeat photography should continue to be tested and their strengths and weaknesses recorded. Black and white images for 1995 and 2005 precluded the use of a supervised classification technique due to high inaccuracy within single-band images. Due to this, an analysis utilizing a supervised classification technique was tested using the available digital 2015 images (see Appendix C).

Several of the limitations discussed within this study were the amount and type of data available to be used in order to examine the extent and drivers of vegetative change. The use of only three time steps (1995, 2005, and 2015) of the repeat photographs may potentially suitable for long-lived plant species. However, it precludes analysis of change on a shorter time scale more suitable for plant species, such as many herbaceous plant species, that tend to vary more with changing climatic and grazing impacts. Due to ten-year intervals of data collection, significant difficulties have arisen when addressing the already challenging determination of the relative roles of climate and grazing in driving vegetation cover change. It is recommended that the intervals be shorted to an average of five years between focal dates, with the possibility of photographs taken opportunistically in response to high or low rainfall. It would also be advantageous to take photographs two consecutive years every ten years or so to detect the impact of interannual variation. It is recommended that any future species-level data collection correspond with these shortened intervals.

Further engagement with the community of Riemvasmaak is highly recommended in order to both improve the frequency of data collection and to further a sense of collaboration between researchers and the community. Several potential opportunities exist for engagement. The first concerns the intervals between focal dates within this study's repeat photography component. Although five years between focal dates is an improvement upon ten, these still relatively long intervals might be complemented by potentially engaging and employing people from Riemvasmaak to take yearly photographs at sites in order to gain a more continuous, albeit more informal, sense of change.

Photographs taken at different times of year by community members may also aid in understanding the impacts of seasonal change not incorporated within the current study design. More community involvement in studies concerning environmental change in Riemvasmaak will be useful in spreading awareness of alterations of the landscape, potential impacts, and may influence management.

The second concerns record keeping of livestock. Involvement with the community indicated that there is now no single source of overall livestock numbers in Riemvasmaak after the cessation of the Collective's animal dip program. This is a concern, as knowledge of livestock numbers is vital for sustainable management of livestock. Further engagement may be made with the Collective to set a system in place where overall numbers of animals can be collected.

Third, conclusions with respect to key resource theory were limited by lack of data. In order to fully address key resource theory's assertions as a possible model to explain certain dynamics in Riemvasmaak continually updated data concerning the distribution of stock posts would be useful. Crucially, more detailed data concerning seasonal patterns of land use should be gathered in order to identify areas used by herbivores in the wet and dry seasons, especially considering the presence of the Orange River riparian zone. Further engagement with stock post owners and herders may allow for a seasonal record of herbivore movements to be kept.

Fourth, although there has not been a significant recent encroachment of the alien invasive *Prosopis* spp., the presence of *Prosopis* spp. at Site 16 and Site 23 should be carefully monitored. Although several interviewees reported knowledge of or involvement in *Prosopis* spp. eradication programs, it is essential to highlight areas of highest risk and to further emphasize the importance of management.

Future studies must emphasis the importance of dissemination of results to the community of Riemvasmaak. For example, the results of this study will be presented to the community in a variety of forms. The full copy of this study will be available within the Visitor Center, central in the Municipality, for perusal. As Riemvasmaak is a primarily Afrikaans-speaking community, a short summary of results will be composed in Afrikaans and will also be made available within the Center's library. A presentation of results in Afrikaans will take place with the community in 2016.

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Appendix A: Auxiliary information concerning the 3-9 September interviews within Riemvasmaak

UNIVERSITY OF CAPE TOWN

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5 August 2015

Ms Gabriela Fleury
Department of Biological Sciences

The assessment of environmental change in Riemvasmaak, Northern Cape, South Africa: twenty years after resettlement

Dear Ms Gabriela Fleury

I am pleased to inform you that the Faculty of Science Research Ethics Committee has approved the above-named application for research ethics clearance, subject to the conditions listed below. You are required to:

- Implement the measures described in your application to ensure that the process of your research is ethically sound; and

- Uphold ethical principles throughout all stages of the research, responding appropriately to unanticipated issues: please contact me if you need advice on ethical issues that arise.

Your approval code is: FSREC 36 – 2015

I wish you success in your research.

Yours sincerely

RCHill

Dr Richard Hill
Chair: Faculty of Science Research Ethics Committee

Cc: Prof Timm Hoffman, Supervisor

Personal Information
Name
Date

Did you live in Riemvasmaak before 1974?
Did you farm with livestock before 1974?
When did you return to Riemvasmaak?
Did you start up again immediately with your animals when you returned?
Did you farm in the same areas that you did today?

Livestock numbers
What are your current livestock holdings?

Lewendehawe	Getal
Bokke	
Skape	
Beeste	
Donkies	
Perde	
Totaal	

Is this similar to the number and type of animals you had before 1974?

Sales/Production:
What is the main reason for you keeping animals?
If animals are for sale, how many animals do you sell each year? What types of animals do you sell?
Where do you sell your animals?

Infrastructure and Mobility
Who "owns" the stockpost?
Do you move to other stockposts? How often? Why do you move? Are you moving your animals more often than you used to?
Do you herd your animals daily?
Do you feed your animals? If so, what do you feed them and when do you feed them? Has the type of feed changed, and why?

Climatic and environmental change

1. Climate

Have you noticed changes with the rainfall and temperature patterns compared to:
Before 1974
Last 20 years (1995-2015)

2. Has water availability at boreholes and dug wells changed? How?
3. Rangelands

   What were your impressions of the landscape when you returned in 1995?
   Do you feel that the veld has changed in the last 20 years? How has it changed?
   Which areas appear to have changed the most?
   Why do you think these changes have occurred?

<u>Adaptations</u>
How have these changes affected your way of farming?

<u>Additional Questions for Collective</u>
What is the most common occupation in the area?
How many people solely make their living from livestock farming?
Has this number been changing? Type of stock been changing?

Appendix B: Additional field methodology and results

Table B1: Dimensions of repeat *Acacia erioloba* transects

Site	Transect Length	Transect Width	Number of Live Individuals 1995	Number of Live Individuals 2015
3	70 m	40 m	129	76
9	200 m	20 m	164	56
22	200 m	20 m	109	60
24	110 m	20 m	141	77

Goat dietary observations methodology and results

A large herd of goats was followed for about 5 kms on the 8th of September 2015, to determine the palatability of local plant species. Goats were chosen in lieu of cattle and sheep as they made up the largest proportion of stock numbers within the Municipality and within Greater Riemvasmaak. Species that were both selected and avoided were identified and photographed and the information used to understand the potential causative impacts of grazing on the landscape.

The herd of goats observed ranged for several kilometers and displayed a patchwork feeding strategy. Similar to findings reported by Ouédraogo-Koné *et al.* (2006), they often browsed high in tree canopies upon their hind legs, leaving distinct browse lines. They were seen to feed upon a wide variety of plants, preferentially feeding upon the *Septulina* parasite, *Parkinsonia africana, Acacia erioloba* leaves and pods, *Acacia mellifera* leaves and flowers, *Boscia albitrunca*, the *Indigofera* low shrub, *Hypertilis salsolides* and *Stipigrasstis obtusa* grasses and the *Zygophilum* broadleaf shrub. Nitrogen-fixing plants were preferentially selected as palatable. Goats were not seen to feed upon *Stipagrostis uniplumis*, *Stipagrostis namaquensis* grasses or *Tetragonia.*

Table B2: Observed variety of plants utilized by goats outside of Riemvasmaak Municipality

Trees	Shrubs	Grasses	Parasites
Acacia erioloba	*Cadava aphylla*	*Stipagrostis obtusa*	*Septulina*
Acacia mellifera	*Justica*	*Stipagrostis ciliata*	
Parkinsonia africana	*Monechma*	*Hypertilis salsolides*	
Boscia albitrunca	*Microloma*	*Enneapogon*	
Boscia foetida	*Indigofera*		
	Zygophilum		

Appendix C: Additional results from analyses.

a) Additional results from mixed-effects analysis

Table C1: Results of *post-hoc* testing of differences between years for each cover type

Predictors	Value	95% CI	z value	p-value
Herbaceous 2005 – Herbaceous 1995	-0.27	-0.37- -0.17	-5.61	< 0.001
Herbaceous 2015 – Herbaceous 1995	0.07	-0.05-0.19	1.25	0.66
Herbaceous 2015 – Herbaceous 2005	0.35	0.25-0.45	7.13	< 0.001
Woody 2005 – Woody 1995	-0.02	-0.12-0.08	-0.45	0.99
Woody 2015 –Woody 1995	0.03	-0.09-0.15	0.55	0.98
Woody 2015 – Woody 2005	0.05	-0.05-0.15	1.12	0.75

b) Exploratory temperature analysis

An exploratory annual temperature trend analysis was performed. Maximum and minimum monthly averages of daily temperatures were only available from two different South African Weather Service (SAWS) weather stations (Augrabies Waterval (No 02816060) from 1990-mid-2001 and Augrabies Falls (No 0281606A5) from mid-2001-2015) located near to Riemvasmaak and 1.13 km away from each other. Data from both of these stations were compounded in order to create a more complete dataset. The data from both stations possessed too many missing values and values notated as unreliable to analyze with full confidence. However, an exploratory analysis of annual trend in temperature was tested out of interest with these limitations in mind. This was done by calculating annual averages of the monthly averages of daily maximum and minimum temperature values. Missing values or monthly average values notated as unreliable by SAWS were calculated using the average of daily maximum or minimum temperatures of the appropriate month. Results show a notable increase over time in maximum temperatures, especially from 2012-2015, but no discernable trend in minimum temperatures. This upward trend in maximum temperature, although based upon limited data, is of potential concern and should be addressed in future studies provided sufficient data exists. The importance of the meticulous collection of temperature data at Augrabies Falls should be emphasized.

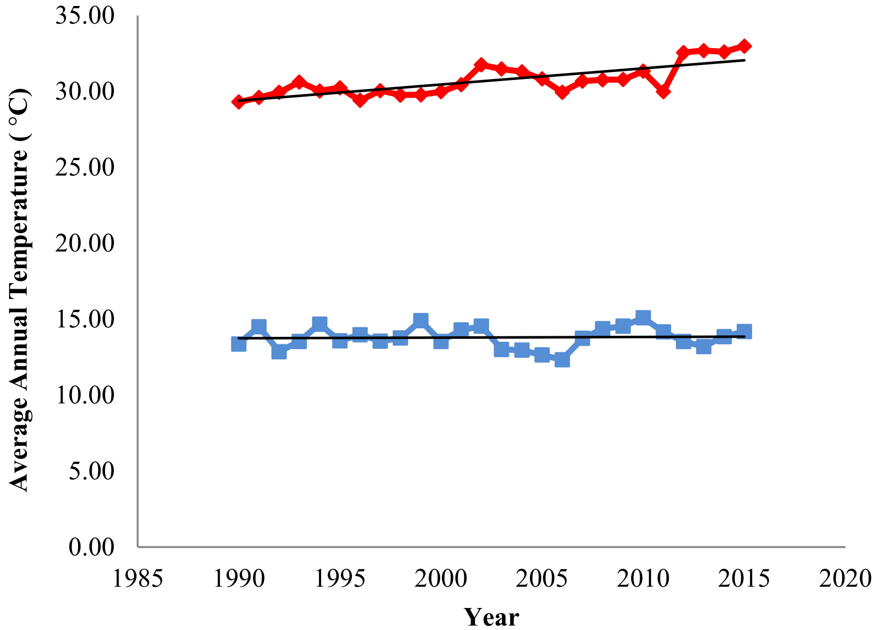


Figure C1: Annual maximum (above) and minimum (below) temperature for combined Augrabies Waterval and Augrabies Falls for the period 1990-2015. The lines show the trend over 26 years for maximum ($y = 0.1068x - 183.23$; $R^2 = 0.5831$) and minimum ($0.005x + 3.8697$; $R^2 = 0.0028$) temperatures

4. Exploratory maximum likelihood classification technique for color photograph assessment

As future research within the area is recommended to include the taking of multi-band digital imagery for ease of analysis, a pixel-by-pixel supervised maximum likelihood classification (MLC) technique was examined for its use in Riemvasmaak as a potential alternative to the visualization technique used in this study. Although repeat photographs for 1995 and 2005 were only available in black and white, the high resolution and color imagery of the 2015 digital imagery allowed for the use of this supervised classification technique for this time step. This technique extrapolated and quantified changes for each site. It was tested comparatively by analyzing percentage cover values extracted from the digital 2015 color images by the technique in ArcMap 10.3 and the percentage cover values extracted from the 2015 digital color images utilizing the visualization technique discussed earlier within this study.

The methodology of the MLC technique was as follows. Within ArcMap 10.3, each 2015 digital color photograph was cropped in order to be comparable to the focal area used for the 2015 digital color photographs in the visualization technique (see Methods). This focal area was delineated as a mask; the same landform units delineated within Adobe Photoshop CC 2015 for the visualization technique were drawn within the general mask.

Cars, kraals, inselbergs and people present within the general mask were removed using Editor's Clip function within ArcMap. The same landforms analyzed visually were analyzed with the supervised classification technique. Supervised classification, which works by selecting objects based on tonal similarity was chosen as a method in preference to unsupervised classification such as Iso-Clustering because of the ability of an analyst to create a training file. This would reduce the amount of error upon the part of the program. In order to perform supervised classification, polygons were drawn within ArcMap to create different classes.

The supervised classification technique utilized five to eight classes of bare ground, tree, shrub, grass, and rock. Shadow was added as a class within photographs that contained a significant amount of shadow in order to avoid unnecessary misclassification. When several species of shrubs were present in a single photograph that had highly varied tonal qualities (e.g. reddish and green shrubs), for example, the unusual species was classified separately from the shrub class and afterwards its values were compounded with the rest of the shrub values. Bare ground and rock classes occasionally also were split into several classes when tonally very dissimilar (e.g. white rock, dark bare ground) with their values later compounded.

Figure C2: Comparison of original 2015 digital image before (above) and after MLC analysis (below) at Site 20, Deksel East, Riemvasmaak. Landforms are not shown delineated in these images. Different classes of growth forms (below) were represented by various colors for ease of visual comparison. Note difficulty with compounding between classes, particularly between tree (dark green) and shrub (light green) and tree and rock (brown).

Each cover type class contained 5 to 20 samples depending upon the prevalence and the tonal variety of the class. After utilizing the MLC to create the five to eight classes, the results of this classification were extracted by the Tabulate Area function in the Spatial Analyst toolbox in order to get a measure of values per landform unit. All values were recorded as pixels inhabited by each class over total amount of pixels within the analyzed area. These percentages were later adjusted within Excel by removing the Shadow class and adjusting the percentages over the new total to equal a hundred. This was done in order to make the pixel percentages more analogues to the visualization percentages for comparative purposes. The shrub and tree values were similarly compounded in Excel as 'woody vegetation' for comparative purposes and due to the difficulty and uncertainty in separating them visually in the photographs.

The amount of error within this technique can be attributed both to the skill of the analyst and the quality of the photograph. Poorer quality photographs that do not have significant contrast between the intended classes will have higher error. Although photographs varied by percentage of error as calculated by the generation of random points in ArcMap 10.3, consistent errors were found between photographs due to the high complexity of the landscape.

For example, significant conflation between shrubs and trees were found at all sites, as well as between rock and bare ground because of the slightly darker/lighter reflectance values and the similar coloration (Fig. C2). Limiting variation in samples of conflated classes when creating the training file assisted in reducing conflation but did not remove the problem. Increasing samples of underrepresented classes such as vegetation, addressed overestimation of rock and bare ground resulting from their highly varied colorations within certain photographs. In general, the best way to reduce error was to as mentioned, split up classes that are highly variable (such as in some cases, bare ground) into subclasses of similar tonal quality and then compound the values later.

Comparisons between the visual estimates and maximum likelihood classification displayed a relatively close relationship (R^2 values ranging from 0.54 to 0.72 for herbaceous and woody vegetation respectively). Herbaceous vegetation displayed more differences between the types of estimations than woody vegetation, likely due to both errors in the maximum classification technique and due to the relatively difficulty of assessing visually the percentage of herbaceous cover as compared to woody cover.

When moderate amounts of herbaceous cover was present, where the estimates were most different, the MLC technique tended to consistently report much lower cover values than the visualization technique, while at the extremes of high and low cover, the MLC technique tended to report higher coverage than the visualization technique. Overall, although errors must be taken into account, this may indicate that the MLC technique might be better at picking up extremes in herbaceous vegetation than the visualization technique, and that the visualization technique has a tendency to overestimate herbaceous values when amount of cover is more ambiguous. There was more variability between visualization and maximum likelihood classification estimates at highly rocky and complex sites such as Site 1 and Site 3.

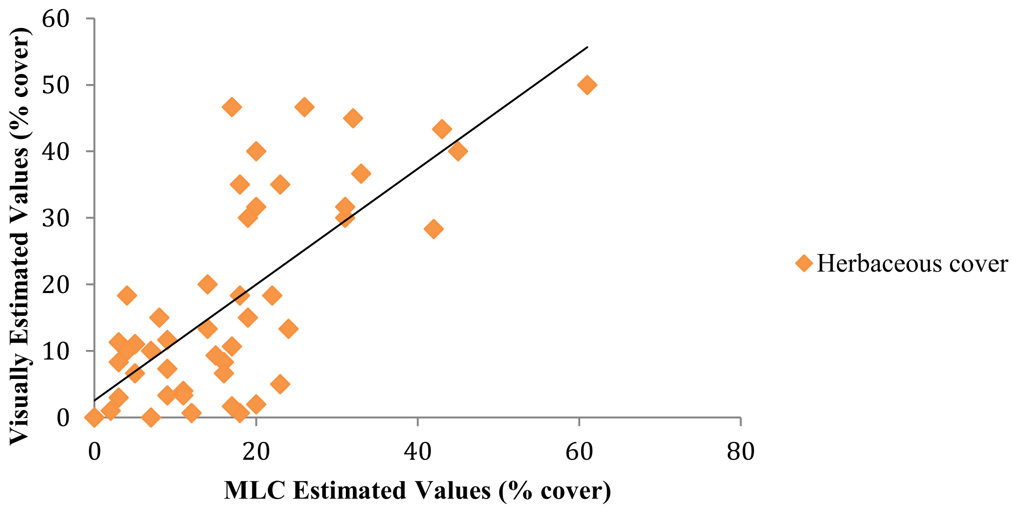


Figure C3: Scatterplot displaying relationship between MLC and visualization herbaceous cover estimated values for each site for the 2015 digital color photographs (R^2 = 0.5374).

Woody cover, although overall more similar than herbaceous, estimates were most dissimilar when there was a moderate or high amount of woody cover present. The former was likely due to the difficulty in accurately accessing ambiguous amounts of cover visually. The latter may have been partially due to the difficulty inherent in determining amount of woody vegetation visually when the woody vegetation is located near the back of the photograph, as this is where the highest amount of woody vegetation tended to be despite efforts to remove landforms located too far away. Similarly to what was found with herbaceous cover, the main outliers where differences in estimates were highest tended to be highly complex and rocky sites such as Site 1 and Site 21. An overall, although not universal, tendency for the MLC technique to have higher estimates than the visualization technique may be also due to conflation difficulties between rocks and woody cover due to their shared dark tonal quality (Fig. C2).

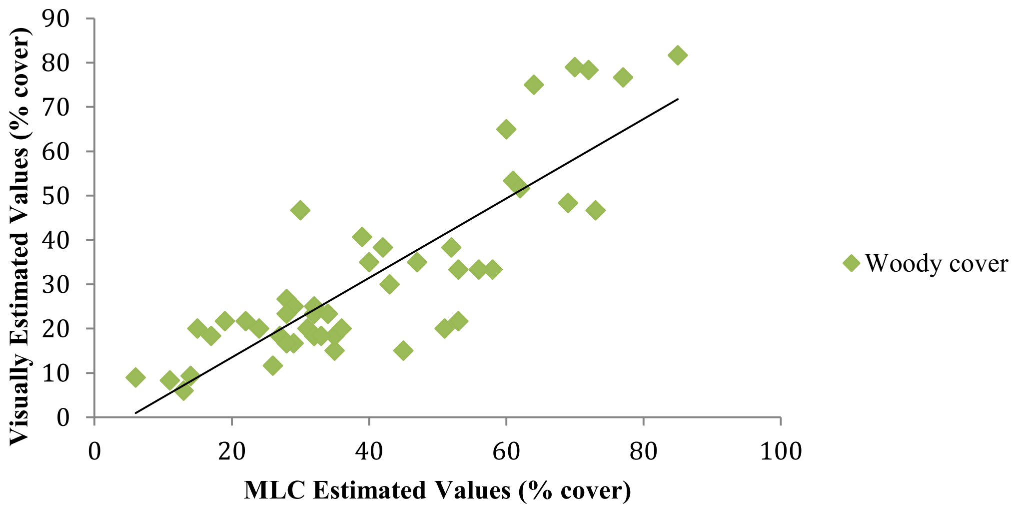


Figure C4: Scatterplot displaying relationship between MLC and visualization woody cover estimated values for each site for the 2015 digital color photographs (R^2 = 0.71864).

Although this exploration was beneficial in examining relative strengths and weaknesses in both techniques, in an area such as Riemvasmaak that is highly rocky and contains high variation in focal growth types, it proves potentially problematic. Due the relative agreement between both techniques save at highly rocky and particularly complex sites and the extensive time required in order to complete the MLC technique (approximately four hours per photograph as opposed to several minutes for the visualization technique), it did not seem for this particular study area that benefits outweighed costs.

It is important also to reemphasis that the MLC technique would not completely eliminate the bias that is often a concern with the visualization technique, as this supervised classification requires the manual selection of training classes and will therefore be similarly biased by the skills and choices of the analyst. The visualization technique in contrast allows for several analysts to compare values, which may help to provide more consistent values, provided each analyst determines their values independently before any discussion. Although this technique, due to limited suitable photographs and the limitations discussed above was not chosen to provide the cover values analyzed in this study, it is possible that in an area with more homogenous vegetation types, such as many agricultural areas, and in a study that required analysis of significantly fewer repeat photographs and time steps this technique may prove useful. Examination in ways to further reduce error if this technique is chosen should be rigorously explored.

Appendix D: Additional information about Riemvasmaak

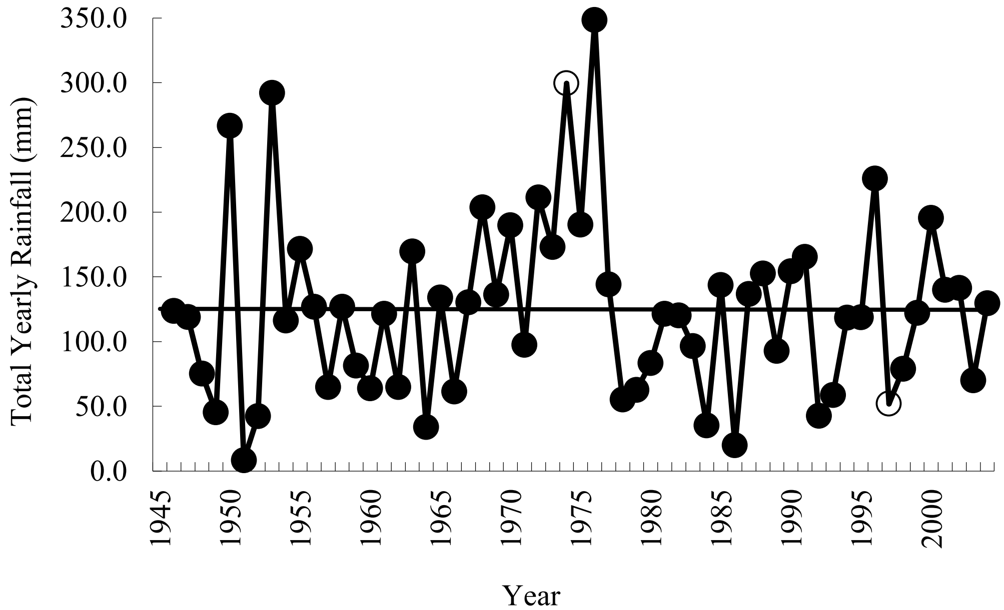


Figure D1: Annual rainfall for Augrabies for the period 1946-2004 (Hoffman and Todd 2010). The mean value for total rainfall is 125 mm while the line shows the trend over the 58 years (y = -0.0136x +125.34; R^2 =0.00001). Open symbols emphasize the high and low rainfall years of 1974 and 1997 mentioned by interviewees.

Table D1: Example species list within Riemvasmaak as determined by 1995 and 2005 transect surveys at each site (Hoffman and Todd 2010)

Growth Form	Species
Annual/Forb	*Abutilon pycnodon*
	Aizoon asbestinum
	Arctotis fenuosa
	Berkheya spinosissima
	Cleome angustifolia
	Cleome oxyphilla
	Codon royeni
	Crotalaria virgultalis
	Cucumis sagittatus
	Forsskaolea candida
	Limeum cristatus
	Ocimum canum
	Osteospermum microcarpum
	Pergularia daemia
	Sesamum capense
	Tribulis pterophorus
	Tribulis terrestris
	Trichodesma africanum
	Zygophyllum simplex
Geophyte	*Dipcadi gracillimum*
Grass	*Aristida congesta*
	Cenchrus ciliaris
	Cyperus marginatus
	Enneapogon cenchroides
	Enneapogon scaber
	Eragrostis aspera
	Eragrostis lehmanniana
	Heteropogon contortus
	Leucophrys mesocoma
	Odyssea paucinervis
	Panicum arbusculum
	Panicum sp.
	Schmidtia kalahariensis
	Setaria appendiculata
	Setaria verticillata
	Sporobolus iocladus
	Stipagrostis anomela
	Stipagrostis ciliata
	Stipagrostis hochstetteriana

	Stipagrostis namaquensis
	Stipagrostis obtusa
	Stipagrostis uniplumis
	Triraphis ramossisima
Leaf Succulent	*Aloe gariepensis*
	Augea capensis
	Ceraria namaquensis
	Mesembryanthemum crystallinum
	Ruschia sp.
Low Shrub (<0.25m)	*Acanthopsis disperma*
	Aptosimum spinescens
	Baleria secunda
	Barleria lichtensteiniana
	Barleria rigida
	Blepharis furcata
	Galenia secunda
	Geigaria ornativa
	Geigaria pectidea
	Giseckia pharnaceoides
	Hermannia spinosa
	Hypertilis salsoloides
	Limeum aethiopicum
	Limeum myosotis
	Monsonia umbellata
	Plexipus pumilis
	Plinthus arenarius
	Rhynchosia longiflora
	Rosenia sp.
	Solanum capense
	Solanum gifbergense
	Solanum rautenenii
	Asparagus sp.
Medium Shrub (0.25-1.5m)	*Antizoma miersiana*
	Aptosimum albomarginatum
	Calicorema capitata
	Curoria decidua
	Dyerophytum africanum
	Galenia africana
	Hermannia stricta
	Hermannia tomentosa
	Hibiscus elliotiae
	Indigofera heterotricha
	Indigofera pungens

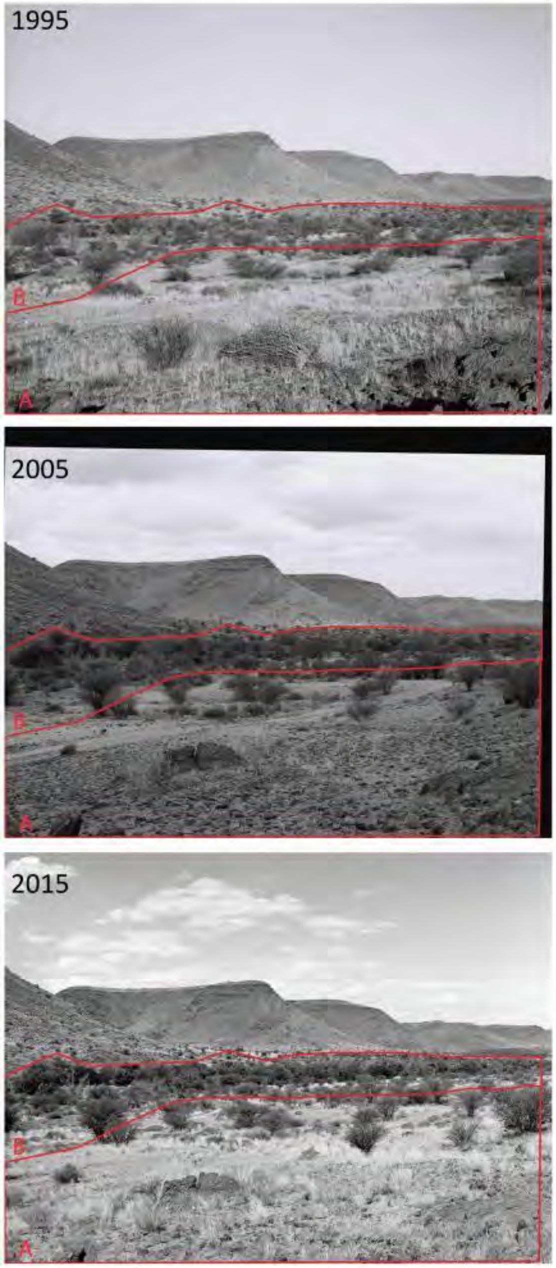
	Indigofera sp.
	Indigofera spinescens
	Justicia sp.
	Lebeckia sericea
	Limeum sp.
	Lycium cinereum
	Lycium sp.
	Microloma incanum
	Monechma genistifolium
	Monechma incanum
	Monechma spartioides
	Nidorella resedifolia
	Peliostemon leucorhizum
	Pentzia argentea
	Petalidium lucens
	Petalidium spinescens
	Phaeoptilum spinosum
	Plexipus gariepensis
	Polygala leptophylla
	Protasparagus africanus
	Protasparagus retrofractus
	Protasparagus sp.
	Pteronia sp.
	Rhigozum trichotomum
	Salsola aphylla
	Sericocoma avolans
	Sutera ramosissima
	Sutherlandia frutescens
	Tephrosia dregiana
	Tetragonia arbuscula
	Tetragonia sp.
	Thesium lineatum
	Zygophyllum gilfillani
	Zygophyllum microcarpum
	Zygophyllum retrofractum
	Zygophyllum suffruticosum
Parasite	*Tapinanthus oleifolius*
Stem Succulent	*Commiphora gracillifrondosa*
	Euphorbia avosmontana
	Euphorbia gregaria
	Euphorbia rhombifolia
	Hoodia sp.
	Kleinia longiflora

	Psilocaulon absimile
	Sarcocaulon pattersonii
	Sarcostemma viminale
Tall shrub (>1.5 m)	*Cadaba aphylla*
	Lycium prunus-spinosa
	Montinia caryophyllacea
	Putterlickia pyracantha
	Rhus populifolia
	Sisyndite spartea
Tree	*Acacia erioloba*
	Acacia karroo
	Acacia mellifera
	Adenolobus gariepensis
	Aloe dichotoma
	Boscia albitrunca
	Boscia foetida
	Diospyros acocksii
	Diospyros lycioides
	Ehretia rigida
	Euclea pseudebenus
	Euclea undulata
	Maerua gilgii
	Ozoroa crassinervia
	Pappea capensis
	Parkinsonia africana
	Prosopis glandulosus
	Rhus pendulina
	Schotia afra
	Tamarix usneoides
	Ziziphus mucronata

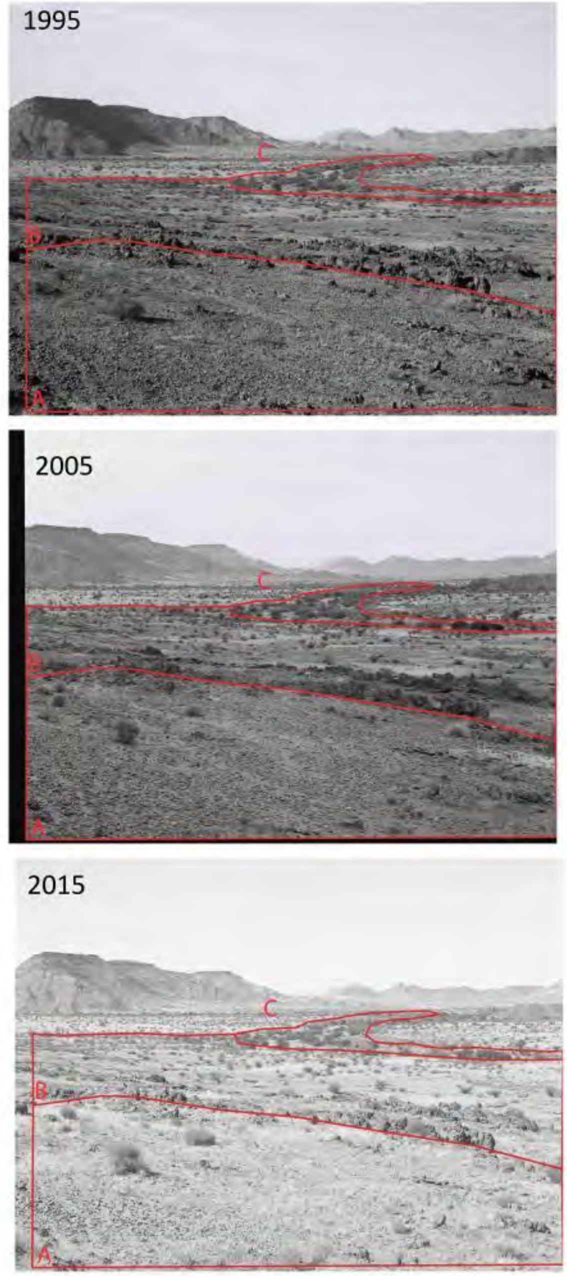
Appendix E: Photographic sites and black and white repeat photographs (1995, 2005, and 2015) with landforms delineated

Table E1: Photo station (sites) names, numbers, and GPS coordinates within the area of Riemvasmaak

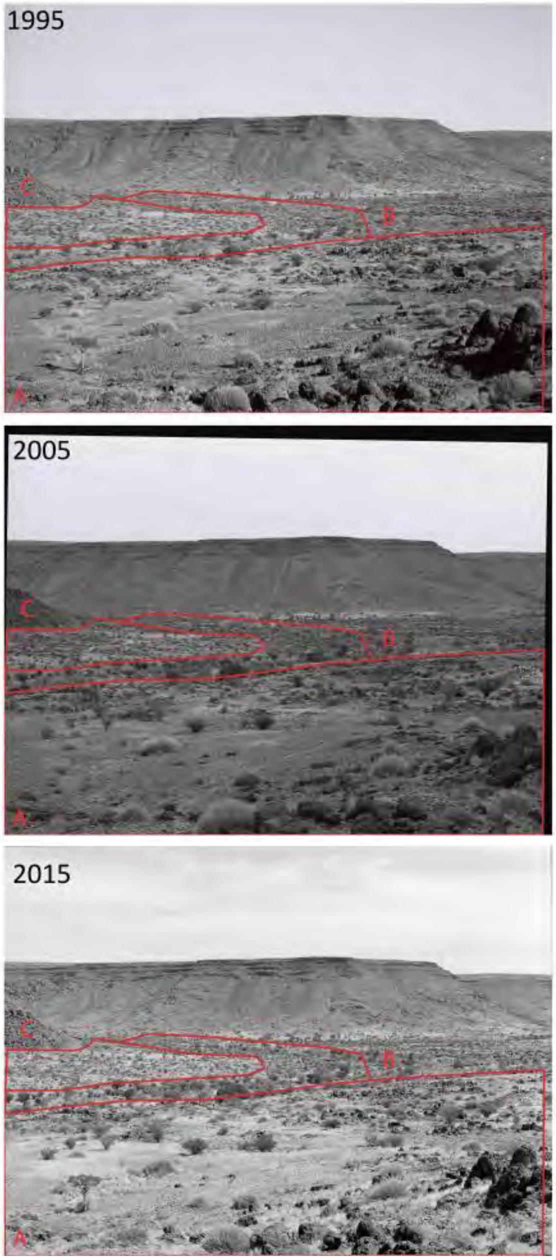
Site Number	Site Name	Coordinates
1	Deksel West	28.36025°S;20.14656° E
2	Upper Kourop Valley	28.36991°S;20.15680° E
3	Deksel South	28.36956°S;20.15686° E
4	Naruxas	28.33805°S;20.20587° E
6	Berylkop	28.40493°S;20.30905° E
7	Xanaxas	28.47836°S;20.21818° E
8	Mostert's Hoek	28.46015°S;20.17552° E
9	Xubuxnap	28.47034°S;20.11906° E
10	Petrus' Hoek	28.44605°S;20.11114° E
11	Above Xubuxnap	28.46465°S;20.14012° E
12	Molopo 1	28.50752°S;20.21514° E
13	Molopo 2	28.48275°S 20.23018° E
14	Riemvasmaak Municipality	28.45628°S;20.31658° E
15	Loeriesfontein	28.34992°S ;20.08570°E
16	Upper Bak River	28.28978°S; 20.02119°E
17	Donkiemoud	28.35203°S; 20.01629°E
18	Bok se Puts	28.32617°S; 20.03810°E
19	Deurspring	28.40874°S; 20.14266°E
20	Deksel East	28.35883°S; 20.17697°E
21	Above Hotsprings	28.45384°S; 20.29285°E
22	Droeputs	28.44608°S; 20.24869°E
23	Perdepoort	28.39931°S; 20.39785°E
24	Gyam (Vaalputs)	28.37387°S; 20.36583°E
25	Waterval	28.53417°S; 20.33721°E
26	Waterval North	28.43718°S; 20.34751°E
27	Gyam (Perdepoort)	28.42395°S; 20.38605°E
28	Riemvasmaak North	28.43402°S; 20.30684°E



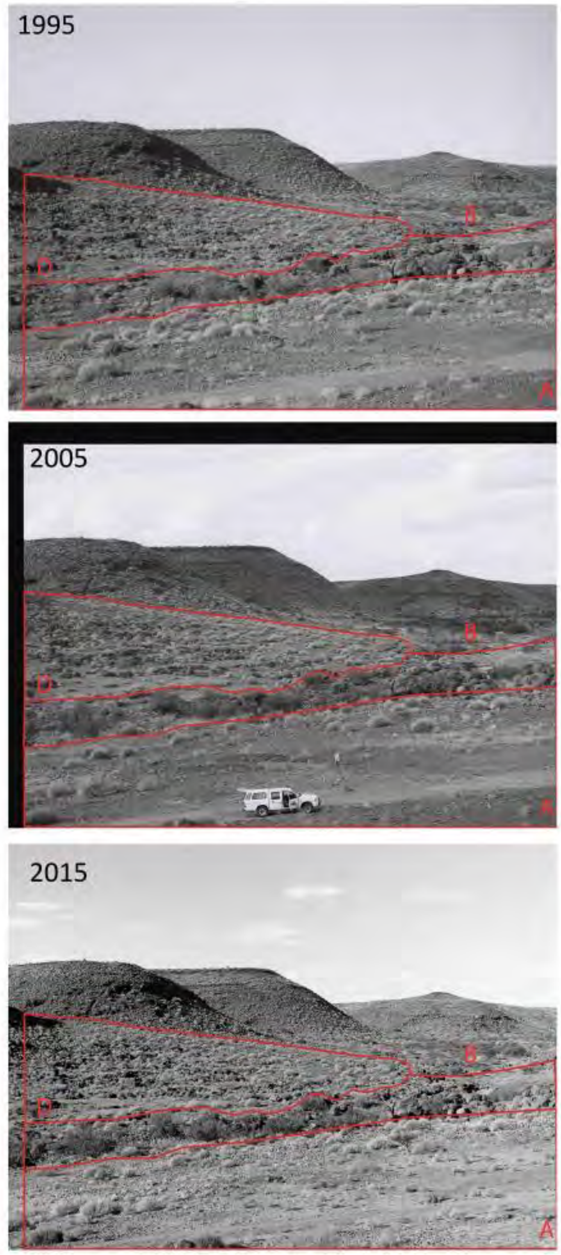
Site 1, Deksel West



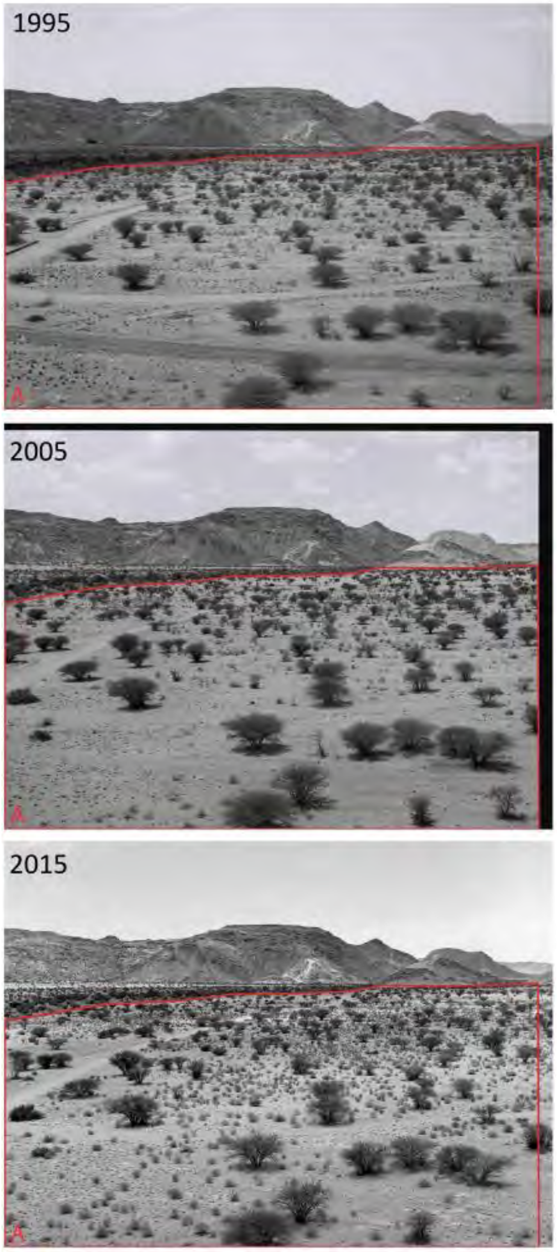
Site 2, Upper Kourop Valley



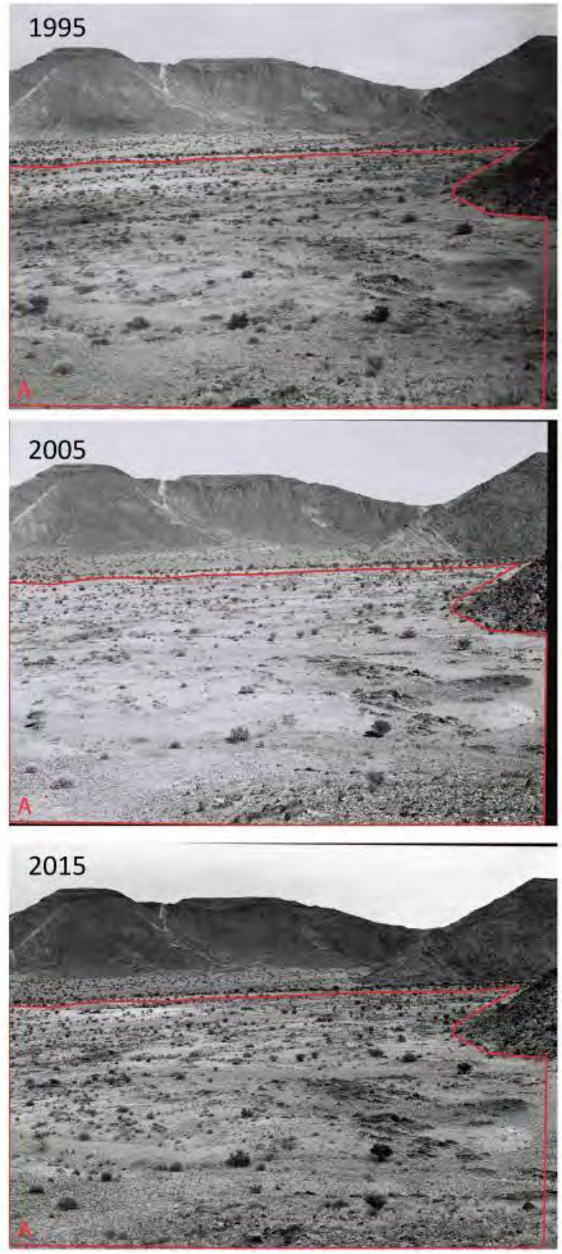
Site 3, Deksel South



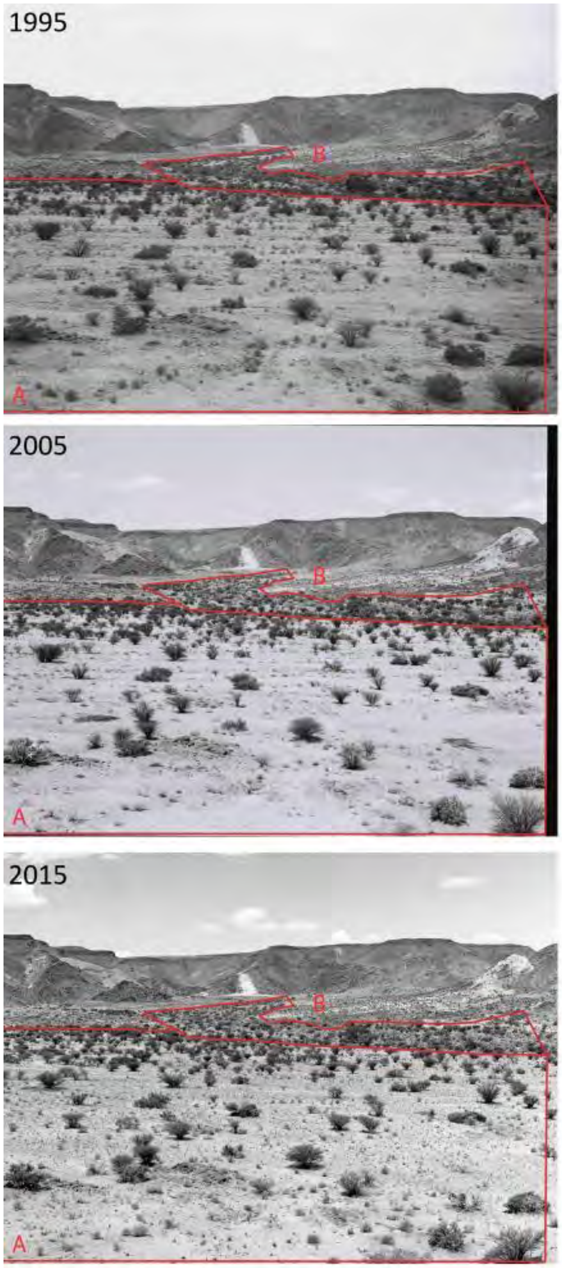
Site 4, Naruxas



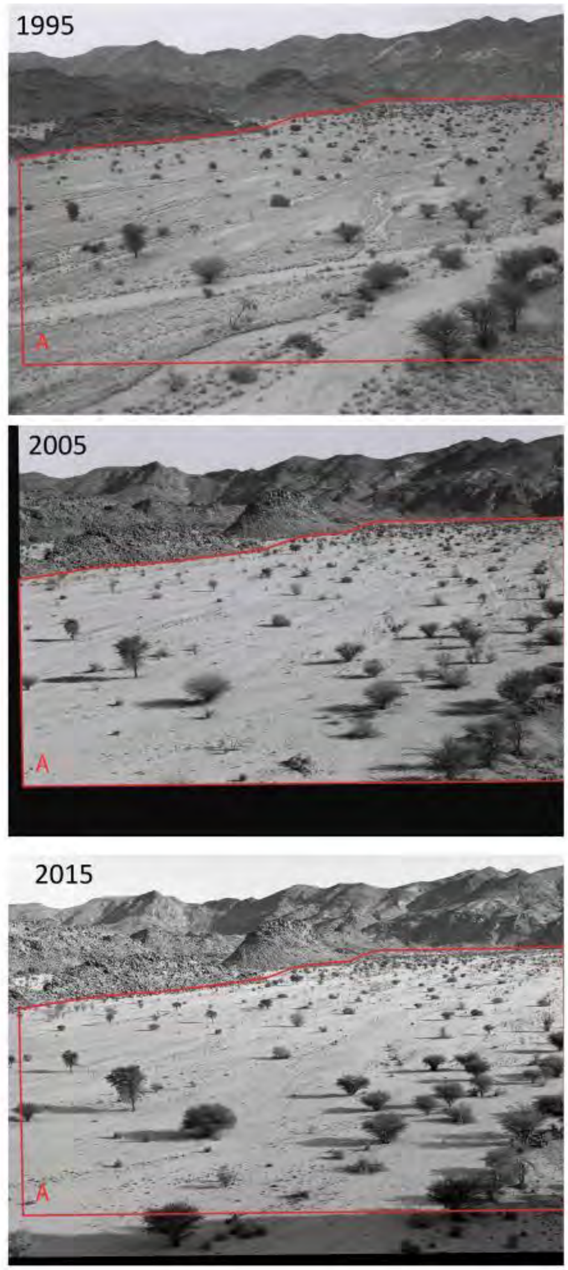
Site 6, Berylkop



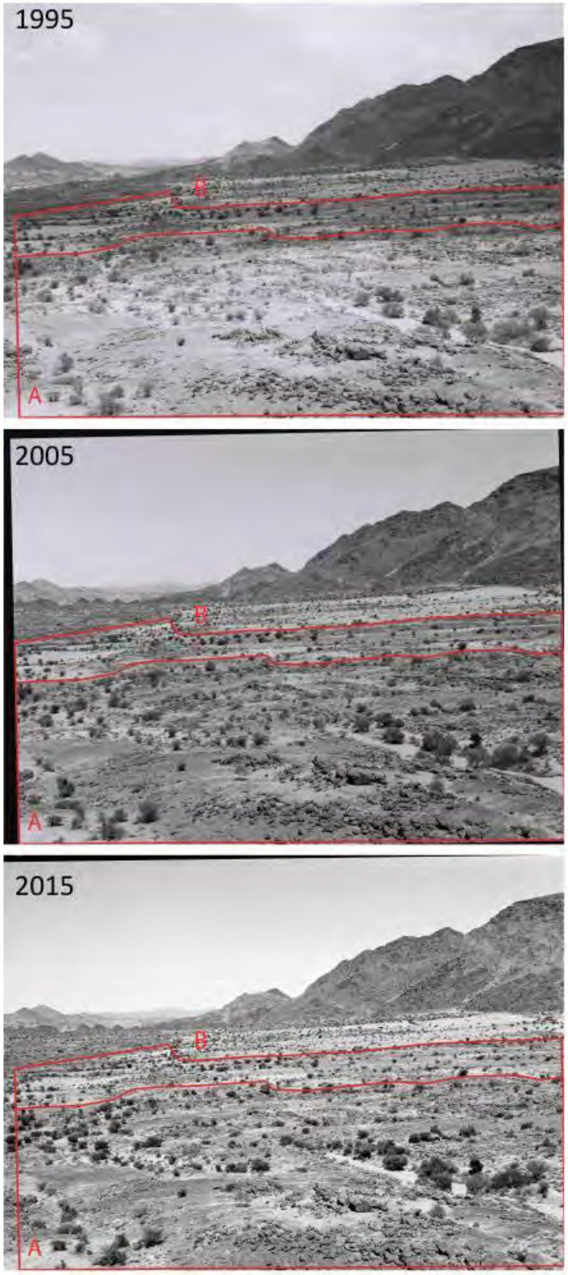
Site 7, Xanaxas



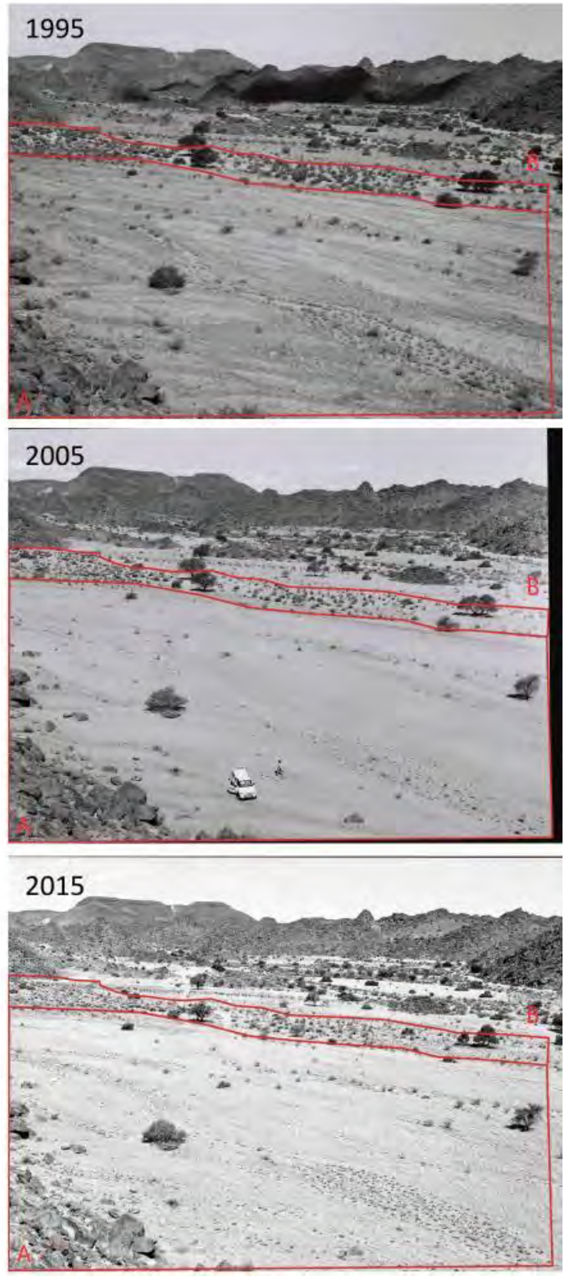
Site 8, Mostert's Hoek



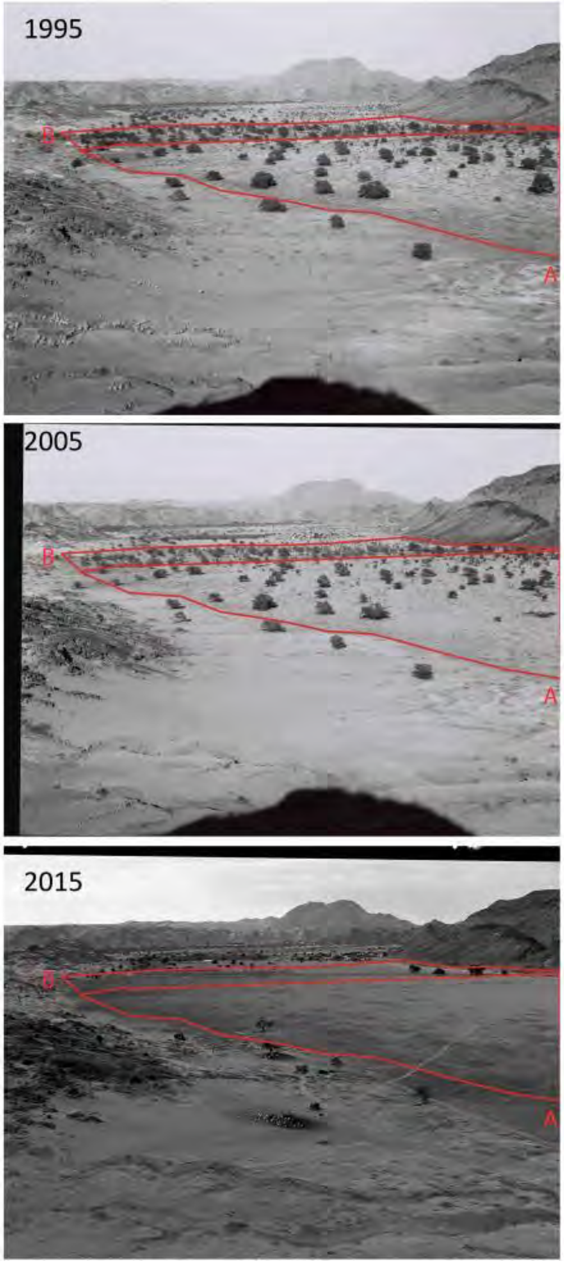
Site 9, Xubuxnap



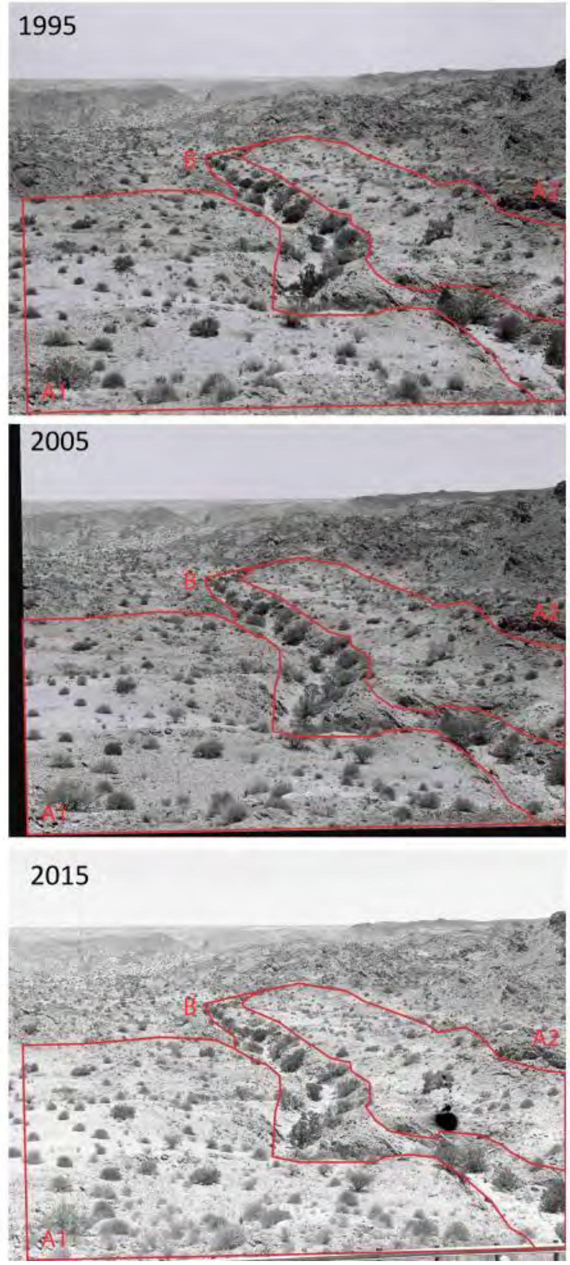
Site 10, Petrus' Hoek



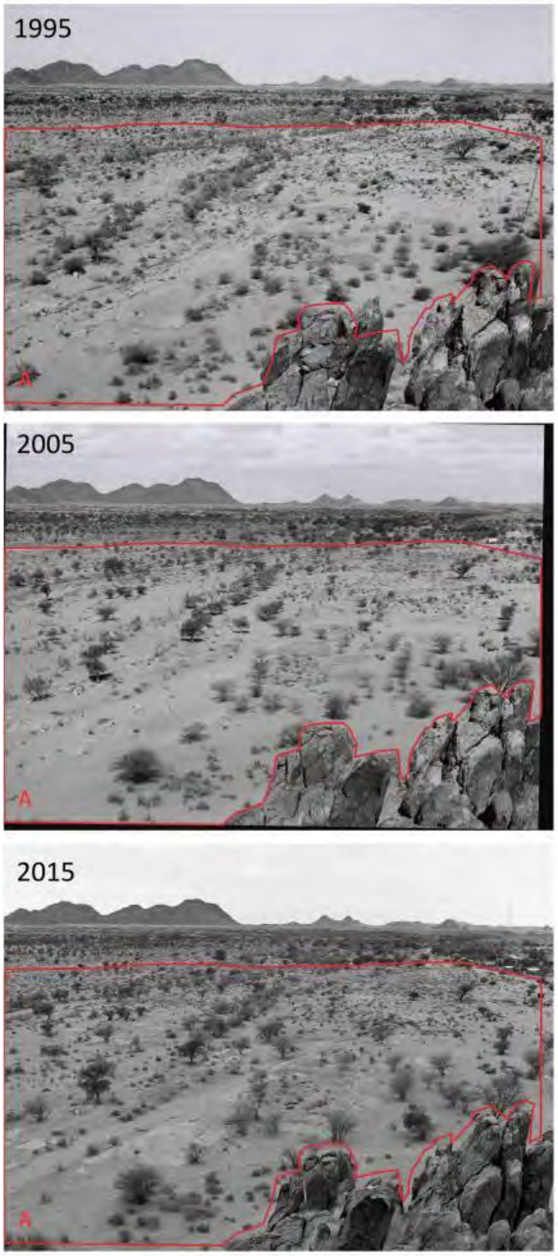
Site 11, Above Xubuxnap



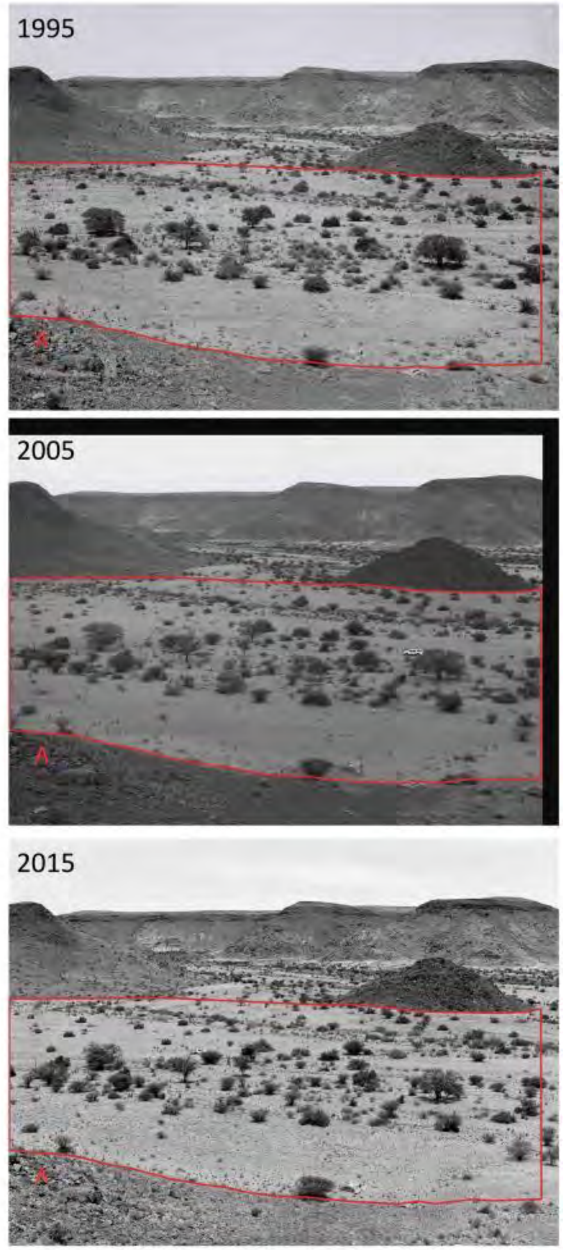
Site 12, Molopo 1



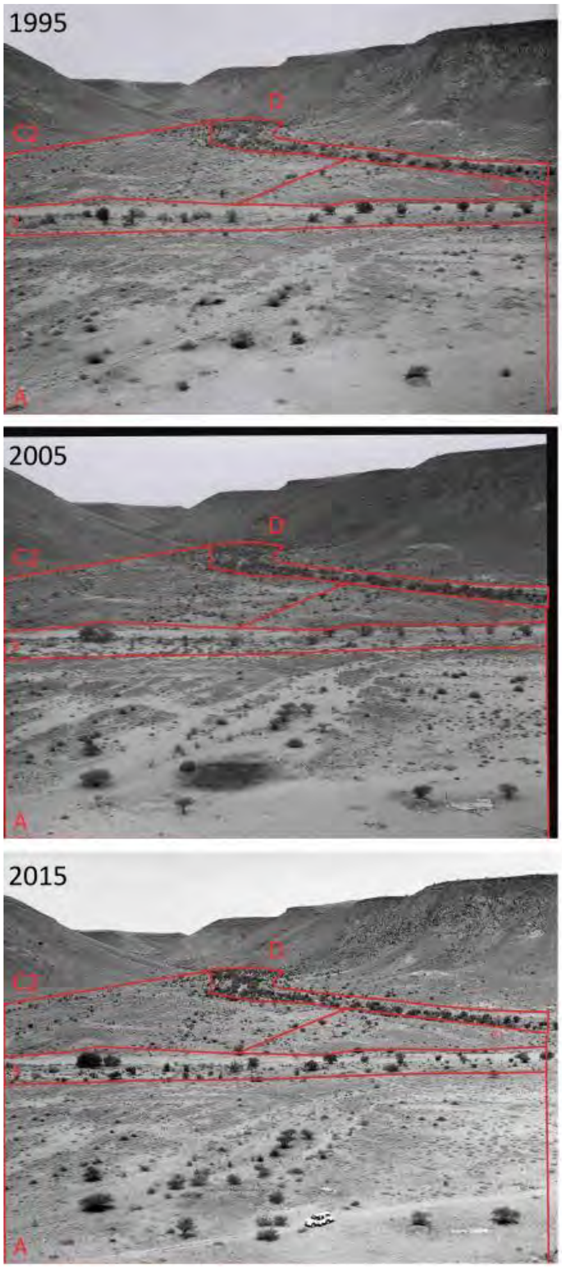
Site 13, Molopo 2



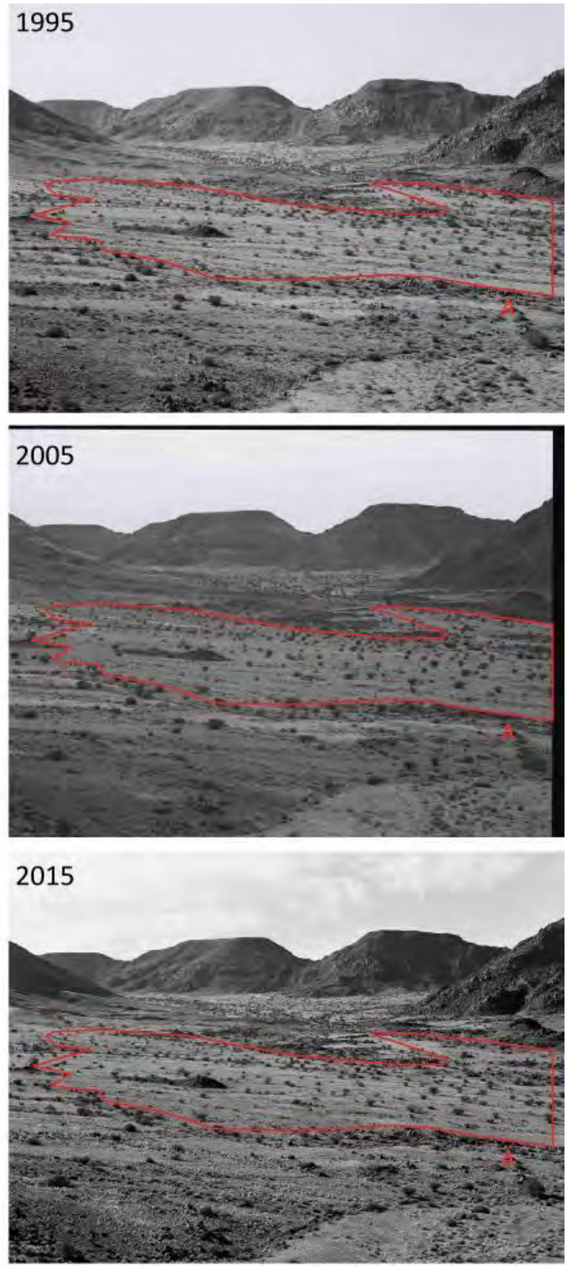
Site 14, Riemvasmaak Municipality



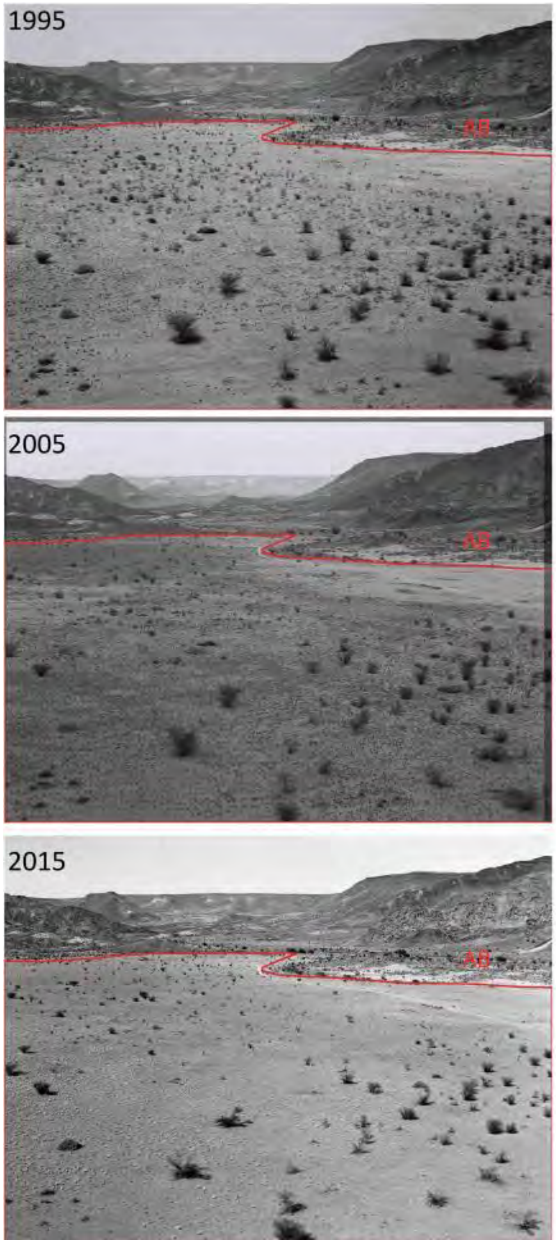
Site 15, Loeriesfontein



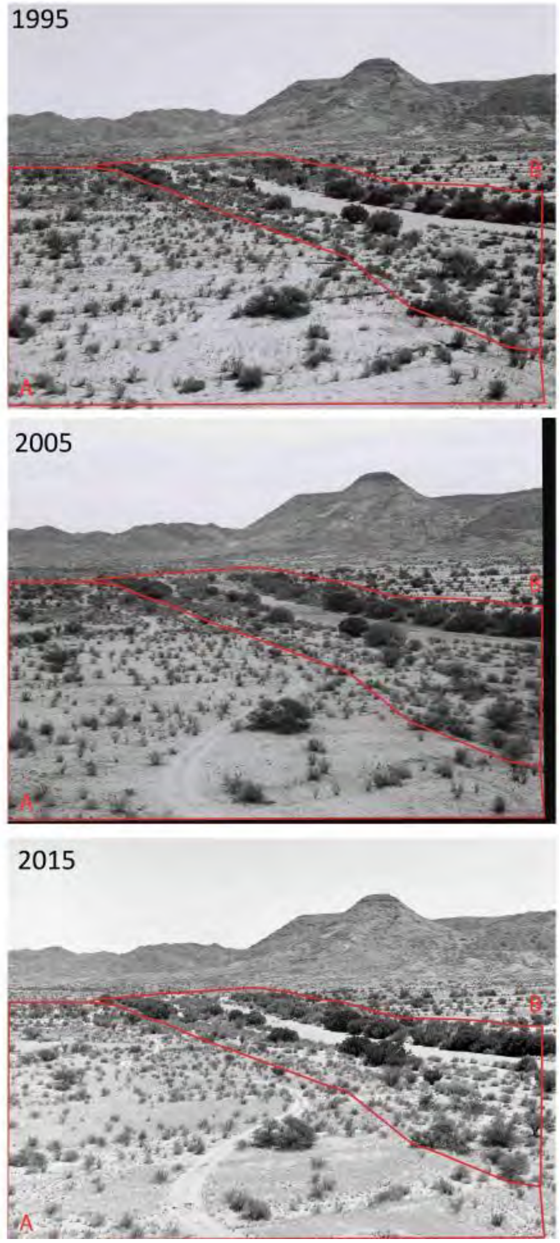
Site 16, Upper Bak River



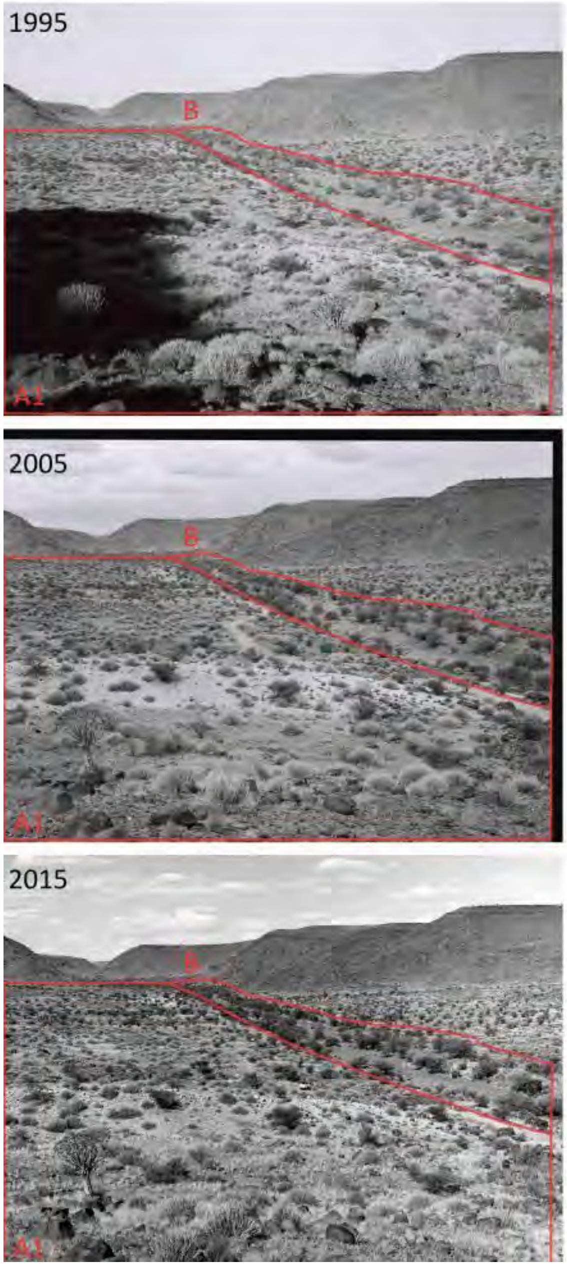
Site 17, Donkiemoud



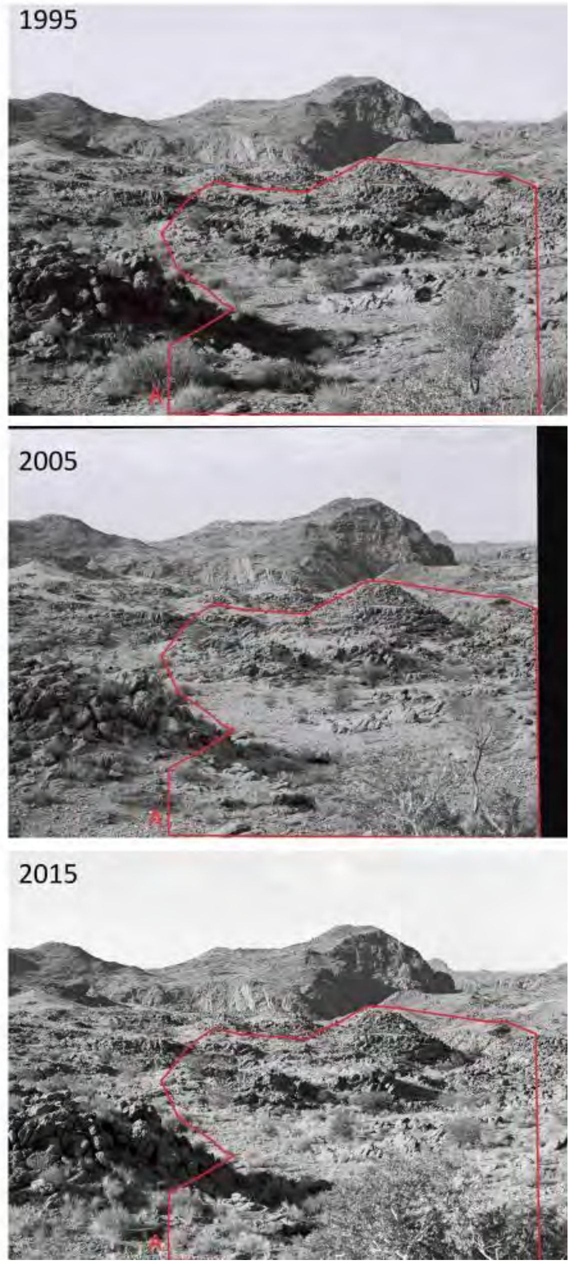
Site 18, Bok se Puts



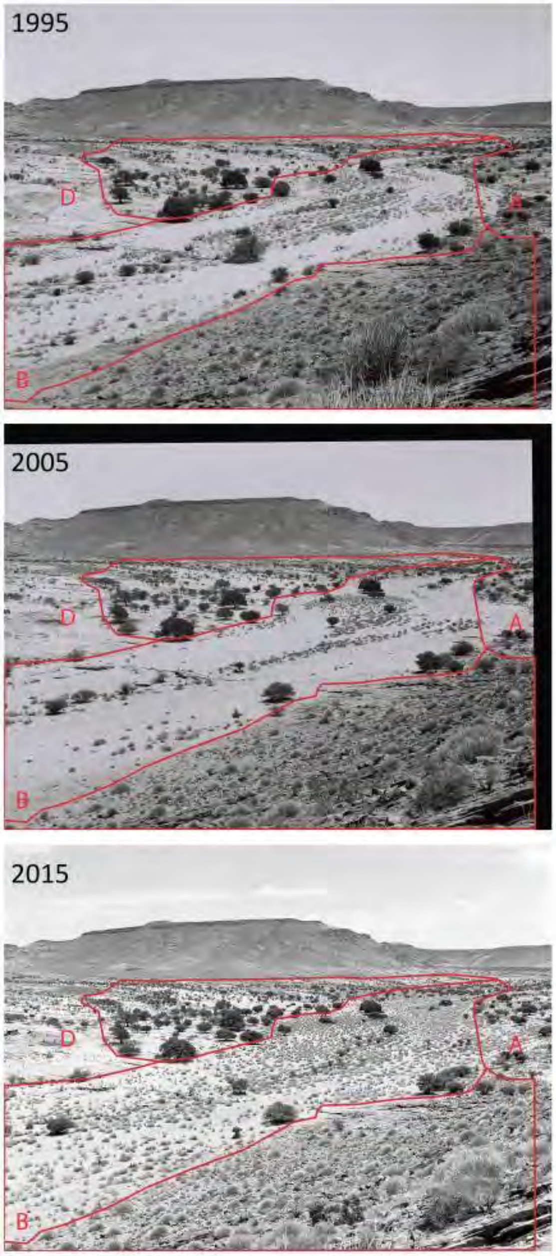
Site 19, Deurspring



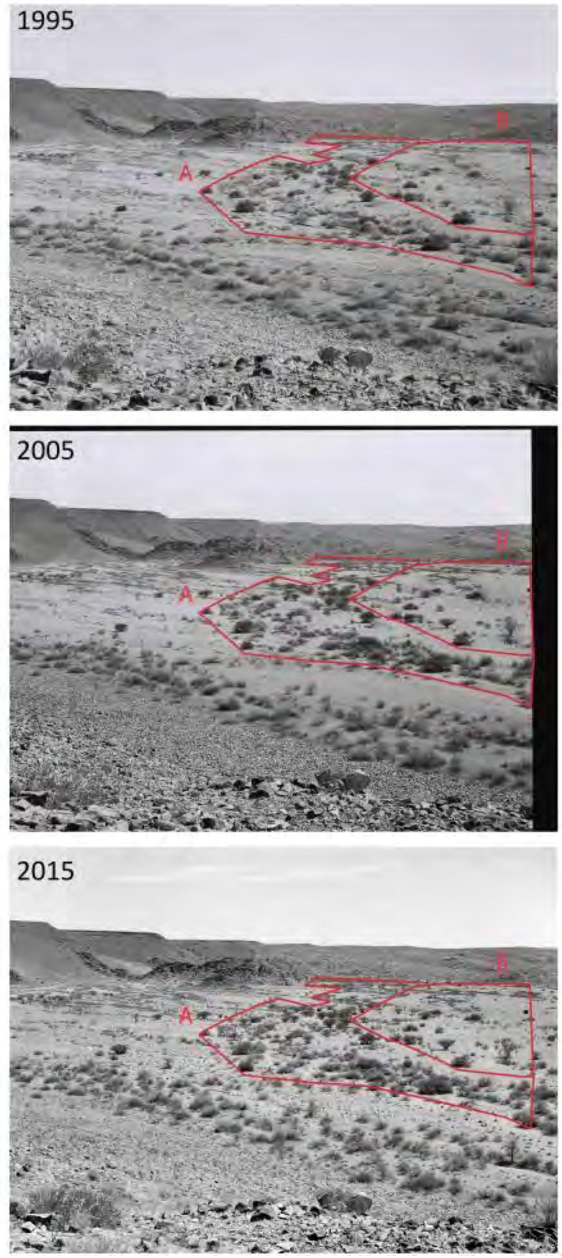
Site 20, Deksel East



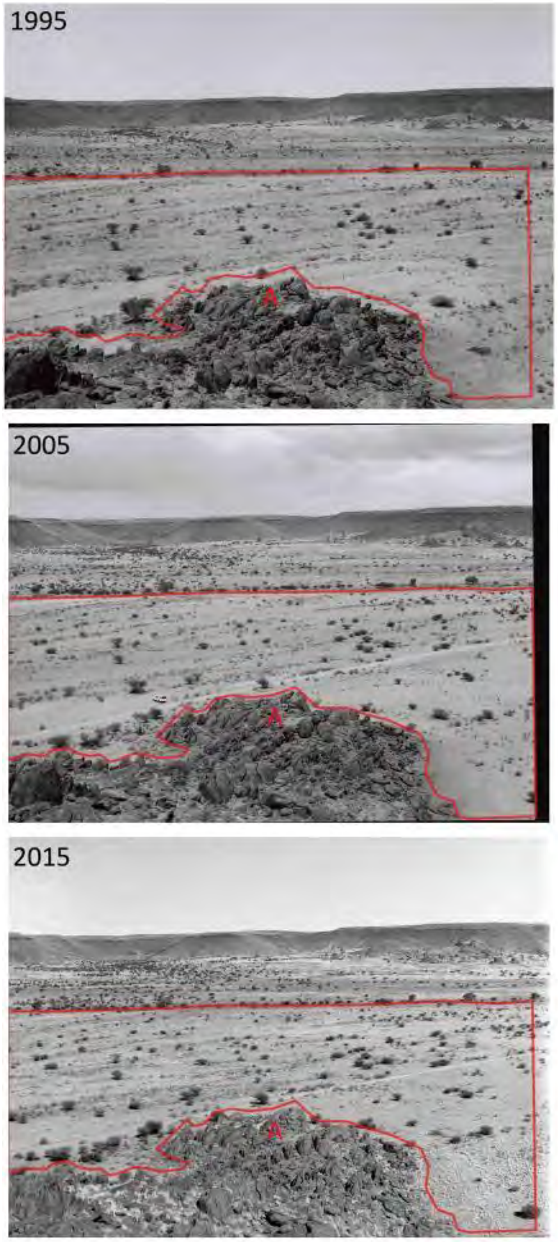
Site 21, Above Hotsprings



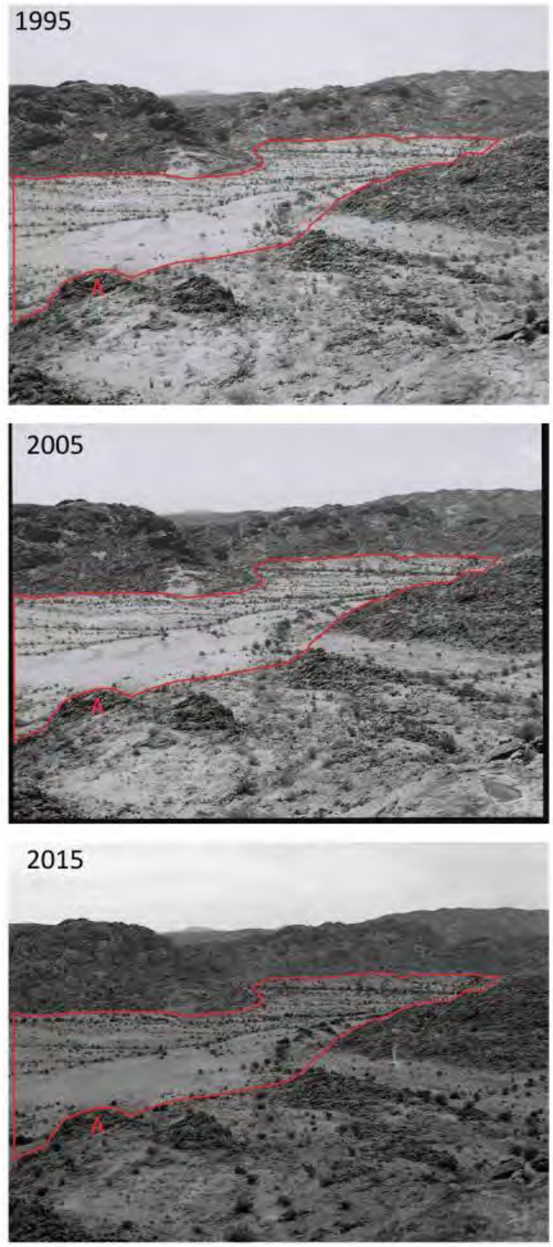
Site 22, Droeputs



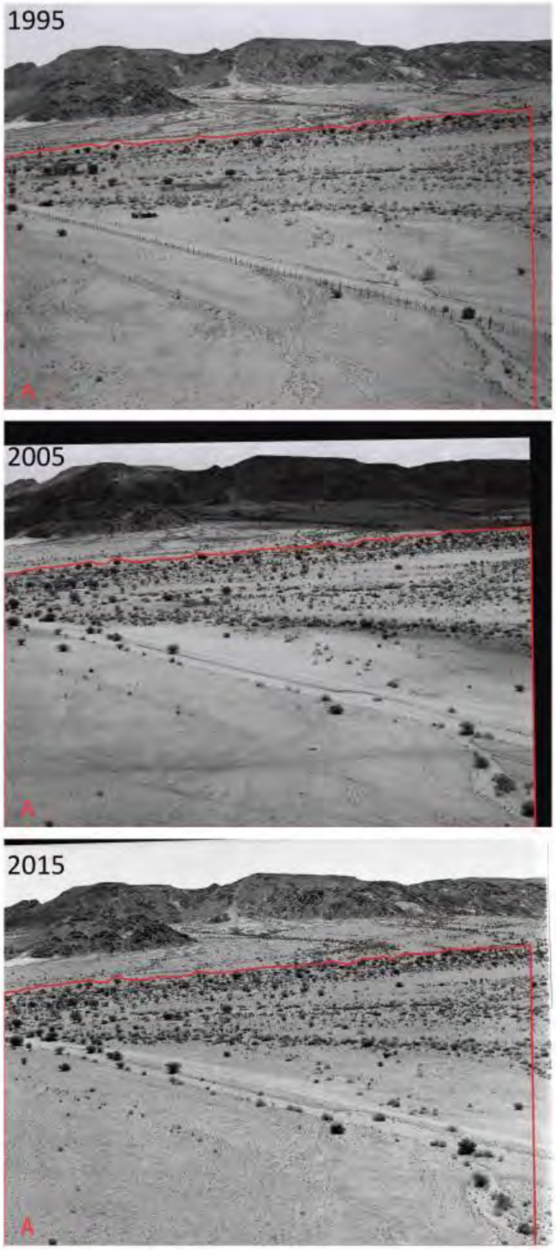
Site 23, Perdepoort



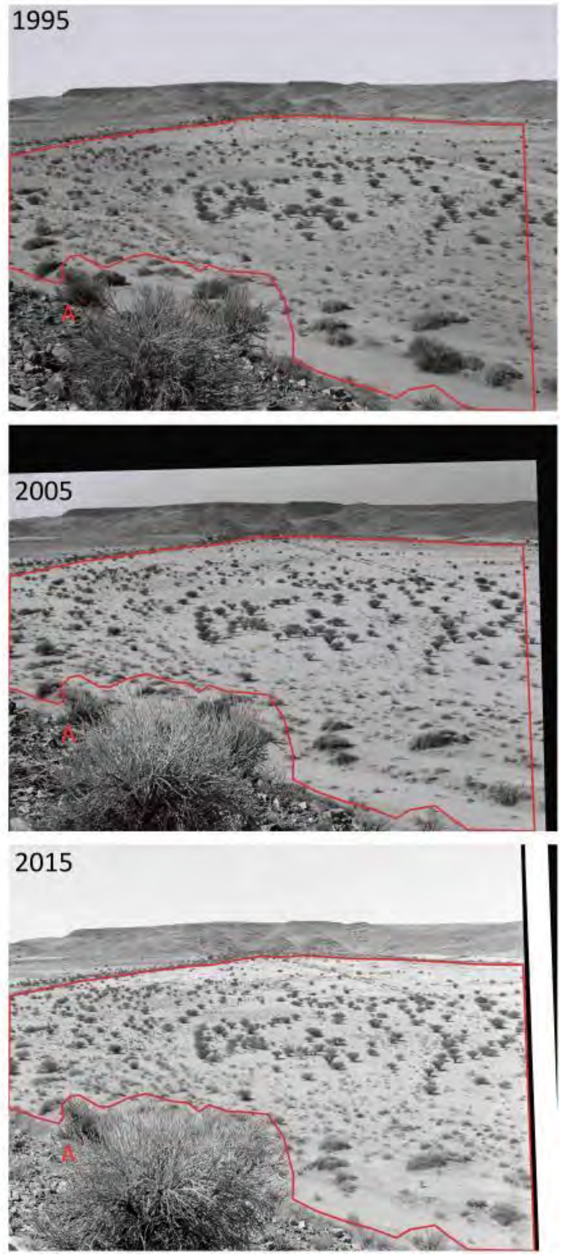
Site 24, Gyam (Vaalputs)



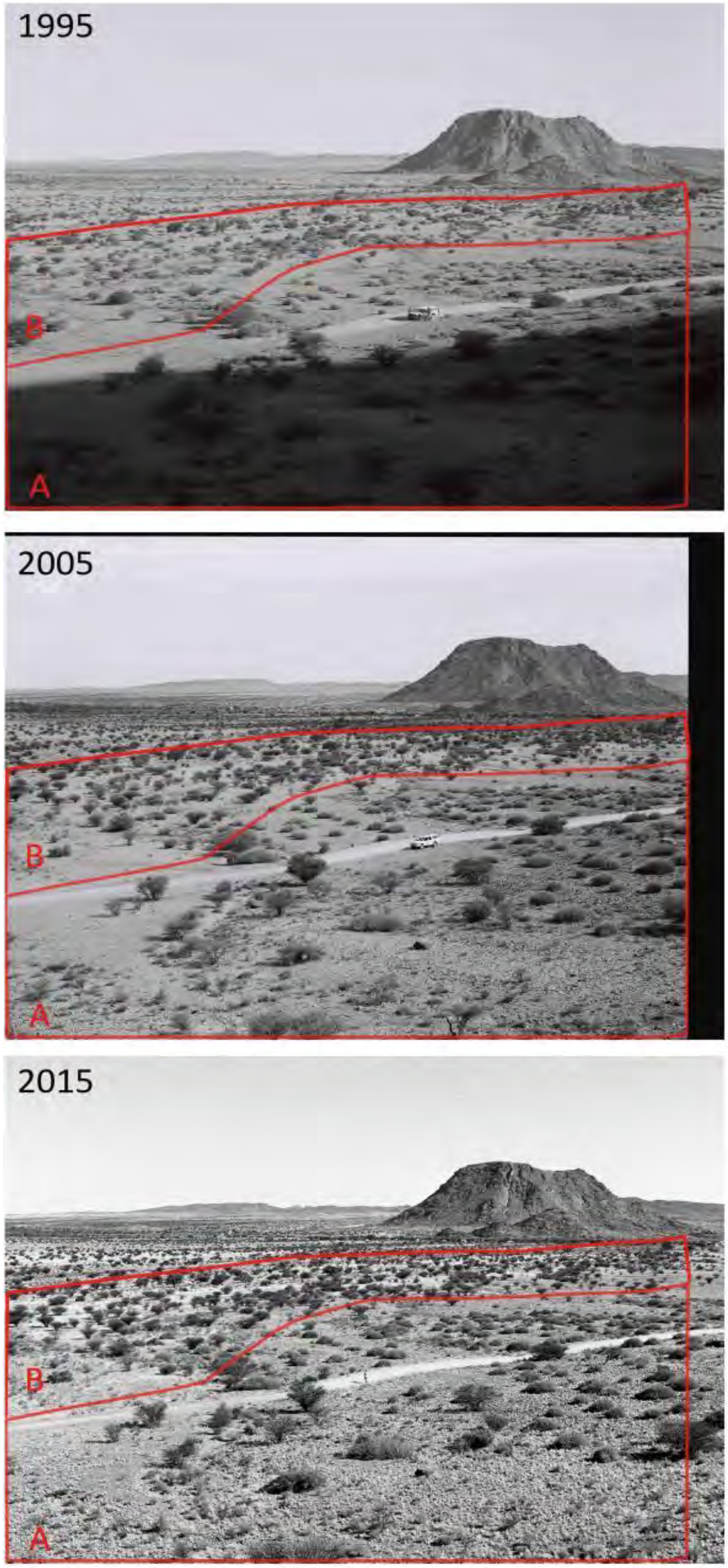
Site 25, Waterval



Site 26, Waterval North



Site 27, Gyam (Perdepoort)



Site 28, Riemvasmaak North