The Effects of Short-Duration Overnight Kraaling on Herbaceous Vegetation and Soils in Mesic Grassland

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PREFACE

The research contained in **The Effects of Short-Duration Overnight Kraaling on Herbaceous Vegetation and Soils in Mesic Grassland** was completed by the candidate while based in the Discipline of Botany, Department of Botany, Rhodes University, Makhanda, South Africa.

The contents of this work have not been submitted in any form to another university and, except where the work of others is acknowledged in the text, the results reported are due to investigations by the candidate.

Supervisor: Susanne Vetter

Signed: SVetter.

Date: 15 February 2023

PLAGIARISM DECLARATION

I, Nompendulo Mgwali, declare that:

(i) the research reported in this dissertation, except where otherwise indicated or acknowledged, is my original work;

(ii) this dissertation has not been submitted in full or in part for any degree or examination to any other university;

(iii) this dissertation does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons;

(iv) this dissertation does not contain other persons' writing, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:

a) their words have been re-written but the general information attributed to them has been referenced;

b) where their exact words have been used, their writing has been placed inside quotation marks, and referenced.

(v) where I have used material for which publications followed, I have indicated in detail my role in the work.

(vi) this dissertation is primarily a collection of material, prepared by myself, published as journal articles or presented as a poster and oral presentations at conferences. In some cases, additional material has been included.

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Date of submission: 15 February 2023

ABSTRACT

Land degradation is widespread in communal rangelands in the grassland biome of South Africa, and often attributed to overstocking and lack of coordinated management. Excessive pressure on the herbaceous component has contributed to the uncontrolled spread of opportunistic invasive alien woody species e.g. Acacia *mearnsii* in many degraded areas, resulting in significant loss of ecosystem service capacity, along with soil and land productivity. Short-duration overnight kraaling has been suggested as a tool for restoring degraded rangelands. Recent studies in semi-arid savannas and shrublands have reported increased grass cover, soil nutrients and palatability and concluded that short-duration kraaling is a low-cost and effective way of restoring degraded rangelands using livestock. However, the response of different plant functional types and communities to such intense livestock impact may vary depending on local context.

This study used twelve paired kraal and control sites to investigate the effects of short-duration (7-24 days) overnight kraaling of livestock on herbaceous vegetation and soils in a mesic grassland. The study area is generally considered to be overgrazed but has considerable variation in grass composition and basal cover. Sites included relatively intact natural grassland and sites where wattle infestations had been cleared and where mostly bare ground remained. I tested the hypotheses that overnight kraaling would result in (1) increased basal cover due to introduction of grass seed and stimulation of germination through hoof action, (2) increased infiltration due to hoof action, and (3) increased soil nutrients and organic matter due to dung and urine deposition. I also hypothesized that factors such as a site's initial grass cover, its slope, the occurrence and amount of rainfall before and during kraaling, and the kraaling intensity (number of livestock and duration of the kraaling event) would influence the magnitude and direction of the kraaling effect.

The effect of kraaling on vegetation was strongly dependent on initial condition. Kraaling increased basal cover of grasses when sites had low initial basal cover, but decreased basal cover if initial values were over 50%. Infiltration increased if kraaling took place during or after rain but decreased if kraaling took place when soils were dry. Kraaling increased soil P and K.

In mesic grasslands, short-duration overnight kraaling is promising as a tool for rehabilitating degraded sites but should be avoided where the grass sward is relatively intact. I recommend that the suitability of kraaling be further evaluated per vegetation type and local context.

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To my Lord and Heavenly Father, my Shepherd and Creator, who has always been with me in this journey and been a lamp onto my feet I give the glory to Him.

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Chapter 1

General introduction and literature review

Land degradation in communal rangelands

Over 3 billion people are affected by land degradation globally. Land degradation results in loss of biodiversity and ecosystem services that humans and animals rely on for living (Scholes et al., 2018). Land degradation is also a major problem in South Africa (SA), where 60% or more of land is estimated to be degraded (UNEP, 1997). There are several different definitions of land degradation in the South African context (Palmer and Bennett, 2013), but they all agree that it involves a decline in the ability of ecosystem functions to deliver services such as freshwater availability, biodiversity habitat, and rangeland carrying capacity (Scholes, 2009).

Rangelands include grasslands, woodlands, scrublands, wetlands and (semi-) deserts (Alkemade et al., 2013). Amongst other goods and services, these lands provide about 91% of available grazing land globally for both livestock and wildlife (Reid et al., 2008). The productivity of these rangelands is however under threat due to a combination of often interacting factors such as overgrazing, soil erosion, invasive alien plant species (Le Maitre et al., 2004; Neke and Du Plessis, 2004), too frequent burning (Uys et al., 2004), inappropriate land-use practices such as cropping on marginal soils (Mucina and Ruthford, 2006; SANBI, 2014), and other human activities leading to environmental change (Lamprey, 1983; Scholes, 2009). Chief among these factors is overgrazing (Rutherford and Powrie, 2013).

Overgrazing refers to excessive grazing pressure, whereby grazing by livestock or wild herbivores exceeds the rangeland carrying capacity. Grazing without periodic rest can lead to an increase in vegetation loss, soil erosion, increased soil compaction, and reduced water infiltration rates (Good et al., 2013, Soliveres and Eldridge, 2014). Overgrazing is often attributed to continuous grazing at high stocking rates (O’Connor et al., 2021) and concentration of livestock around villages and stock posts (Mucina and Ruthford, 2006; SANBI, 2014), and is commonly observed in communal rangelands (Hardin, 1968; Palmer and Bennett, 2013).

Communal rangelands are a type of common property resource, which means that access is difficult to control, and individuals may take away resources to the detriment of all (Bennet and Barrett, 2006), or, at best, they are communally managed for the common benefit (Palmer and Bennett, 2013). In SA, communal rangelands are home to some of the poorest people in the country, who depend on rangelands for their livelihoods, including through extensive livestock grazing (Sayre et al., 2013). The widespread occurrence of overgrazing and land degradation in communal rangelands may be driven by various factors. Often there is an absence of a grazing management system, which leads to livestock grazing anywhere anytime. (Lesoli, 2008). This lack of planning may be the result of a land tenure system that fosters a lack of individual responsibility for the land. In other words, there is a lack of accountability and land ownership by communal farmers and little incentive for the sustainable use of the rangeland (Kgasikoma et al., 2012). Also, poverty in these areas means that rangelands may be overused due to a lack of economic alternative (Rosanne Stanway, Conservation South Africa, pers. comm. 2019).

Overgrazing is often associated with selective grazing and loss of palatable plant species while non-palatable species may dominate, ultimately leading to a loss of biodiversity (Kgasikoma et al., 2012). Besides biodiversity decline, a decline in forage quality and quantity reduces the overall rangeland condition and value as an agricultural resource (Kirkman and de Faccio Carvalho, 2003). Uncontrolled grazing also leads to intensive trampling and loss of plant cover, ultimately resulting in soil erosion and degradation of ecosystems. (Sanky et al., 2009; Rutherford and Powrie, 2013; Cingolani et al., 2014). When soil is exposed to erosion, it can lead to a decrease in soil macro-nutrients, high compaction, low infiltration rates, and a loss of faunal and floral diversity (Abdel-Magid et al., 1987; Van der Westhuizen et al., 1999). This can be exacerbated by inappropriate crop cultivation practices that increase soil compaction, disturb soil structure (Allmaras et al., 1993; Flinton et al., 2011), and accelerate rates of soil erosion (Vetter 2007).

Degradation of rangelands through erosion results in the loss of fine soil particles and associated soil nutrients, weakening soil aggregate stability. Rangeland degradation impacts carbon storage not only because of a reduction of net primary productivity and basal cover but also because of the loss of these fine particles, soil organic matter (SOM), and associated soil carbon. Because of reduced SOM and less fine soil particles, degraded lands are often high in soil bulk density and this in turn results in decreased soil water infiltration, and reduced soil moisture holding capacity (Haile et al., 2007; Gebreskel and Pieterse, 2007; Kassahun et al., 2012). In a study conducted in Ethiopia, it was reported that soil contents of nitrogen (N), phosphorus (P), and potassium (K), the most important soil nutrients determining ecosystem production, declined due to rangeland degradation (Kassahun et al., 2012). As erosion and loss of plant cover progresses, soil texture is altered and erosion gullies can form (Kassahun et al., 2012). Rangeland degradation thus affects soil at the scale of physical and chemical characteristics but also landscape features.

Poor management of livestock can result in a decrease in aboveground biomass and vegetation cover, which decreases physical heterogeneity (Ludwig and Tongway, 1995; Coller, 2014). Long term consequences of poor animal management result in negative feedback: land degradation through soil erosion, inability of the land to support biodiversity, woody encroachment and spread of invasive plant species, followed by reduced grazing habitat and poor livestock condition (Conant et al., 2001). Reduction of vegetation cover increases the likelihood of soil erosion and decreases inputs into the soil organic carbon (SOC) pool because of soil exposure to water, wind, and other environmental elements during grazing; all his has a negative impact on rangeland and livestock productivity (Conant et al., 2001; McCloren et al., 2008).

Besides poor rangeland management, climate change is a major contributor to land degradation. Climate change is a long-term change in weather patterns, including changes in rainfall patterns, increased temperatures. These changes may be natural, for example because of fluctuations in the solar cycle. But human activities have been the main driving force behind climate change, mainly due to the burning of fossil fuels such as coal, oil, and gas. Climate change can have a negative impact on livestock production as a result of decreased vegetation cover and water available for livestock (Thornton and Gerber 2010). As a result, climate change can increase livestock mortality and impact the livelihoods of rural communities (Maleko and Koipapi, 2015; Magita and Sangeda, 2017; Chamliho, 2017).

Alien Invasive Plants

Besides overgrazing, invasive alien woody species are one of the top threats to rangeland ecosystem function. Excessive pressure on the herbaceous component has facilitated the uncontrolled spread of opportunistic invasive alien woody species in degraded grasslands, resulting in loss of ecosystem services and productivity (Turpie, 2003; Egoh et al., 2009).

Invasive Australian *Acacia* (wattle) species are rapidly increasing in South African grasslands. *Acacia mearnsii* is a fast-growing tree (Campbell, 2000) and poses severe environmental management problems once infestation occurs (Nyoka, 2003). *Acacia mearnsii* is very competitive species and threatens indigenous species, becoming dominant in grass communities (Nyoka, 2003; Ogden and Rejmanek, 2005). This plant is used for commercial purposes and as well as for domestic use by rural communities e.g., firewood, fencing, and building materials (DWAF 1997; de Neergaard et al., 2005; Shackleton et al., 2007). The most invaded areas are generally wetter areas such riparian zones, dams, wetlands, springs, rivers or even roadsides (Muslin, 1993). These invasive trees pose a threat to water security, biological diversity and ecological functioning of natural systems and land productivity (Galatowitsch and Richardson 2004). Invasive plant species can reduce river flow and water yields because they use more water than native trees due to their large canopies and high transpiration rates (Richardson and van Wilgen 2004; Le Maitre et al., 2011). They leave soil drier than it is under indigenous species (Dye and Jarmin 2004). *Acacia mearnsii* is resistant to drought (Bromilow 1995) and remains green all year round (Muslin, 1993; Hess et al., 2006). Aside from their high evapotranspiration rates, invasive wattles also threaten biodiversity and ecosystems properties through disruption of soil microbial functioning (Galatowitsch and Richardson 2004). They also suppress grass cover (Jobbagy and Jackson 2004), which can lead to soil erosion and sediments in rivers and dams (Surridge, 2006).

The South African National Department of Environmental Affairs (DEA) introduced the Working for Water programme, which aims to eradicate alien invasive plants and to rehabilitate areas affected by erosion, while reducing unemployment by creating jobs (DWAF, 1997). However, clearing of woody invasive plants has left many areas of bare soil, which make the soil vulnerable to soil erosion and re-establishment of invasive plants. Land rehabilitation programs are needed following wattle clearing (van Wilgen *et al*., 2002).

In the Matatiele area of the Eastern Cape within SA's Grassland Biome, some rural communities have formed grazing associations and decided to maintain areas cleared of wattle through follow-up clearing of wattle regrowth (Rosanne Stanway, Conservation South Africa, pers. comm., 2019). This initiative seems to have been effective in increasing grass cover and preventing wattle re-establishment, but it is labour intensive and without follow-up treatment the land is left vulnerable to re-invasion and soil erosion as soil remains exposed (Rosanne Stanway, Conservation South Africa, pers. comm. 2019).

Grazing management and grassland restoration

The United Nation Decade on Ecosystem Restoration (2021 – 2030) aims to reduce degradation by restoring ecosystems to improve biodiversity, people's livelihoods, and reduce impact of climate change (UN Decade, 2021). Everyone is called upon to participate in restoring the ecosystems in order to benefit from ecosystems goods and services. Restoration actions promoted include eradication of invasive alien species, re-introduction of native grasses and trees, and practice of sustainable land management.

Manipulating livestock movement and thus the timing, duration and intensity of grazing, trampling and nutrient input has received much attention as a feasible, low-cost way to combine current land use with grassland restoration. Traditionally, this has focused on reducing stocking rates, rotational grazing and periodic resting (Eneboe et al., 2002, Heitschmidt et al., 2005, Gillen and Sims, 2006). In the context of communal rangelands, herding has been explored as a way to achieve this in rangelands that are typically not fenced into paddocks (Briske and Woodward, 2016).

In contrast, Savory (2013) has argued that the only option to reverse degradation and to restore rangelands is to use livestock, bunched and moving at high densities, to replicate the apparently non-selective grazing and browsing of former herds being chased by predators, i.e., short duration grazing. The argument is that livestock hoof action (i.e., trampling) improves herbaceous cover by loosening the soil surface, stimulating grass seed germination and biological decay of grass, while herded livestock contribute nutrients through dung and urine to the soil. It is claimed that without livestock and biological decay, grasses can only be broken down by the relatively slow process of oxidation, delaying the new growth and allowing the woody species to outgrow grass, ultimately resulting in more bare soil that will lead to soil erosion (Savory, 1983, 2013). Hoof action is said to improve rainfall infiltration into the soil and to reduce soil erosion, even when livestock are maintained at double or triple the recommended stocking rates (Savory and Parsons 1980, Savory 1983).

Claims about the benefits of short duration high-intensity grazing have been widely refuted (e.g., Briske et al., 2008, 2011, Hawkins 2017; Venter et al., 2019; Hawkins et al., 2022). Physical effects of livestock trampling have been shown to cause compaction of the soil surface and loss of vegetation . The key factor in rangeland or ‘veld’ damage was the amount of animals walking and it has been stated that any factor that reduces walking should reduce veld damage. Stocking rates and not grazing system appear to remain key: heavy stocking rates are detrimental to rainfall infiltration and cause sediment loss, regardless of the grazing practice in use (McCalla et al., 1984a, 1984b; Gamougoun et al., 1984).

However, less controversial than Savory’s short duration grazing approach is short-duration kraaling (corralling), which has received considerable attention as a restoration tool especially in Africa (Huruba et al., 2018, McManus et al., 2018; Momberg et al., in press). Stock theft and predator attacks on livestock are common in many rangelands in Africa, and overnight kraaling is widely used as a form of livestock protection. Traditionally in SA, rotation or moving of kraals is not a common practice as kraals are a central and permanent part of the homestead. Elsewhere in Africa, kraal occupancy can range from months to decades, depending on climate condition and soil type of the area, and the particular pastoral system (Porensky et al., 2013).

Long-term kraaling has been shown to result in persistent nutrient hot-spots with distinct soil and vegetation qualities (Blackmore et al. 1990, Veblen et al. 2012). Even in short duration kraaling (days to weeks), however, dung and urine are deposited by livestock in kraals resulting in nutrient-enriched sites that persist after livestock move to a new kraal area (Young et al., 1995; Augustine 2003, Porensky and Veblen, 2015; Momberg et al., in press). Nutrients that persist in short duration kraaling include N, P, and K as well as carbon, but most of these studies are in savannas (Momberg et al., in press). These nutrient hotspots are often highly productive and sought out by livestock and wildlife, resulting in feedbacks that maintain the elevated nutrient status of these sites (Blackmore et al.,1990, Treydte et al., 2006, Veblen et al., 2012).

Short-duration overnight kraaling has been proposed as a tool to rehabilitate and restore degraded rangelands and to improve soil fertility in crop fields (Savory, 2008, Huruba et al., 2018, Peel and Stalmans, 2018). Studies conducted on short duration overnight kraaling have reported increased water infiltration through livestock hoof action, breaking of soil surface in bare soils, increased soil nutrients, and increased vegetation cover and grass diversity through grass seeds harvested by livestock during grazing and dispersed through dung (e.g. Sibanda et al., 2016, Huruba et al., 2018, McManus et al., 2018). Cattle graze and can be expected to return a portion of the nutrients from grazing in the form of dung and urine to the ground that might also improve soil fertility. Livestock kraaling has also been reported to improve seed emergence through trampling (Porensky and Veblen 2015).

Overnight kraals provide high animal impact and could possibly be used to restore eroded gullies or extremely compacted soil, but kraals should be moved because excess dung and urine become pollutants when animals kept in one place for longer periods (Porensky and Veblen, 2018). Overnight kraals can also be used in crop fields before planting for soil preparation to increase yields (Peel and Stalmans, 2018). Short duration kraals have been found to create nutrient-rich patches and improve rangelands condition (Sibanda et at., 2016). While permanent kraals have been found to result in dominance by one or two grass species (Porensky et al., 2013), short term kraaling seems to promote greater species diversity (Sibanda et al., 2016). However, recent work has shown that shrublands (McManus et al., 2018) and grasslands (Hawkins et al., 2022) respond differently to kraaling compared to savannas. It is therefore important to test the impact of short-duration kraaling in diverse ecological contexts, and test whether the soil nutrient hotspots remain within the ecological bounds of the vegetation type in question.

Research objectives

This study formed part of a participatory action research project. Communal farmers in the Matatiele District Municipality within the Grassland Biome of SA started a rangeland restoration initiative through a Conservation Agreement model with the help of the NGO's Conservation South Africa and Environmental and Rural Solutions. Part of the agreement was the employment of herders, or so-called Ecorangers, who kraaled livestock overnight and this presented an opportunity to explore kraaling as a restoration tool. Kraaling could help restore grass cover post-clearing of wattle trees according to anecdotal information (Nicky McLeod, Environmental and Rural Solutions, 2015, pers.comm). Since this newly introduced short duration kraaling was already being practiced by the livestock farmers, a study testing the efficacy of kraaling on grasslands could be conducted. This allowed the study to capitalize on existing infrastructure, willing livestock owners, and Ecorangers, while contributing to scarce knowledge on working lands. The results of this research should thus feeds directly into rural land-use planning and the Conservation Agreement model.

In communal areas in mesic grasslands of South Africa, short-duration kraaling has been proposed as a way to restore degraded areas. This is based on findings in the literature about increased soil nutrients and the observation that short duration kraaling led to increased grass cover in savannas (Sibanda et al., 2016, Huruba et al., 2018), and in degraded grassland areas that had been cleared of invasive wattle (Nicky McLeod, Environmental and Rural Solutions, 2015, pers. comm). However, the effects of short duration kraaling need to be tested in the ecological context of mesic grasslands before the practice can be recommended to local communal and other farmers.

While short duration kraaling has shown promising results in certain ecological contexts, it cannot be assumed that every vegetation and soil type responds in the same way. Studies conducted in semi-arid savannas showed that short duration kraaling increased soil nutrient content, plant diversity in kraal sites, and were associated with a change in plant species composition from less to more palatable species (Muchiru et al., 2008, Sibanda et al., 2016, Porensky and Veblen, 2018). Huruba et al. (2018) found that biomass decreased following short duration kraaling, but this may have resulted from warthogs grazing at abandoned kraal sites. McManus et al. (2018) found no effect of short-duration kraaling on grasses, but a decreased diversity of shrubs following kraaling in arid Karoo vegetation in South Africa.

I investigated the response of soils and grasses to short duration kraaling in mesic montane grasslands using a paired kraal and control design at twelve locations within the Matatiele District Municipality, South Africa. Mesic grasslands were expected to have different dynamics to semi-arid savannas, especially as the grasses are long lived and have low population turn-over naturally (Cingolani *et al.,* 2014; Chamane *et al.,* 2017). In addition, this study compared kraaling on relatively intact as well as severely degraded grassland, and at sites with and without previous wattle clearing, and examined whether the effect is the same regardless of the initial condition.

My research aimed at testing the following hypotheses:

1. Kraaling would increase grass cover and reduce bare ground through livestock hoof action, deposition of nutrients in dung and urine, and introduction of seeds into the kraals in dung of animals that have been freely grazing in the day.
2. Kraaling with its high intensity of hoof action may lead to reduced herbaceous basal cover on steep slopes.
3. Cumulative hoof action (via a greater number of animals kraaled and/or a longer duration of kraaling) would lead to a greater increase in grass cover in line with predictions of Savory (2008).
4. Rainfall during kraaling (and during the preceding week) would increase grass basal cover and reduce the percentage of bare ground (when rain infiltrates the soil, soil moisture increases, which is expected to lead to seed germination and emergence).
5. Positive effects of kraaling would be more pronounced on the bare areas, such as those left behind after wattle clearing, whereas on the relatively intact veld, kraaling may have little effect or even be detrimental if hoof action damages the perennial grass tufts.
6. Kraaling would increase soil organic matter (SOM), through livestock hoof action incorporating live and dead leaf (litter) material as well as dung and urine into the soil.

7. Kraaling would increase soil nutrients through dung and urine dropped and incorporated into the soil through hoof action/animal impact.
8. The effect of kraaling on soil nutrients would be greater with greater animal density and/or duration of kraaling.
9. Initial condition (per cent bare ground, as a proxy for soil and vegetation and soil degradation) would influence the effect of kraaling on soil nutrients and SOM.
10. Kraaling would decrease soil bulk density and increase infiltration, as livestock hoof action would loosen the soil resulting in less soil compaction. This effect was expected to be influenced by whether soils were wet or dry during kraaling.

The approach I took was to first compare each response variable between kraaled and control sites. Where there was a significant effect, or evidence that the effect size was highly variable, I used linear models and best model selection to examine the effects of slope, cumulative kraaling intensity (as LSU*days, where 1 LSU is the metabolic equivalent of a 450 kg steer), rainfall before and during kraaling, and initial condition on the effect size. The effect size was quantified as the difference between the kraaled and control plots at each site.

Thesis Overview

Chapter 2 introduces the study area and the experimental design.

Chapter 3 reports on the effects of short-duration overnight kraaling on the herbaceous vegetation, including the basal cover of grasses, the percentage of bare ground, standing biomass, and grass composition.

Chapter 4 examines the effects of short-duration overnight kraaling on soil properties (SOM, soil nutrients, bulk density and infiltration), and to determine whether kraal intensity and initial conditions had any influence on soil physical properties.

Chapter 5 discusses the findings of the research and their implications for rangeland management in mesic montane grasslands.

Chapter 2. Study Area and Experimental Design

Study area

The study was conducted at two sites in the Eastern Cape Province of South Africa. Motseng (30°17'45"S and 28°22'08"E) and Mvenyane (30°32'13"S and 29°1'32"E) are in Wards 14 and 21, respectively, of the Matatiele Local Municipality in the Alfred Nzo District Municipality (Figures 2.1 and 2.2). The local municipality comprises 24 wards and accounts for 58% (4352 km^2) of the Alfred Nzo District. The municipality is situated alongside the Drakensberg and Maluti mountain ranges, in an area that is characterized by a relatively high level of environmental sensitivity and highly endangered species (NBA, 2018).

The study sites are located in a bioregion that has a high species richness and species turn over associated with environmental conditions, altitude and changing gradients. The catchment is characterized by high diversity but degraded grasslands (Mucina et al., 2005, Driver et al., 2012). These habitats provide ecosystem services that provide communities with animal forage, food security (bush meat through hunting, harvesting of wild fruits etc.), traditional medicines, and material for community use such as firewood, water provision, and erosion control. The study area is threatened by poor rangeland management, soil erosion and alien invasive plant infestation (Nel et al., 2011).

Communal grazing lands in the high-lying grasslands of the Eastern Cape have a history of poor or little grazing management that has been associated with severe soil erosion, river siltation, and reduced soil fertility (Vetter et al., 2006). Both of the wards included in this study were identified by stakeholders of the uMzimvubu Catchment Partnership Program (UCPP) and other community members as priority sites to engage local private and communal farmers based on ecological and social surveys (Hawkins, 2014). A multi-stakeholder UCPP platform provides a governance structure supporting local government in terms of research and development in the area. Specifically, a Natural Resource Management (NRM) program from the SA Department of Environmental Affairs supports development projects in the area, comprising the funding of Ecorangers. Some of these Ecorangers act as herders in rotational grazing systems, and some act as clearers of alien invasive plants (AIPs). Non-profit organizations, for-profit companies, and government departments in the UCPP are working with communal farmers to find alternative, innovative grazing systems that can ensure sustained beef cattle production and improved grazing areas.

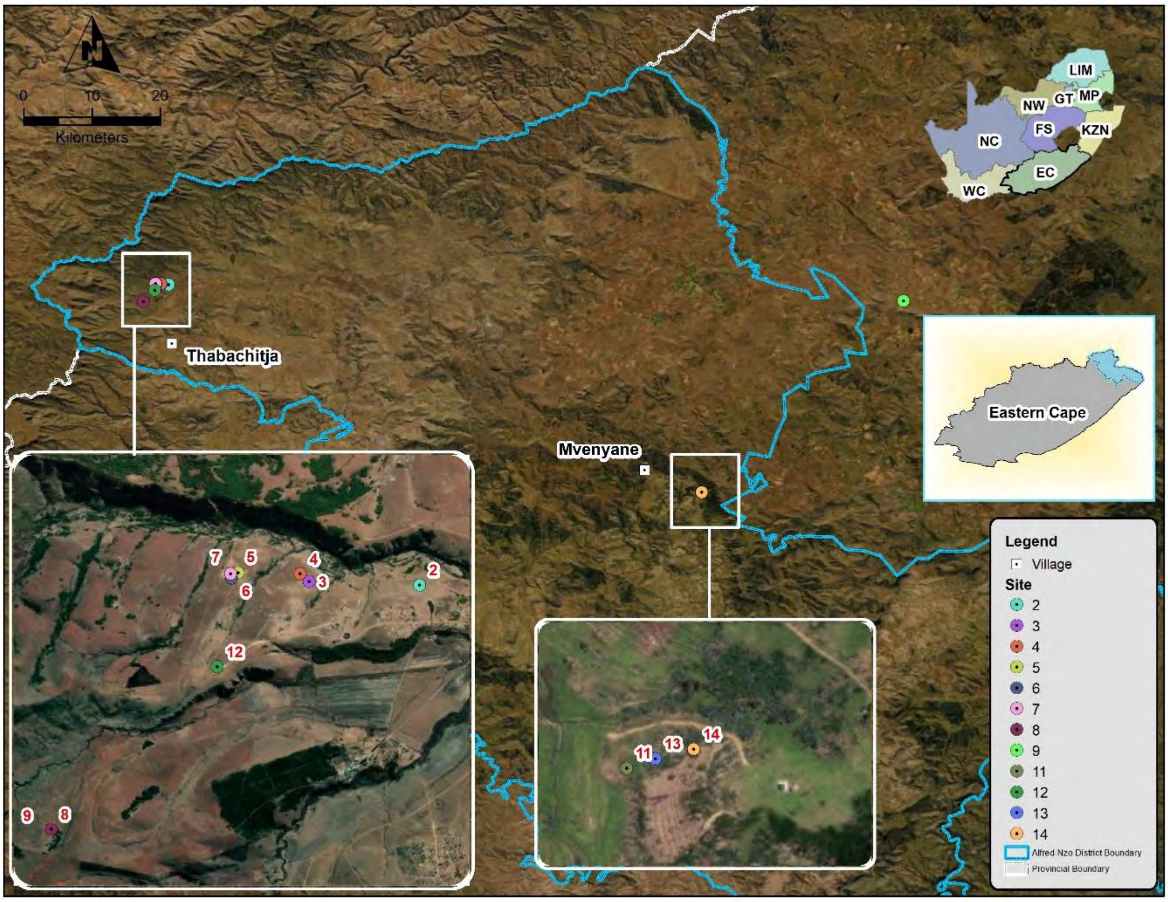

Figure 2.1. Map of Motseng grazing land and Mabheleni divided into grazing camps. Different dots represent kraal sites.

The climate of the Matatiele Local Municipality is characterized by warm and wet summer months, and cold, dry winter months with frost. Between 2012 and 2018, mean annual rainfall and temperature were 710 mm and 15.9°C respectively, with most rainfall occurring during the austral summer months (WorldClim v 2.1 database according to Hijmans et al., 2005). Mountainous areas and the border region in the north of eastern parts can expect snow most winters.

In Matatiele Local Municipality, topography and slope vary from very steep gradients along the western boundary and along the southeastern boundary to relatively gentle slopes in the foothills of the mountains and river plains such as farming areas. The landform and soil type based on Soils Grid (Hengl et al., 2014) was predominantly steep land with Regosols. The northern study sites (2 to 9, 12) were high-gradient mountain with Leptic Regosols, while the southern sites (11, 13, 14) were medium-gradient mountain with Eutric Regosols (Figure 2.1,

Table 2.1). The steep northern sites had a gradient of more than 30%, a relief index greater than 300 m km^{-2} and a drainage density of 0 to 15 potential drainage density (PDD). The less steep southern sites had a gradient of 15 to 30%, a relief index of 150 to 300 m km^{-2} and a drainage density of 0 to 15 PDD (van Engelen and Dijkshoorn 2013).

The study area comprised various grassland vegetation types including Highland Basalt Grassland at the highest altitude, Southern Drakensberg Highlands Grasslands, East Griqualand Grassland, and Drakensberg Foothill Moist Grasslands at lower altitudes, and Mabela Sandy Grasslands in alluvial/saturated soils (Mucina and Rutherford, 2006). The study sites were largely located on Mabela Sandy Grasslands and East Griqualand Grassland (Table 2.1). The vegetation is commonly referred to as sour grassland, a term used to describe grasslands where grasses lose their nutritional value during the dormant season and often occur on highly leached nutrient poor soils (Mucina and Rutherford, 2006; 2012). Plant species common to this vegetation include forbs, bunch grasses (*Themeda triandra, Tristachya leucothrix, Heteropogon contortus, Eragrostis curvula, Andropogon appendiculatus*), small shrubs, (*Chrysocoma ciliata, Pentzia cooperi*) and larger shrubs or trees (*Leucosidea sericea, Acacia karroo*).

Experimental design

The study design consisted of 12 paired sites that were randomly selected at the location of available stock posts (grazing camps) (Table 2.1, Figure 2.2). Each paired site comprised a kraal and non-kraaled 'control' on sites with and without previous wattle infestation and clearing. Kraaling lasted between 7 and 24 days. It is important to note that the study was part of a working development project, where kraaling times and locations were determined in collaboration with communal livestock farmers and according to needs and constraints posed by livestock and weather conditions. Stocking rates were determined by farmer's willingness to combine their livestock and kraal them overnight at designated site or area.

Matatiele is situated just outside the borders of Lesotho, which makes it difficult for veld fires to be controlled. Fires from Lesotho Mountains often cross the southern border into Ongeluksnek Nature Reserve and then into the surrounding communities.Four study sites, all of which were previously cleared of wattle, were unexpectedly burned by run-away fires after kraaling. This created an unintended unbalanced where sites were either neither wattle cleared nor burned, wattle cleared but unburned, or wattle cleared and burned (Table 2.1).

Table 2.1. Sites locations, soil and vegetation characteristics, slope, month of kraaling, duration of kraaling and number of cattle per kraal. Abbreviations: WRB (World Reference Base); EGG (East Griqualand Grassland); MSG (Mabela Sandy Grassland); NV (Ngongoni Veld), NWNF (No wattle no fire), WNF (wattle no fire), WF (wattle fire), LSU (Large and small stock unit).

Site No.	Location	Ward	Altitude (masl)	Soil type (WRB)	Vegetation type	Wattle x Fire	Slope (%)	Month and year of kraaling	Duration of kraaling (days)	LSU days
2	S30.290°; E028.388°	14	1513	Leptic Regosols	MSG	NWNF	7.4	March 2014	23	5718,26
3	S30.288°; E28.377°	14	1534	Leptic Regosols	MSG	WNF	2.5	April 2014	21	5221,02
4	S30.288°; E028.370°	14	1555	Leptic Regosols	MSG	NWNF	3.7	April-May 2014	24	4596,96
5	S30.289°; E028.371°	14	1558	Leptic Regosols	MSG	WF	0.1	May-June 2014	7	2925,15
6	S30.288°; E28.370°	14	1563	Leptic Regosols	MSG	WF	0.1	June 2015	16	3120,16
7	S30.289°; E28.371°	14	1560	Leptic Regosols	MSG	WF	0.1	Mar-April 2015	19	3412,78
8	S30.311°; E28.353°	14	1617	Leptic Regosols	MSG	NWNF	0	April-May 2015	13	2266,29
9	S30.310°; E28.353°	14	1614	Leptic Regosols	MSG	NWNF	0	May 2015	21	3530,73
11	S30.563°; E29.088°	21	1303	Eutric Regosols	EGG	WNF	5.5	April-May 2016	15	2093.25
12	S30.296°; E028.369°	14	1576	Leptic Regosols	NV	WF	1	June 2014	14	1827,42
13	S30.563°; E29.088°	21	1308	Eutric Regosols	EGG	WNF	7.7	May 2016	16	2322,56
14	S30.562°; E29.089°	21	1315	Eutric Regosols	EGG	WNF	25.9	May-June 2016	20	2903,2

Herds of herds of between 123 and 250 cattle and 115 to 286 small stock were kept overnight in mobile corrals (locally known as and hereafter referred to as a 'kraals') for between 7 to 24 days before being moved to a new location. Stocking rates were determined by farmer's willingness to combine their livestock and kraal overnight at designated site or area. Kraaling intensity was calculated as a single variable (LSU days) that quantified the combined activity of cattle and small stock by multiplying their number by the number of nights they spent in the kraal. Numbers of cattle and small stock were converted to LSU, which is the metabolic equivalent of a 450 kg steer, using the same conversions used by Vetter and Bond (2012) in a similar ecological and farming context in montane Eastern Cape grasslands. Kraal sizes varies from 50m x 100m to 100m x 100m depending on number of animals available to be kraaled.

The movable corral was made from heavy-duty, UV-stabilized poly wires and 3 x 0.2 mm stainless steel conductors per horizontal fence line. Poly wires of length 50 m and height 1.08 m were attached to nets (four to six joined with metal clips) and fastened to corner posts, which were stabilized using a two-prong foot. The corner posts formed a circular corral of approximately 50 m^2, big enough for a maximum of 300 cattle. The horizontal wires comprised nine electrified and one non-electrified (ground) components. The fence was electrified by a 2.5-joule energizer with Adoptive Power Technology (Nemtek Electric Fencing Products, Randburg, South Africa).

Kraal sites were chosen by joint consultation with livestock owners and Conservation South Africa (CSA) as part of Conservation Agreements. During the day, livestock were herded by local herders and Ecorangers to the nearby grazing camps for 10 hours between 07:00 and 17:00 and kraaled for 14 hours overnight. Ecorangers slept close to the kraals in tents provided by CSA to protect livestock from theft and predators. The number of days per each kraal was determined by weather conditions and forage availability. Each kraal was only used once during the study. Due to a severe drought that started in 2015, kraaling was discontinued at the request of the livestock owners during 2016.

Sampling took place from February to early May 2017. Vegetation responses were standing biomass, percent basal cover and percent bare ground and are reported in Chapter 3; Soil responses were bulk density, slope, infiltration rate and soil samples for nutrients and are reported in Chapter 4.

Kraal 3 (May 2014) during kraaling

Kraal 3 (November 2014) 6 months after kraaling

Kraal 11 (April 2016) during kraaling

Kraal 11 (April 2017) 11 months after kraaling

Kraal 4 (November 2014) during kraaling

Kraal 4 (April 2017) 6 months after kraaling

Figure 2.2. Temporary kraal sites photographed during and various times after kraaling. Kraals 3 and 11 had been invaded by wattle and cleared, while Kraal 4 was on natural uninvaded grassland.

Chapter 3: Effect of kraaling on herbaceous vegetation

Introduction

Poor rangeland management practices, especially continuous heavy grazing at high stocking rates, can lead to a loss of grass cover, changes in herbaceous composition and soil erosion (Oztas *et al.,* 2003; Vetter 2005; Tefera *et al.,* 2007). In South Africa, reduction of stocking rates and occasional destocking campaigns in the form of state programs was implemented to meet the rangeland carrying capacity and to address the issue of fodder shortages (Camp 1999; 2000). In some places, rotational grazing and/or resting were also applied to reduce grazing pressure and to allow vegetation to recover in growing seasons (Ainslie et al 1998; Everson and Hatch 1999). However, in most South African communal rangelands grazing is largely unregulated, and at higher than recommended stocking rates, due to a lack of effective governance and cooperation among land users (Hoffman and Ashwell 2001; Meadows and Hoffman 2002).

Continuous heavy grazing can also facilitate the infestation of grasslands by alien invasive plants. Herbaceous vegetation cover protects the soil, reduces soil erosion, and allows water to infiltrate to the soil (NDA, 1999). In South African grasslands, invasion by non-native woody species such as Australian black wattle (*Acacia mearnsii*) and silver wattle (*Acacia dealbata*) reduces the productivity of grasses, decreases vegetation cover, increases bare ground and subsequently can lead to soil erosion (Le Maitre *et al*., 2000). Invasive woody species such as wattle invade grazing land and compete with indigenous species for water, nutrients, and light. Such invasions replace the native grass community, increase water loss from the riparian zones, reduce biodiversity and reduce the carrying capacity of the land (DWAF 1997; Nyoka, 2003). These non-indigenous trees have higher evapotranspiration rates than native woody vegetation, leading to drying of soil streams and rivers (DWAF, 1997; Le Maitre *et al*., 2000; Nyoka, 2003).

The National Department of Environmental Affairs (DEA) introduced a program called Working for Water that aims to eradicate alien invasive plants and erosion while creating jobs (DWAF, 1997). However, clearing of woody invasive plants has left many areas of bare soil, which made the soil vulnerable to soil erosion and re-establishment of invasive plants. Land rehabilitation programs are needed following wattle clearing (Van Wilgen *et al*., 2002). Some organized communities (Grazing Associations with signed Conservation Agreements) in Mvenyane decided to maintain those areas by doing follow-up pulling out of wattle regrowth

(Conservation South Africa, pers comm 2019). This initiative seems to have been effective as it has led to increased grass cover and prevented wattle re-establishment so far in Mvenyane, but in most areas, the land is left more vulnerable than before as there is no plan in place for rehabilitating the cleared areas (Conservation South Africa, pers comm 2019).

Savory (1978; 1983; 2008; 2013; 2016) advocates that herding livestock, to keep them bunched and moving, is an effective way to reverse degradation and to restore rangelands. In this way, livestock mimic nature by acting as proxy for the apparently non-selective grazing and browsing of herds of native ungulates kept moving by pack-hunting predators. Trampling is claimed to improve soil cover by loosening the soil surface, stimulating grass seed germination and accelerating the biological decay of grass, while herded livestock contribute nutrients through dung and urine inputs to the soil. Savory (2013) claims that without livestock and biological decay grasses can only be broken down by the relatively slow process of oxidation, delaying the new growth and allowing woody vegetation to outcompete grass. This is hypothesized to result in more bare soil with loss of water and carbon (Savory 2008; 2013). Regardless of the number of livestock, animals bunched in a single herd are relatively more effective than scattered individuals in breaking the soil surface with the hooves and trampling plants into litter to cover the soil, and this allows air and water to infiltrate facilitating plant growth (Savory 2008).

Short-term overnight livestock kraaling can be thought of as a form of localized intensive grazing that can also be used to restore eroded areas and bare areas via animal impact. This is achieved by breaking the biological soil crust through hoof action (trampling), incorporating plant material, and dung and urine dropped by the animals into the soil, which leads to an increase in plant growth (Savory 1983; 2008; 2013). Several studies have been conducted to test these proposed benefits of short-duration kraaling. In semi-arid savannas in Zimbabwe, grass nutrient content and diversity increased with short duration kraaling, with a shift towards palatable, grazing-tolerant species (Huruba et al. 2018; Sibanda et al. 2016). These grasses mostly established from seed on ground that was bare immediately after kraaling (Sibanda et al. 2016). In a Kenyan savanna utilised by high densities of wildlife and cattle, single short duration kraaling events resulted in persistent nutrient-enriched patches dominated by palatable, grazing tolerant grasses (Porensky and Veblen, 2015). However, care should be taken to generalize between vegetation types. In arid shrublands of South Africa, McManus et al. (2018) found that grasses were unaffected by short duration kraaling, but the diversity and cover of long-lived succulent and non-succulent shrubs in a study of the effects of were reduced by short-term kraaling. Chamane et al. (2016) recorded higher live and dead (moribund) plant biomass under short-duration intensive grazing camps.

I investigated the response of grasses to short-term kraaling in mesic montane grasslands, which are likely to have different dynamics to semi-arid savannas, especially as the grasses are longer lived and have less turn-over naturally (Cingolani *et al.,* 2014; Chamane *et al.,* 2017). In addition, this study compares kraaling on relatively intact as well as severely degraded grassland, and at sites with and with our previous wattle clearing and examines whether the effect is the same regardless of the initial condition. The aim of this chapter is to examine the impact of short-duration overnight kraaling on the herbaceous vegetation: the basal cover of grasses, the percentage of bare soil, standing biomass, and grass composition using a paired kraal and control design at twelve locations (see Chapter 2). Unplanned fires took place in two consecutive years (2014 and 2015), and at least four kraal sites were burned since kraaling. While the fire was not part of the experimental design, its effects were also examined.

I tested the following hypotheses:

1 Areas previously cleared of wattle would have lower basal cover before kraaling than sites where wattle were not previously present. I had no specific hypothesis regarding the effects of the unanticipated fires (which only affected four of the wattle cleared sites).

2 Kraaling would increase grass cover and reduce bare ground through livestock hoof action, deposition of nutrients in dung and urine, and introduction of seeds into the kraals in dung of animals that have been freely grazing in the day.

3 The magnitude and possibly direction of the effect of kraaling would be affected by the following factors:

    a. Kraaling with its high intensity of hoof action may lead to reduced herbaceous basal cover on steep slopes, which are more prone to erosion.

    b. Cumulative hoof action (via a greater number of animals kraaled and/or a longer duration of kraaling) would lead to a greater increase in grass cover in line with predictions of Savory (2008). I thus expected a positive relationship between the total LSU days (livestock units * days, where one livestock unit is 450 kg) and the percentage of grass cover in kraal plots.

    c. Rainfall during kraaling (and during kraaling and the preceding week) would increase grass basal cover and reduce the percentage of bare ground (when rain infiltrates the soil, soil moisture increases, which is expected to lead to seed germination and emergence).

   d. Positive effects of kraaling would be more pronounced on sites with low grass cover and a higher percentage of bare ground, as was commonly observed in areas left behind after wattle clearing. On relatively intact veld, kraaling may have little effect or even be detrimental if hoof action damages the perennial grass tufts.

4 Grazing, prior infestation and clearing of wattle, and possibly fire would affect the species composition of the grass sward. Kraaling was expected to favour disturbance tolerant grasses.

Materials and Methods

The study area and experimental design are described in Chapter 2.

Data collection

To investigate the impact of short-duration kraaling on the percent basal cover of grass and the percentage of bare ground, I used a Levy bridge with 10 drop pins 25 cm apart, dropped 10 times to sample 100 points per kraal or control sites. At each pin strike, I recorded the species if its base was touched by the pin, or bare ground if the pin did not strike the rooted base of a plant. Grass species were identified to species, while sedges, dicotyledonous herbs and karroid dwarf shrubs were categorized as forbs (Vetter et al., 2006). Since the study took place after kraaling had already occurred. the initial condition before kraaling was assumed to be represented by that recorded in the control plots.

A disc pasture meter (DPM) was used for comparing the standing biomass on kraal and control plots, because it gives a good indication of standing biomass (Trollpe and Potgieter, 1986). A DPM is a 1.5 kg metal disk, 45 cm in diameter that is dropped on the grass sward from a standard height. The height at which it rests above the ground is a measure of the grass biomass under the disk (Bransby and Tainton, 1977; Tainton, 1977). The biomass was measured every two meters randomly along a 20 m transect, 5 m apart, totaling 100 DPM measurements per kraal or control plot. DPM values closely reflect standing biomass, except for very tall grasses and when tall, lignified culms are present (Zambatis et al., 2006) which was not the case at my study sites. Since the DPM has not been calibrated for the study area and my aim was to tell whether there was an effect of variables on standing biomass, rather than accurately determine the amount of biomass, I used the raw DPM value (in cm) rather than estimated biomass (see, for example, Archibald et al., 2004). Sizes varies from 50m x 50m to 100m x 100 M depending on number of animals available to kraal at that time. Points were randomly selected in each plot.

Data analyses

I first examined the effect of wattle infestation and clearing, and the unplanned fire events at previously wattle cleared sites, on initial basal cover, per cent bare ground and standing biomass. I performed single factor ANOVA followed with Tukey's HSD post-hoc tests. The response variables were the values in the control plots.

Paired t-test (assuming unequal variance) were performed to determine effect of kraaling on herbaceous basal cover, standing biomass (DPM) and bare ground by comparing the paired kraal and control plots at each site. To determine what factors influenced the effect size (i.e., difference in each response variable between each paired kraal and control site) I used best model selection using the "regsubsets" function in the package "leaps", selecting the best models based on the Akaike Information Criterion (AIC; Akaike, 1983; Burnham and Anderson, 2002). I performed best subsets model selection starting with a model that included four predictors: the initial condition (value in the control site), rainfall during kraaling, slope, and LSUdays. I was also interested in the effect of wattle/fire on effect size, but it was found to be strongly related to initial condition (Figure 4.1) and was thus excluded from the analysis to avoid effects of collinearity. I then ran the linear model for each best model using the "lm" function and recorded the adjusted R^2, p and AIC value for each of the best models. Data was analyzed using R (R Core Team, 2022). To determine whether individual predictor variables contributed significantly to the model, I compared models with and without the factor using the "anova" function in R (see Winter, 2013).

Grass composition was analyzed using the PRIMER v6 software (Clarke and Warwick 1994). Similarities between sites according to their grass species composition (using square-root transformed data and Bray-Curtis similarity) were explored with cluster analysis (group average linkage) and non-metric multidimensional scaling (NMDS; Clarke, 1993). A two-way ANOSIM (Mantel-type Monte Carlo analysis) analysis was performed to test for significant differences in the grass composition by kraaling and wattle/fire treatment combination. Similarity percentage (SIMPER) analyses were conducted to determine which species contributed the most to the differences in vegetation composition between kraal and control sites and between the wattle/fire treatment combinations.

Results

Effect of wattle clearing and fire on initial conditions

Previous wattle clearing and fire significantly affected per cent bare ground ($F_{2,9}$ = 13.67, p = 0.002), grass basal cover ($F_{2,9}$ = 24.56, p = 0.0002), and standing biomass ($F_{2,9}$ = 12.60, p = 0.003). Wattle cleared sites that had remained unburned had significantly lower basal cover and standing biomass, and higher per cent bare ground, than sites that were never wattle cleared or were wattle cleared and had subsequently burned (Figure 3.1). The latter two treatments did not differ significantly.

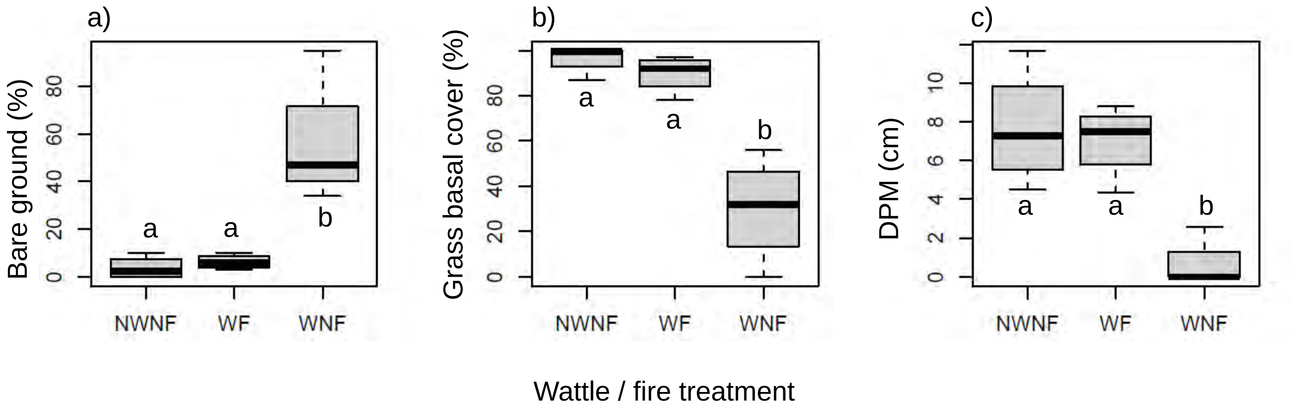

Figure 3.1. Effect of previous wattle clearing and fire (NWNF – no wattle or fire; WF – wattle plus fire; WNF – wattle, no fire) on a) per cent bare ground, b) grass basal cover, and c) standing biomass in control plots. Treatment labeled with the same letter were not significantly different.

Effect of kraaling and influence of other factors

Kraaling did not significantly affect bare ground, grass basal cover, or standing biomass. It was notable, however, that while kraal sites were fairly similar in their values, the values of control sites ranged widely (Figure 3.2). The effect size (value at kraal – value at control site) thus ranged considerably from negative to positive.

The effect of kraaling on the percentage bare ground was significantly influenced by initial bare ground (as measured at the control site). The single factor model with bare ground at the control site as the only predictor variable had the highest AIC value and was thus the best model (Table 3.1). Sites that had more bare ground initially (which, according to Figure 3.2 were sites with wattle, no fire) showed a significant decrease in bare ground with kraaling, whereas sites with low bare ground showed an increase (Figure 3.3 a, d). Rainfall during and after kraaling marginally influenced effect size (Table 3.2), with more rainfall generally leading to a reduction in bare ground after kraaling (Figure 3.3 c). Adding slope or LSU days to the model did not increase its predictive power (Table 3.2, Figure 3.3 b, e).

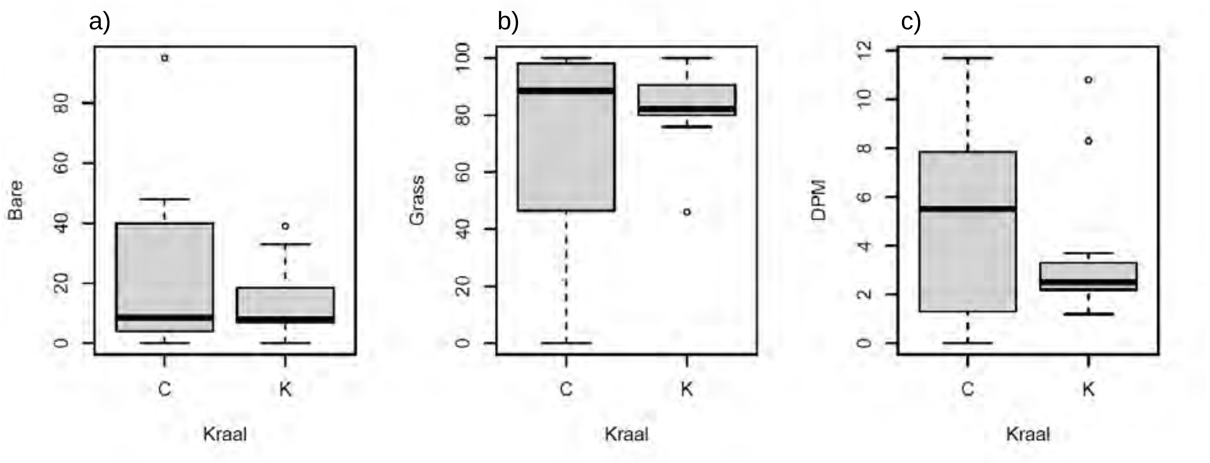

Figure 3.2. Effect of kraaling on a) per cent bare ground, b) per cent grass basal cover, and c) standing biomass (DPM)

Table 3.1. Results of best model selection to determine predictors of the effect size of kraaling on per cent bare ground. Variables are per cent bare ground at control sites, rainfall before and during kraaling, slope, and kraaling intensity (LSU days).

Model	Variables	R^2_{adj}	d.f.	P	AIC
lm 1	Bare (C)	0.81	10	$3.96*10^{-5}$	96.47
lm 2	Bare (C), Rainfall	0.86	9	$5.4*10^{-5}$	93.43
lm 3	Bare (C), Rainfall, Slope	0.89	8	$8.4*10^{-5}$	90.85
lm 4	Bare (C), Rainfall, Slope, LSU days	0.88	7	0.0005	92.64

Table 3.2. Comparison of successive models to determine whether the additional variable in each case leads to a significant difference in the predictive power of the model.

Effect of:	Models compared	ANOVA result	p
Rain	lm 1, lm 2	$F_{9.1} = 4.69$	0.058
Slope	lm2, lm 3	$F_{8.1} = 3.71$	0.09
LSU days	lm 3, lm 4	$F_{7.1} = 0.13$	0.73

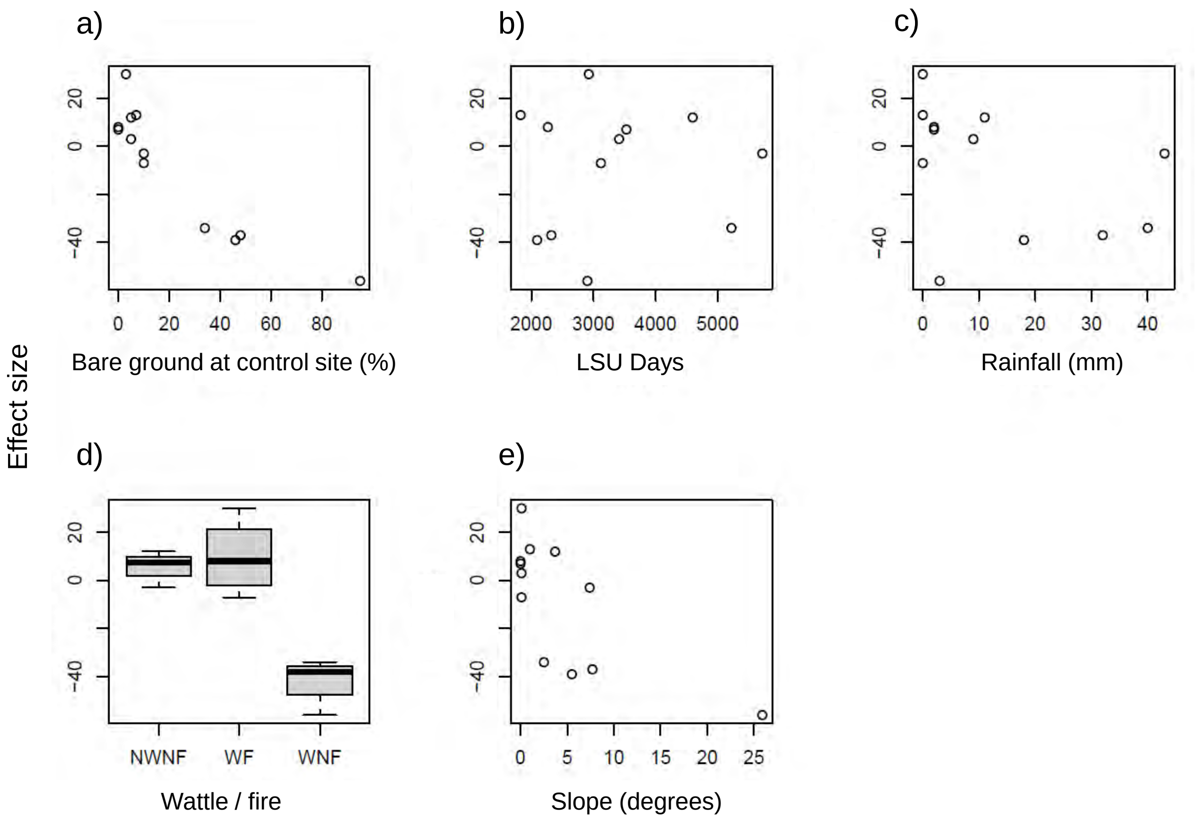

Figure 3.3. Effect size (per cent bare ground in kraal – per cent bare ground in control site) as a function of a) the per cent bare ground at the control site (reflecting the initial condition), b) kraaling intensity (LSU days), c) rainfall before and during kraaling, prior wattle/fire treatment, and slope.

In the case of grass cover, the findings were similar in that the model with grass cover in the control site as the only predictor variable was the best model with the highest AIC value (Table 3.3). Sites with low initial grass cover (those with wattle, no fire) experienced an increase in grass cover while those with high initial grass cover (> 70 %) saw grass cover remain the same or decrease with kraaling Figure 3.4 a, d). Slope and LSU days also contributed significantly to the predictive power of the model, while rainfall before and during kraaling had no significant effect (Table 3.4).

Table 3.3. Results of best model selection to determine predictors of the effect size of kraaling on per cent grass basal cover. Variables are per cent bare ground at control sites, rainfall before and during kraaling, slope, and kraaling intensity (LSU days).

Model	Grass kc	R2 adj	D,f	P	AIC
Lm1	Grass. C	0.83	10	2.22	98.46
Lm2	Grass. C, Slope	0.91	9	6.55	91.15
Lm3	Grass. C, Slope, LSU days	0.96	8	2.29	83.35
Lm4	Grass.C, Slope, LSU days, Rainfall	0.95	7	1.87	84.57

Table 3.4. Comparison of successive models to determine whether the additional variable in each case leads to a significant difference in the predictive power of the model.

Effect of:	Compare	Anova	P
Slope	Lm1, Lm2	F(9.1) = 10.55	0.01
LSU days	Lm2, Lm3	F(8.1) = 10.09	0.01
Rainfall	Lm3, Lm4	F(7.1) = 0.47	0.52

The effect of kraaling on standing biomass was also best predicted by initial condition, represented by the DPM value at the control site (Table 3.5). Sites with low initial standing biomass (wattle, no fire sites) saw increased standing biomass, while sites with high initial biomass saw a decrease (Figure 3.4 a, d). The effect was also significantly influenced by kraaling intensity (LSU days) and marginally by rainfall before and during kraaling, while slope had no effect (Table 3.6, Figure 3.4 b, c and e). Greater kraaling intensity led to a greater increase in standing biomass a year or more after kraaling, and more rainfall before and during kraaling also led to greater increase in standing biomass.

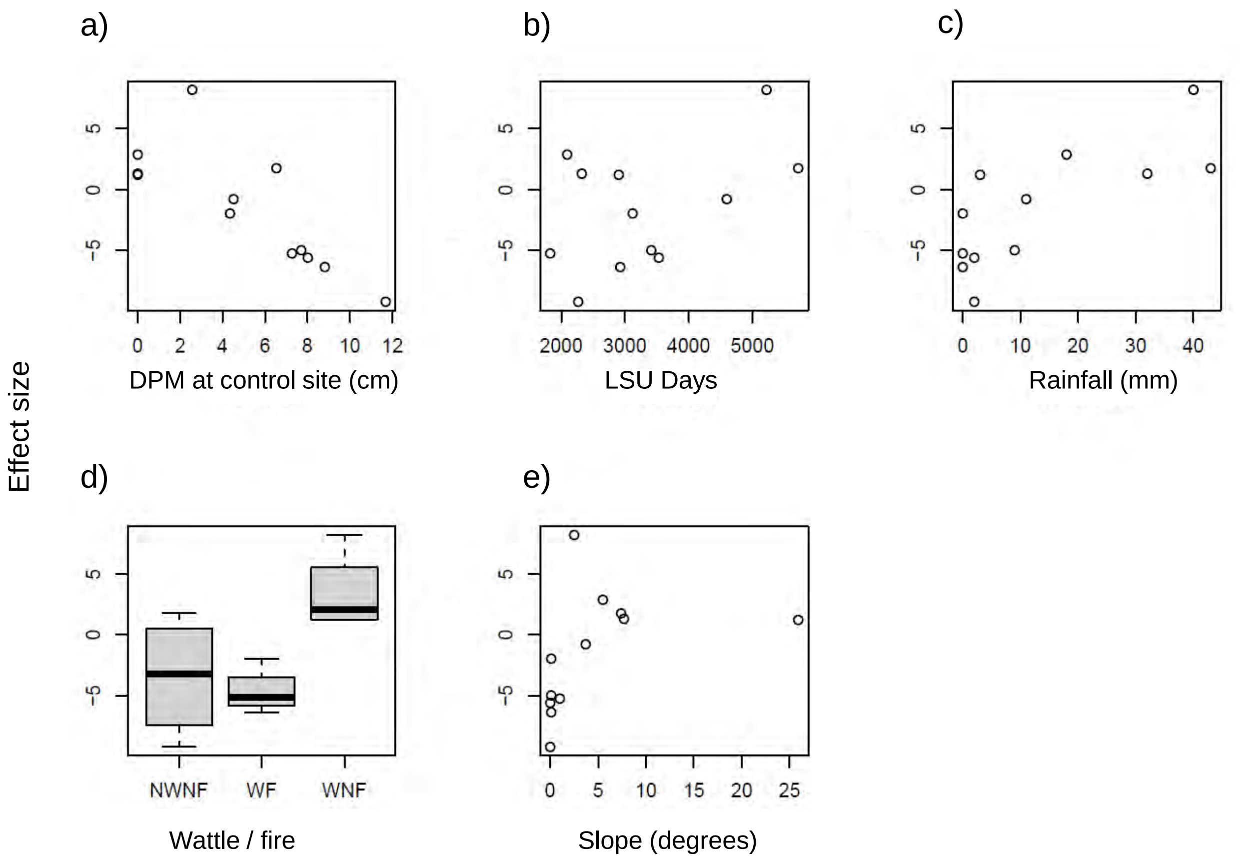

Figure 3.4. Effect size (per cent grass basal cover in kraal – grass basal cover in control site) as a function of a) the per cent grass basal cover at the control site (reflecting the initial condition), b) kraaling intensity (LSU days), c) rainfall before and during kraaling, prior wattle/fire treatment, and slope.

Table 3.5. Results of best model selection to determine predictors of the effect size of kraaling on standing herbaceous biomass (expressed in DMP units). Variables are per cent bare ground at control sites, rainfall before and during kraaling, slope, and kraaling intensity (LSU days).

Model	DPM kc	R2 adj	D,f	P	AIC
Lm1	DPM. C	0.61	10	0.0016	64.68
Lm2	DPM. C, LSU days	0.86	9	5.26	52.9
Lm3	DPM. C, LSU days, Rainfall	0.90	8	5.86	49.38
Lm4	DPM.C, LSU , Rainfall, Slope	0.90	7	0.0003	50.58

Table 3.6. Comparison of successive models to determine whether the additional variable in each case leads to a significant difference in the predictive power of the model.

Effect of:	Compare	Anova	P
LSU days	Lm1, Lm2	F(9.1) = 19.26	0.0017
Rainfall	Lm2, Lm3	F(8.1) = 4.73	0.06
Slope	Lm3, Lm4	F(7.1) = 0.48	0.51

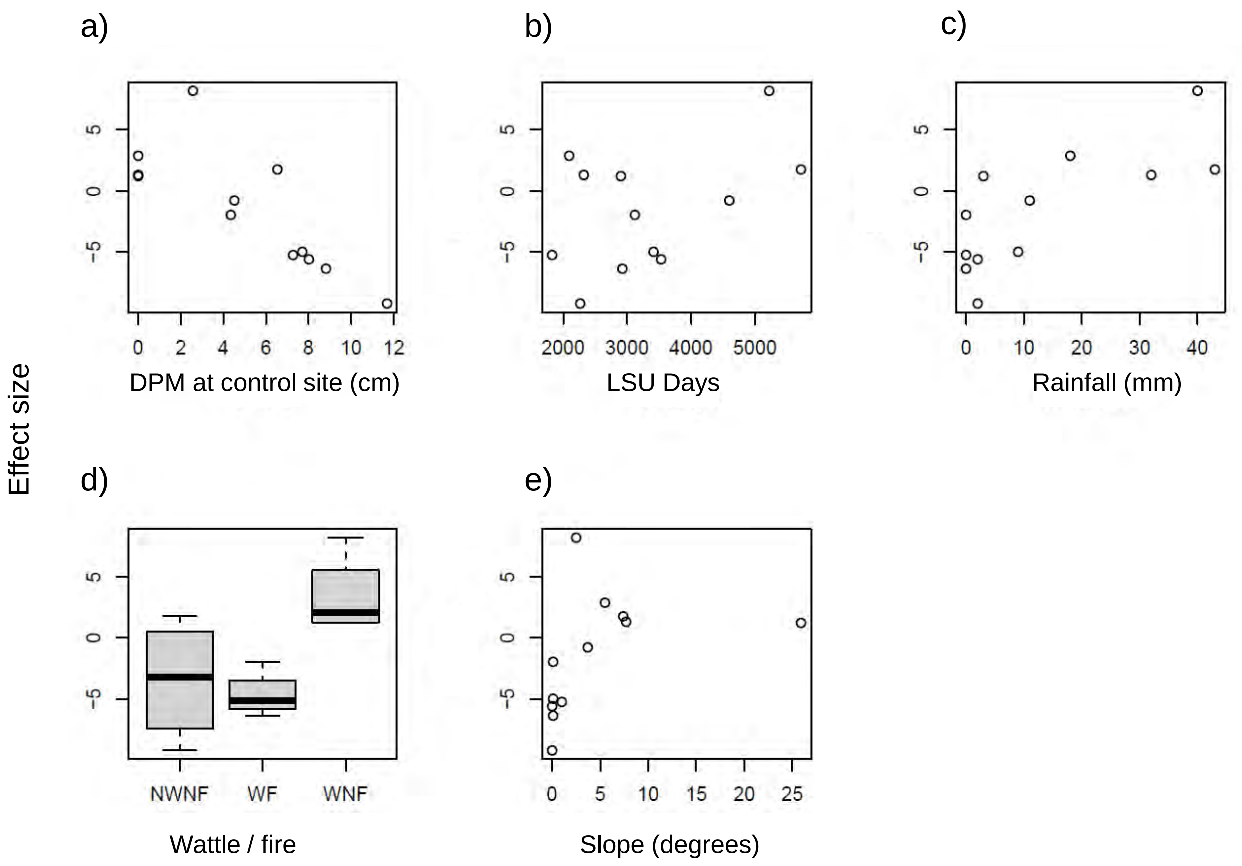

Figure 3.5. Effect size (standing biomass in kraal – standing biomass in control site) as a function of a) the standing biomass (expressed as DPM in cm) at the control site (reflecting the initial condition), b) kraaling intensity (LSU days), c) rainfall before and during kraaling, prior wattle/fire treatment, and slope.

Herbaceous plant composition

A two-way ANOSIM showed that there was a significant effect of kraaling (Global R = 0.26, $p < 0.05$) and Wattle/Fire treatment (Global R = 0.24, $p < 0.01$) on grass composition (Figure 3.7).

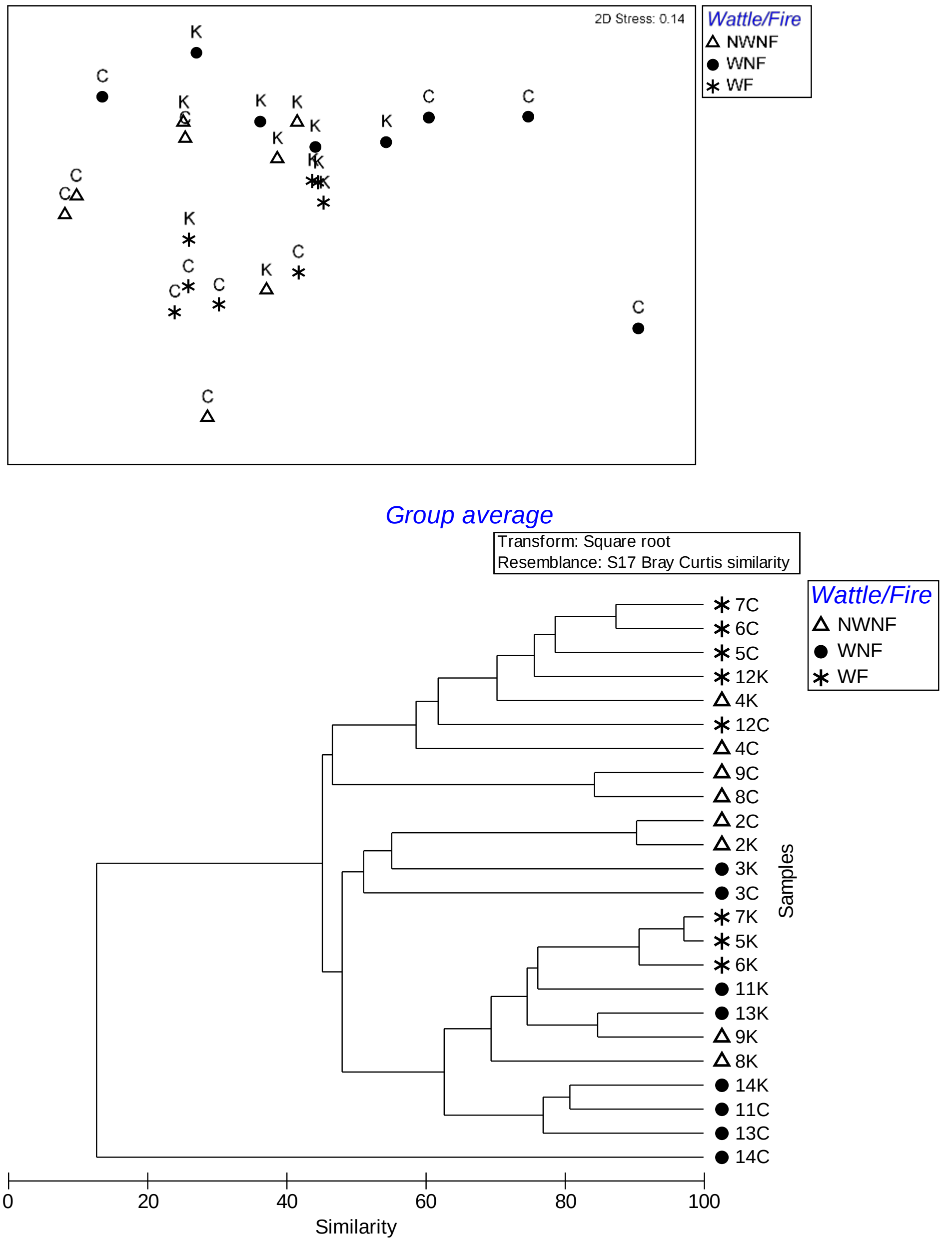

Figure 3.6. NMDS ordination plot (a) and cluster analysis dendrogram (b) to show similarities in vegetation between plots (Kraal = K, Control = C, No Wattle No Fire = NWNF, Wattle No Fire = WNF, Wattle Fire = WF and numbers = site numbers).

Kraaled plots were characterized by *Sporobolus africanus*, *Eragrostis plana*, *Pennisetum clandestinum* and forbs (Table 3.7). Control plots also had some of the same species contributing to within-group similarity but had some species that were not characteristic of the kraaled plots, such as *Aristida junciformis* and *Merxmuellera disticha*. Differences in the abundance of *Sporobolus africanus*, which was more abundant on kraal sites, contributed most to the dissimilarity between kraal and control sites (Table 3.8).

Table 3.7. Species contributing to within-treatment similarity in grass composition (from SIMPER analysis). For each treatment, the average abundance of each species in the treatment is shown, as is the percentage contribution the species makes to within-group similarity. Only species that cumulatively contribute to 90 % of within-treatment similarity are listed. The average within-group similarity is shown in brackets under each treatment.

Treatment	Species	Average abundance (%)	Contributing (%)	Cumulative contribution (%)
Kraal	*Sporobolus africanus*	25.7	36.2	36.2
(44.3 %)	*Eragrostis plana*	23.8	33.2	69.9
	Pennisetum clandestinum	15.7	17.4	87.2
	Forbs	7.9	7.7	94.9
Control	*Sporobolus africanus*	18.7	32.1	32.1
(61.5 %)	*Eragrostis plana*	15.8	24.9	56.9
	Aristida junciformis	9.4	13.4	70.3
	Forbs	4.8	9.0	79.3
	Merxmuellera disticha	5.1	6.3	85.6
	Pennisetum clandestinum	4.3	5.8	91.3

Unburned plots that had no wattle were characterized by *Eragrostis plana* and *Sporobolus africanus* (Table 3.9). Wattle plots that had burned were dominated by *Pennisetum clandestinum, Eragrostis plana,* and *Sporobolus africanus.* Burned wattle plots were characterized by *Eragrostis plana* and *Sporobolus africanus*. Key species contributed to dissimilarities are as follows *Sporobolus africanus* was the main specie that contributed to the dissimilarities, followed by *Eragrostis plana* (Table 3.10).

Table 3.8. Species contributing to dissimilarities between kraal and control plots. The mean dissimilarity between kraal and control sites was 52.4 %.

Species	Average abundance: kraal (%)	Average abundance: control (%)	Contributing (%)	Cumulative contribution (%)
Sporobolus africanus	25.7	15.8	18.2	18.2
Pennisetum clandestinum	15.7	4.3	17.1	35.2
Eragrostis plana	23.8	18.7	13.8	49.1
Forbs	7.9	4.8	9.17	58.2
Aristida junciformis	5.7	9.4	6.8	65.1
Marxmeullera disticha	1.3	5.1	6.1	71.1
Hetoropogon contortus	0.8	5.5	5.1	76.3

Table 3.9. Species contributing to similarities within wattle/fire treatment combinations: no wattle no fire (NWNF), wattle no fire (WNF), and wattle plus fire (WF)

Treatment	Species	Average abundance (%)	Contributing (%)	Cumulative contribution (%)
NWNF	*Eragrostis plana*	23.9	39.8	39.8
	Sporobolus africanus	23.6	38.9	78.7
	Heteropogon contortus	7.9	6.8	85.5
WNF	*Pennisetum clandestinum*	16.4	30.5	30.8
	Eragrostis plana	15.1	27.0	57.5
	Sporobolus africanus	15.3	25.4	82.9
	Forbs	7.6	17.1	100.0
WF	*Eragrostis plana*	24.6	31.8	31.8
	Sporobolus africanus	23.3	29.8	61.6
	Aristida junciformis	15.8	18.3	79.9
	Pennisetum clandestinum	9.6	8.3	88.2
	Merxmeullera disticha	6.4	5.7	94.0

Table 3.10. Key species contributing to the dissimilarities in herbaceous composition between NWNF (No Wattle No Fire) and WNF (Wattle No Fire) plots. Values are average abundance and values in brackets are between-group dissimilarities.

Treatment	Species	NWNF (%)	WNF (%)	Contrib. (%)	Cumulative contrib. (%)
NWNF vs	*Sporobolus. africanus*	23.6	15.3	16.6	16.6
WNF	*Eragrostis plana*	23.9	15.1	14.1	30.7
(65%)	*Pennisetum clandestinum*	3.4	16.4	13.4	44.1
	Heteropogon contortus	7.9	0.0	8.6	52.7
	Hyperrhenia tamba	7.4	0.0	8.4	62.0
	Forbs	3.5	7.6	7.7	68.8
NWNF vs	*Aristida junciformis*	6.9	15.8	17.6	17.6
WF	*Sporobolus africanus*	23.6	23.3	10.7	28.3
(45.5 %)	*Erograstis plana*	23.9	24.6	10.1	38.4
	Pennisetum clandestinum	3.9	9.6	9.2	47.5
	Merxmuellera disticha	3.1	6.4	8.6	56.5
	Hyperhenia. tamba	7.4	0.0	8.4	64.8
	Heteropogon contortus	7.9	1.6	8.1	72.9
WNF vs	*Aristida junciformis*	0.0	15.8	19.2	19.2
WF	*Sporobolus africanus*	15.3	23.3	17.7	36.9
(57.4 %)	*Eragrostis plana*	15.1	24.6	15.9	52.8
	Pennisetum clandestinum	16.4	9.6	13.4	66.1
	Forbs	7.6	7.9	9.8	76.0
	Merxmuellera. disticha	0.0	6.4	8.4	84.5

Discussion

The effect of short-duration overnight kraaling depended on initial condition of each kraal site. Areas that were degraded to start with (post-wattle cleared with little or no vegetation cover at all) had increased basal cover after kraaling. In contrast, kraal sites on intact veld had lower vegetation cover after kraaling took place. I conclude that short-duration overnight kraaling has the potential to be used as a tool for rehabilitating wattle cleared areas but should be avoided on veld with high basal cover**.** The effect of fire was taken into consideration even though the fire was not planned. I found that burning post-clearing of wattle resulted in lower basal cover and more percent bare ground compared to the wattle no fire treatment, regardless of kraaling.

Recently, Sibanda et al. (2016) conducted a study testing the impact of short-duration overnight kraaling in savanna in northern Zimbabwe. Sibanda's findings showed that kraaling improved vegetation cover, which is the similar findings to my study, but in my study vegetation only improved in severely degraded sites during kraaling. In contrast, I found that that kraaling had no significant effect on grass cover at sites that had relatively high initial grass cover (~70 % or more). An important finding of this study is that short-duration kraaling improves vegetation cover depending on the initial site condition, and this should be taken into consideration when selecting sites for overnight kraaling to avoid great damage to the grass standing biomass.

Standing grass biomass was very low in kraal sites where there was wattle and which were burned, while there was high standing grass biomass in unburned kraal sites that had wattle clearing and there was high standing grass biomass in control sites with no wattle clearing and no fire. Unburnt kraal sites with previous wattle clearing showed increased cover with kraaling, but the grass was very short. The grasses at kraal sites may have had higher nutrient content after the dung and urine inputs caused by kraaling and this attracted more grazers. Small stock was frequently observed grazing in previously kraaled sites. Standing grass biomass increased with time after kraaling took place but was lower in kraaled sites than the control sites see (Figure 3.4). This was predicted by initial condition of each kraal site. Porensky and Veblen (2005) reported similar results of lower standing biomass in long-term abandoned previous kraaled sites, and Huruba at el. (2018) reported low standing biomass in previously kraaled sites as compared to the surroundings.

Livestock numbers and the duration of kraaling had no effect on the percentage of bare ground and grass basal cover in the kraal sites. However, where there were high numbers of livestock during kraaling, standing biomass increased at the time of sampling. The effect appears to be driven by three sites where livestock numbers and duration of kraaling (total LSU days) were particularly high. The results might be caused by a greater fertilization effect. A negative effect of slope was observed at very steep slopes, where the percent grass cover was low in both kraal and control sites. Standing biomass was also negatively affected by the slope in control plots (low standing biomass) and high percent of bare ground in control plots as well as found by El-Hassanin et al. (1993).

Long-term overnight kraaling is common in many African pastoral systems and leads to substantial alteration of grass communities where one or two species are dominant (Young et al. 1995; Muchiru et al. 2009; Veblen 2012). In contrast, Sibanda et al. (2016) and McManus et al. (2018) reported a variety of grasses found in sites where short-duration overnight kraaling had occurred. This study also found a variety of grass species at kraal sites, although some species (*Aristida junciformis*, *Heteropogon contortus* and *Merxmuellera disticha*) were less abundant at the kraal sites. The dominating grass species in kraaled sites were *Sporobolus africanus, Eragrostis plana* and *Pennisetum clandestinum*. All the above-mentioned species are the increaser II (i.e. Species that increase under high grazing pressure) and are poorly palatable, although *Pennisetum clandestinum,* which is an exotic species, is palatable (Kwaza, 2013). The grass species found in kraaled sites were the reflection of the veld condition in the area. Control plots were dominated by *Aristida junciformis, Merxmuellera disticha*, and *Sporobolus africanus*. *Aristida junciformis and Merxmuellera distacha* are found mostly in disturbed soils, indicating that there has been overgrazing caused by poor rangeland management as well as run-away veld fires in the area (Edwards et al., 1979).

Conclusion

Short-duration overnight kraaling can improve vegetation cover depending on the initial condition. Kraaling proved to be a useful tool for rehabilitating degraded areas, especially after wattle clearing. Intact veld kraaled sites did not respond positively to kraaling and led to decreased basal cover. My recommendation would be an intact veld to be avoided and only kraal on severely degraded areas for rehabilitation purposes. Also, the slope of a site needs to be taken into considerations, to avoid causing more veld damage. Fire before and after kraaling needs to be taken into considerations, e.g. kraals should be avoided on areas that have had wattle infestation followed by fire, i.e. very high disturbance.

Chapter 4: Effect of kraaling on soil characteristics

Introduction

As discussed in previous chapters, short-duration and overnight kraaling involves livestock at high densities kraaled in a very small area for short period of time. The impact of short-duration kraaling on soil properties is variable, with varying reports in the literature (Chapter 1). Short-duration overnight kraaling resulted in increase of soil nutrients through dung and urine deposited into the soil (Young et al., 1995, Muchiru et al., 2009, Veblen, 2012). Also, it is claimed that short-duration kraaling increases soil water holding capacity as animal hoof action breaks up soil crusts and increases water infiltration (Savory, 1983). Da Silva et al. (2003) reported that animal hoof action resulted in soil compaction. High stocking rates may cause soil compaction, increasing soil bulk density and reducing soil pores (Maitima, 2009). An increase in soil bulk density may lead to soil erosion if plant roots cannot adequately penetrate the soil, leading to bare ground (Stonkovicova et al., 2008). Therefore, livestock hoof action can be associated with rangeland degradation.

In African countries, kraaling is used for different numerous reasons including protection purposes from predator and stock theft and preventing crops from being destroyed by livestock during ploughing seasons (Western and Dunne, 1979; Blackmore et al., 1990). In long-term kraaling, livestock are kraaled in the same location for months or even decades (Blackmore et al.1990). An increasing shift in livestock management due to increasing human population and industrial development has been documented Tiffen, 2006; Kangalane et al., 2008). Because of the growing human population, more land is now used for residences and industries for economic purposes, which reduces the land for livestock grazing and having livestock thus lead to abandoned kraal sites. Because of the amount of dung and urine deposition unto the soil, these abandoned kraal sites tend to be relatively richer in soil nutrients, that is the results of dung and urine accumulating into a relatively small surface area of soil (Veblen, 2012, Augustine, 2003; Augustine et al., 2011). The abandoned kraal sites are relatively high in plant diversity as compared to surroundings (Blackmore et al., 1990, Veblen et al., 2012, Muchuri et al., 2009).

Considering the lack of consensus on the effects of different kraaling practices on soils, I investigated the response of soil characteristics to short-duration overnight kraaling. This study compares kraaling on intact veld and severely degraded (previous wattle cleared) and examines whether the effect is the same regardless of the initial condition. It is not clear if short-term kraals provide sufficient dung and urine input to create persistent nutrient hotspots. The aim of this chapter is to examine the impact of short-duration overnight kraaling on soil physical (texture, bulk density, infiltration) and chemical (soil organic matter, nutrients) properties. This was done by comparing paired kraal and control sites at twelve locations (see Chapter 2) and examining how the effect of kraaling on soil is influenced by the intensity and duration of kraaling (LSU days), previous wattle infestation and clearing, slope angle, and rainfall immediately before and during kraaling, and fire.

I predicted that nutrients and soil organic matter (SOM) would increase in the kraal sites because of the dung and urine deposited by the livestock during kraaling, and that these inputs would be measurable as increased nutrients in the soil, with uncertain effects on soil physical properties.

I tested the following hypotheses:

1. Kraaling would increase soil nutrients through dung and urine dropped and incorporated into the soil through hoof action/animal impact. This effect would be greater with greater animal density (LSU days).
2. Initial condition (bare ground, which is straightforward to measure) influences the effect of kraaling on soil nutrients and SOM.
3. Kraaling will increase SOM when livestock hoof action incorporates live and dead leaf (litter) material into the soil. Further, I expect that additional organic matter will be brought into the kraal sites via livestock dung.
4. Kraaling will decrease soil bulk density, as livestock hoof action would loosen the soil resulting in less soil compaction. This effect is likely to be altered by whether soils were wet or dry during kraaling.

Unplanned fires took place in two consecutive years (2014 and 2015), and at least four kraal sites were burned since kraaling. While the fire was not part of the experimental design, its effects were also examined.

Methods

The study area and experimental design are described in Chapter 2. Soil samples were taken inside kraals and in control sites at the same time as vegetation sampling (March 2016).

Soil sampling and analyses

Five soil samples were collected at each kraal and control site to make a total of 120 samples using a soil auger (0 to 20 cm depth, 10 cm Ø) at site locations (Chapter 2, Table 2.1). Soil samples were air-dried, sieved to 2-mm and subsequently stored in sealed plastic bags prior to laboratory analysis. Soil pH (1 M KCl) was determined using a pH meter. Soil samples for elemental analysis were ground with a mortar and pestle prior to X-Ray Fluorescence (XRF) analysis to determine total elemental concentrations in soil samples (SPECTRO XEPOS XRF analyzer, SPECTRO, AMATEK materials analysis division, Kleve, Germany). Soil organic matter (SOM) was measured as loss on ignition of a 5 g subsamples of the 2 mm air-dried soil, and the weight losses at 105°C, 550°C and 1000°C were recorded to estimate soil residual humidity, organic matter, and carbonates and residual water, respectively (Heiri et al., 2001). Soil total carbon was measured using the Walkley-Black method (Nelson and Sommers 1982). Soil total nitrogen was measured by combustion (Leco FP528 Nitrogen Analyzer).

To measure soil infiltration rate, five measurements were taken per each kraal and control site a mini disc infiltrometer was used in the field (Meter Group Inc, USA). The suction rate was set to 3 for all plots since soil types were similar. The infiltrometer was filled with water and placed flat on the soil surface after removing litter and other organic matter. Infiltration was calculated based on the equations of Zhang (1997) using the average volume of water lost to the soil every 60 s (n = 5 per kraal and control site).To measure soil bulk density in the 0 to 10-cm soil layer, a steel ring (volume 79.48 cm^3) was placed on the soil after removing organic matter on as flat a surface as possible and gently hammered into the soil with a block of wood placed over the ring. Five samples were collected per each kraal and control site to make a total of 120 samples. The soil was then excavated around the ring without disturbing the soil inside it to ensure that a precise volume was removed for each sample. Any plants or roots were cut off at the ring surface with scissors. The soil was emptied into plastic bags and sealed. Soil samples were weighed on the day of collection, large stones removed, volume adjusted and then oven-dried at 105°C to constant weight and re-weighed. Bulk density ($g\ cm^{-3}$, fine fraction) was calculated as dry soil weight (g)/adjusted soil volume (cm^3) according to McKenzie et al., (2014).

Data analyses

Paired t-tests (assuming unequal variance) were performed to determine effect of kraaling on soil nutrients (N, P, K and S), and soil organic matter, infiltration, and bulk density by comparing the paired kraal and control plots at each site. To determine what factors influenced the effect size (i.e., difference in each response variable between each paired kraal and control site) I used best model selection using the "regsubsets" function in the package "leaps", selecting the best models based on the Akaike Information Criterion (AIC; Akaike, 1983; Burnham and Anderson, 2002). I performed best subsets model selection starting with a model that included four predictors: the initial condition (per cent grass basal cover in the control site), rainfall before and during kraaling, slope, and LSUdays. While the initial condition wuld ideally be expressed as the soil variable, for practical (management) purposes bare ground is something that can be readily assessed, and corresponds to the level of degradation.

I was also interested in the effect of wattle/fire on effect size, but it was found to be strongly related to initial basal cover (see Figure 3.1) and was thus excluded from the analysis to avoid effects of collinearity. I then ran the linear model for each best model using the "lm" function and recorded the adjusted R^2, p and AIC value for each of the best models. Data was analyzed using R (R Core Team, 2022). To determine whether individual predictor variables contributed significantly to the model, I compared models with and without the factor using the "anova" function in R (see Winter, 2013).

Results

Effect of kraaling

Kraaling had no significant effect on most soil variables, except for soil P (t = -2.3787, df = 11, p-value = 0.037), soil S (t = -3.4422, df = 11, p-value = 0.0055) and soil K (t = -2.2067, df = 11, p-value = 0.0495; Figure 4.1). While highly variable, the paired t-test identified consistently higher values at the kraaled sites. Initial bare ground affected the extent to which kraaling elevates soil P, with plots with more bare ground initially showing greater increase in soil P (Tables 4.1, 4.2, Figure 4.2). None of the variables significantly affected the magnitude of the kraaling effect on soil K or soil S.

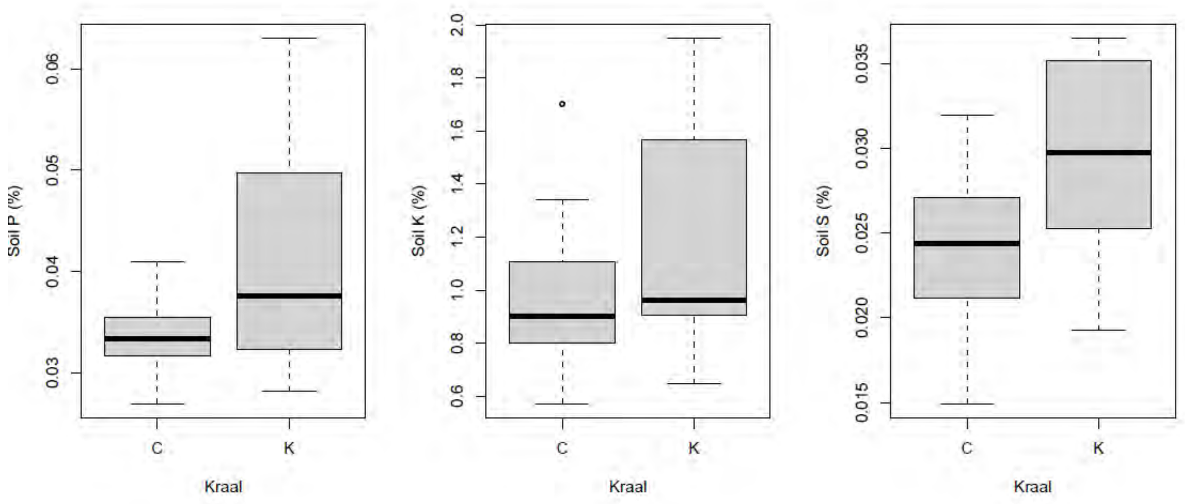

Figure 4.1. Effect of kraaling on soil P, soil K and soil S.

Table 4.1. Results of best model selection to determine predictors of the effect size of kraaling on per cent Soil P. Variables are per cent bare ground at control sites, kraaling intensity (LSU days), slope and during kraaling.

Model	Variables	R^2_{adj}	df	p	AIC
lm1	Bare	0.309	10	0.035	-75.784
lm2	Bare, LSU days	0.360	9	0.054	-75.971
lm3	Bare, LSU days, Slope	0.382	8	0.080	-75.8016
lm4	Bare, LSU days, Slope, Rainfall	0.419	7	0.099	-76.14284

Table 4.2. Comparison of successive models to determine whether the additional variable in each case leads to a significant difference in the predictive power of the model.

Effect of:	Models	anova	p
LSU days	lm1 vs lm2	$F_{(9,1)} = 1.80$	0.21
Slope	lm2 vs lm3	$F_{(8,1)} = 1.32$	0.28
Rainfall	lm3 vs lm4	$F_{(7,1)} = 1.51$	0.29

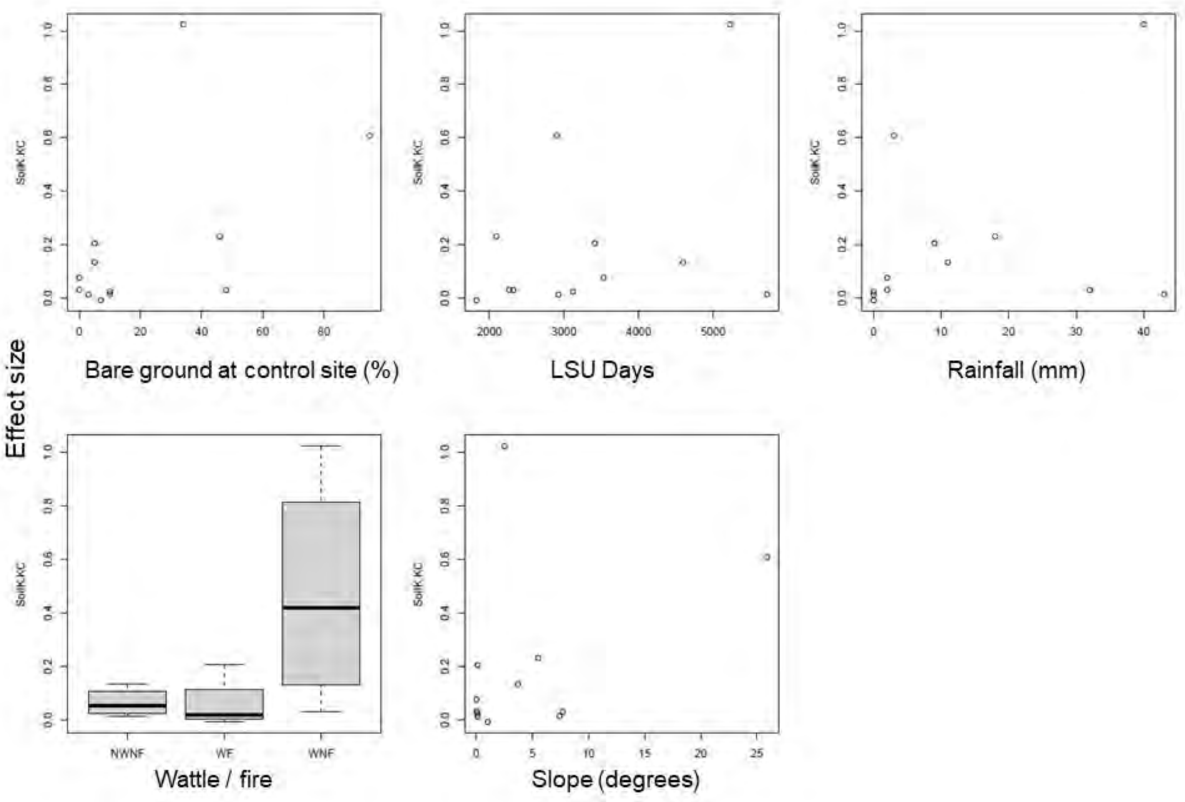

Figure 4.2. Effect size (per cent soil P in kraal – soil P in control site) as a function of a) the per cent bare ground at the control site (reflecting the initial condition), b) kraaling intensity (LSU days), c) rainfall before and during kraaling, prior wattle/fire treatment, and slope.

Discussion

My study investigated the response of soil characteristics to short-duration (7-24 days) overnight kraaling. The results showed the positive effect of kraaling on soil P, K and S. Initially bare sites had a greater increase in P with kraaling, but otherwise the effect was not related to kraaling intensity, rainfall or slope. Contrary to my predictions, short-duration kraaling had little effect on soils, possibly since it was once-off, and of a short duration. Nitrogen may have been elevated initially from urine and faeces but it is highly mobile (Augustine & McNaughton 2006). Phosphorus, which is more stable in soils, was significantly elevated in kraaled plots, with a greater effect on sites that were initially more bare. Soil S was also significantly increased by kraaling, but the effect was not significantly increased by any of the environmental variables investigated.

The results suggest that kraaling, which increased herbaceous cover in initially bare sites, also had a positive effect on soil P and K at initially bare sites. The effects of kraaling on soil N, SOM, infiltration and bulk density were inconclusive. Long-term effects of kraaling on these variables (e.g. Porensky and Veblen 2015) suggest that kraaling could increase soil N and SOM. The effect on infiltration and bulk density and whether it responds to soil texture and whether soils are wet or dry during kraaling should be examined with further studies.

Other studies conducted examining the effect of short-duration kraaling results showed the increase of certain soil nutrients in kraal sites (Sibanda et al., 2016, Huruba et al., 2018). This is also in agreement with number of studies conducted in East Africa, where abandoned long-term kraal sites became nutrients hotspots. The effect of kraaling on soil N and SOM were not significant, likely because organic forms of Nitrogen may have been elevated initially from urine and faeces but it is highly mobile (Augustine & McNaughton 2006) as compared to soil P which is more stable in soils.

Short-duration overnight kraaling effects on P depended on site initial condition, with sites that had lower basal cover and more bare ground initially showing greater increase. This suggests that kraaling may be a way to enhance nutrients in bare sites and together with the results from Chapter 3 this suggests that kraaling should focus on sites with low basal cover.

Bulk density and infiltration rate did not respond consistently to kraaling. When kraaling took place on wet soils, the effect on infiltration was neutral, but at three sites, kraaling on dry soils reduced infiltration (data not shown). This is an important area that warrants further research to inform judicious use of short duration kraaling in mesic grasslands. An increase of soil P was observed in sites where there was wattle clearing before kraaling took place and that were not affected by fire (Figure 4.2). Since the fires were not a planned aspect of the research, resulting in an unbalanced design, further research on the interactions between fire and wattle clearing on soil properties is needed.

Conclusion

Short-duration overnight duration kraaling had a positive effect on soil P, K and S, but the effect was highly variable and most pronounced on initially bare sites. My recommendations is to only to kraal on previous cleared sites for restoration purposes, and to use kraaling during the wet season. My recommendation for that would be to harvest and disperse indigenous grass seeds and brush/stone pack to control soil erosion if there is any. Other important management practices such as prescribed fire and seeding can be useful to improve degraded rangelands and to maintain critical soil functions. More research with greater replication and a fully balanced research design would be very valuable to provide recommendations with more confidence.

Chapter 5: General discussion

My study was the first to examine the effect of short-duration overnight kraaling (7-24 days) in the mesic montane grasslands. My main findings were that short-duration overnight kraaling depended on the initial condition of the site. Kraaling increased vegetation cover, but this happened only if the site was initially bare. Studies on short-duration overnight kraaling in different environments with high wildlife history and diversity (Porensky and Veblen 2015, Sibanda et al., 2016, Huruba et al., 2018) found that short-duration overnight kraaling increased soil nutrients, vegetation cover and palatability. My study results showed that the effect of short-duration overnight kraaling were more variable, and under certain conditions could potentially damage intact veld. Specifically, kraaling led to decrease in basal cover in sites that had more than 50% vegetation cover before kraaling took place, which should be avoided as it can lead to degradation. Short-duration overnight kraaling did not affect grass species composition, which at this heavily grazed site was already dominated by grazing-resistant species such as *Sporobolus africanus* and *Eragrostis plana*.

Short-duration overnight kraaling can thus be used as a tool to rehabilitate degraded mesic montane grasslands, but should focus on post-wattle cleared sites, bare soils and possible croplands that are prone to erosion due to loss of vegetation cover and topsoil (Vetter, 2007). The finding that infiltration increased when kraaling took place when soils were wet but decreased on dry soils suggests that kraaling may be a better choice in the wet season and may be better avoided in the dry season.

The study was conducted under realistic management conditions to test not only the biophysical effects of kraaling but also its viability in a real-world context. This proved to be a challenge, as there was a severe drought between 2014 and 2016 in Matatiele. Livestock farmers were under a lot of stress and suffered as their livestock succumbed to drought. At the same time, funding for the Ecorangers who did the herding, came to an end at a very crucial stage as I was about to start data collection for my study. For these reasons, farmers became unwilling to continue the kraaling trial, as their focus shifted to the crisis brought on by the drought. Security was also a problem as farmers were unable to continue paying the Ecorangers by themselves at a time when they had to purchase supplementary livestock feed. As a result, kraaling took place on fewer sites than planned, and representing less of the variability between sites that I had planned.

The project was community-based, and its continuation depended on the willingness of communal livestock farmers to participate. Some of the livestock owners pulled out of the agreement along the way. We had over 200 animals to begin with and the number decreased over time. This was caused by community conflicts and politics; some people were not happy that their livestock was kraaled with certain other individuals' livestock, claiming that their traditional medicines used in livestock for production will not work well. Others were associated with stock theft, so people were not comfortable working with them. Thus livestock numbers changed from time to time depending on the livestock farmer's willingness to participate.

Matatiele is situated on the international border with Lesotho, which makes it difficult for veld fires to be controlled. Most of the time, fires start on the Lesotho side and cross over to South Africa, all the way down to Ongeluksnek Nature Reserve then the surrounding communities. Our sites were burned two consecutive years by those run-away veld fires after kraaling took place, which led unbalanced design whereby we had sites with wattle fire we never initially planned for (about 4 sites).

Despite these substantial challenges, some very clear results emerged. Short-duration kraaling can improve vegetation cover, but this depends on initial site condition, as well as ecological context. Kraaling shows promise as a restoration tool to increase basal cover in degraded native grassland, for example, post-wattle clearing, but should be avoided on steep slopes or intact grassland. Increase in soil nutrients due to dung and urine dropped by the livestock to the soil, may increase soil fertility in croplands. Further experiments in different areas, studies that include different initial conditions (such as wet vs dry soils) and intensity of kraaling (density and duration) would be very useful to further evaluate the potential utility of kraaling as a low-input restoration method, as well as a method to fertilize croplands prior to planting, or to rehabilitate those areas to grassland. Long term monitoring would be required to determine the long-term effects of livestock short-duration overnight kraaling on both post wattle cleared and intact veld.

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