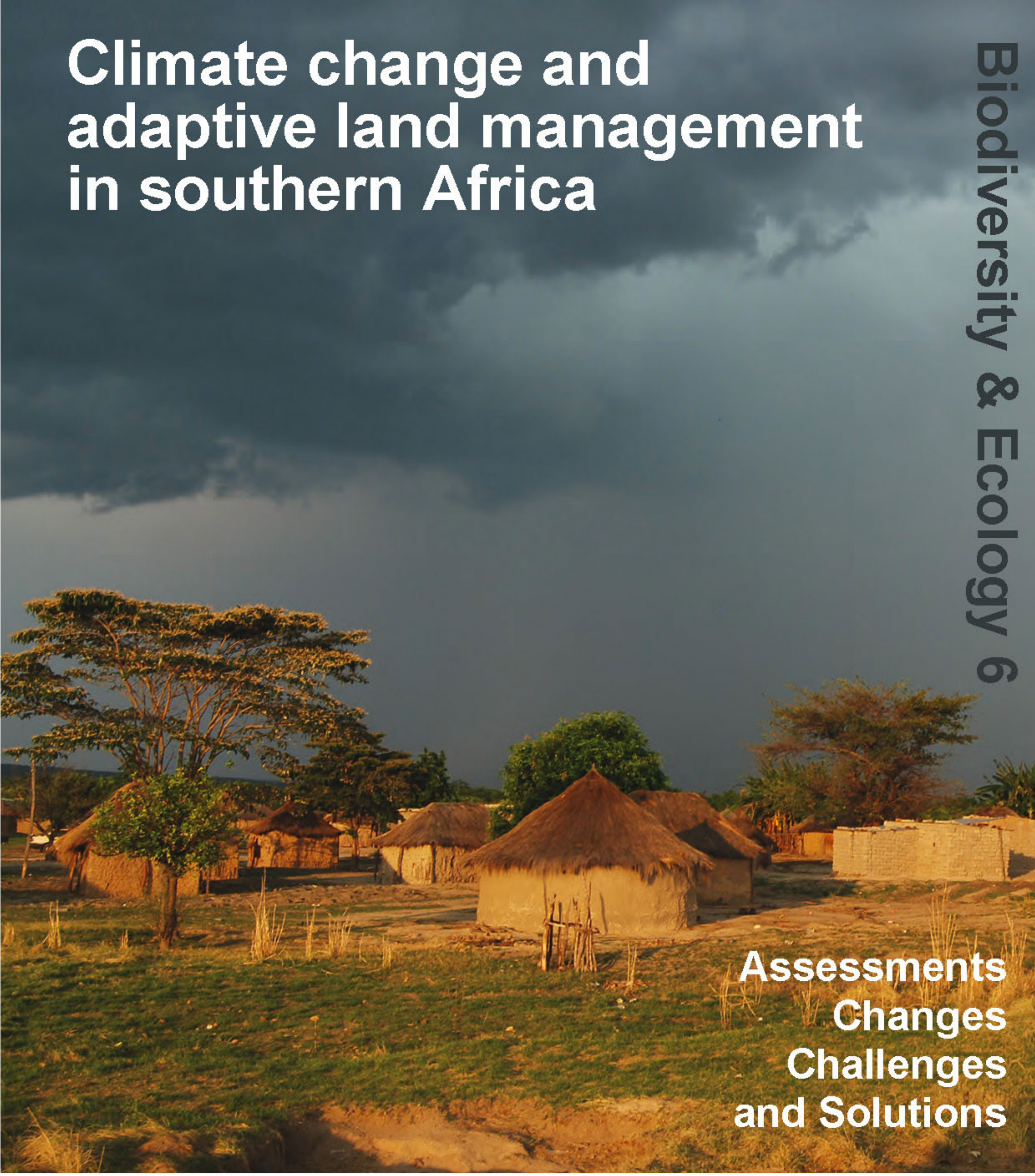

Climate change and adaptive land management in southern Africa

Biodiversity & Ecology 6

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Changes
Challenges
and Solutions

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Climate change and adaptive land management in southern Africa

Assessments, changes, challenges, and solutions

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Rangelands

Rangeland monitoring and assessment: a review

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Abstract: Rangelands provide vast landscapes for grazing and foraging for livestock and wildlife. Services of rangelands are diverse and generally provide food for millions of the world's population, especially the rural and sometimes poor communities. Despite the importance of rangelands, they are also threatened by global change including land use and climate change. Land-use change is exacerbated by the ever-increasing human population, which is projected to reach over 9 billion in 2050. Meanwhile, climate change in the form of erratic rainfall and increasing temperatures, favours increasing woody cover leading to bush encroachment and recurrent droughts. The objective of this overview article is to provide a synopsis of the key areas covered by the subsequent articles, and drawing upon a wider body of literature. Key issues highlighted in this chapter are the definition of rangeland landscapes, their role and threats such as bush encroachment, land degradation (e.g. soil erosion), indicators for monitoring (i.e. quality of grass, trees, and legumes), and assessment of rangelands using in situ and remote sensing techniques. The threats of soil erosion, fire, and bush encroachment are discussed in relation to the functioning of these landscapes for wildlife and livestock. However, in situ and remote sensing techniques provide the opportunity to assess the status or condition, quality, and extent of rangeland environments.

Resumo: As pastagens oferecem vastas paisagens para o pastoreio e procura de alimento ao gado e a animais selvagens. Os serviços das pastagens são diversos e geralmente fornecem alimento a milhões de pessoas no mundo, em especial nas comunidades rurais e, por vezes, pobres. Apesar da importância das pastagens, estas estão também ameaçadas pelas alterações globais, incluindo o uso das terras e as alterações climáticas. A alteração do uso das terras é exacerbada pelo constante crescimento da população humana, a qual deverá atingir os 9 mil milhões em 2050. Entretanto, as alterações climáticas geram precipitação irregular e o aumento da temperatura, os quais favorecem o aumento da cobertura lenhosa, levando ao *bush encroachment* e a secas recorrentes. O objectivo deste artigo de revisão é fornecer uma sinopse das áreas chave que serão abordadas em artigos subsequentes. Para atingir este objectivo, foi realizada uma revisão bibliográfica, incluindo diversos capítulos deste livro. As questões-chave destacadas neste capítulo são a definição da paisagem de pastagem, o seu papel e suas ameaças, tais como a densificação de plantas lenhosas e degradação da terra (e.x.: erosão do solo), indicadores para monitorização, i.e., qualidade das gramíneas, árvores e legumes, e avaliação das pastagens recorrendo ao uso de técnicas *in situ* e de detecção remota. As ameaças em destaque identificadas incluem a erosão do solo, o fogo e a densificação de plantas lenhosas, as quais são alguns dos problemas que afectam paisagens críticas para os animais selvagens e o gado. No entanto, técnicas *in situ* e de detecção remota oferecem a oportunidade de avaliar o estado ou a condição, a qualidade e a extensão dos ambientes de pastagem.

Introduction

Rangelands are defined as landscapes that provide grazing and foraging for livestock and wildlife, where the natural vegetation consists of native grasses, grass-like plants, flowering plants, and shrubs, as well as introduced plant species that are naturalised (Craggs, 2017). Rangelands cover about 51% of the world's land surface (Child & Frasler, 1992) and provide food for millions of the world's population. Rangeland services include the provision of grazing resources for commercial and subsistence livestock or game farming (Naidoo et al., 2013), harvesting of wild products, carbon sequestration, pollination services, and freshwater sources. Millions of people rely on rangelands for their daily sustenance and many are from rural and sometimes poor communities.

In the Eocene epoch (34 to 56 million years ago), the colonisation of new habitats coupled with the exploitation of new, diverse food resources led to the rapid diversification of large herbivores, especially ruminants (Prothero & Foss, 2007). Vestiges of this high diversity of indigenous herbivores are still visible in Africa, especially in the open grassy biomes (Turpie & Crowe, 1994), and are related to the high availability and diversity of food plants. In terms of their abundance, there are an estimated 75 million wild ruminants and 3.5 billion domesticated ruminants in the world (Hackmann & Spain, 2010). In 2014, annual human meat consumption amounted to 82 million tons of ruminant meat (excluding bush meat and meat from game and camelids). This corresponds to 1,684 million individual cattle and buffalo and 2,165 million individual sheep and goats (www.fao.org). One problem with having so many animals on the land is that they have a negative impact on the environment and contribute significantly to the production of greenhouse gases (Steinfeld et al., 2006).

Rapid growth in the human population has significant implications for rangeland utilisation and management. The population in 2050 is projected to be more than 9 billion and most of the increase is estimated to be in developing countries, with more than half in Africa (UNPD, 2015). The population of sub-Saharan Africa is growing at an annual rate of 2.6%. The rapid increase in the human population is placing new demands on rangelands to provide food and shelter to meet its needs, as a result often leading to unprecedented changes in land cover and land use (Thornton, 2010; FAO, 2010). Overexploitation of rangelands leads to land degradation and threatens the quality and productivity of these ecosystems (FAO 2010). Hahn et al. (2005) defined land degradation as the reduction or loss of biological or economic productivity as a consequence of inappropriate land-use practices.

Other global change pressures, including rising temperatures and the increased occurrence of extreme events such as drought and erratic rainfall patterns, are also impacting on the functioning of rangeland systems (Palmer & Bennett, 2013). Drought, bush encroachment, and invasion by alien species are increasing threats on the African continent and hence on rangeland productivity. Increasing anthropogenic CO_2 in the atmosphere is having a fertilisation effect on C3 trees, thereby fuelling the phenomenon of bush or woody encroachment. Furthermore, increasing warming (projected to be 3–5 °C by the end of the century) will favour C4 grasses in place of C3 grasses (Scholes & Archer, 1997; Bond et al., 2003; Palmer, 2003). Global change impacts could be even severer for arid and semi-arid rangelands in southern Africa.

Threats faced by rangeland environments

Large areas of Africa are covered by savanna and grassland systems whose productivity is dependent mainly on the seasonality of climatic variables (rainfall and temperature). African savannas are both utilised as habitats for wildlife (e.g. the "big five") and for livestock and food crop production, thus supporting the livelihoods of millions of people living in these systems. However, rapid changes in land use and anthropogenic climatic changes are negatively impacting on wildlife numbers and the sustainability of rangelands (Lehmann et al., 2009). Harris et al. (2014) investigated the resilience of vegetation cover in relation to disturbance and found different results for different biomes in southern Africa. For some areas (e.g. the western and northern savanna region of Namibia and the eastern part of South Africa), the results imply strong potential impacts of anthropogenic or climatic change on vegetation, which will certainly lead to changes in food availability and also biodiversity. In general, threats to rangeland, including bush encroachment, habitat fragmentation, overgrazing, soil erosion, and human-induced fires, are the major causes of land degradation in many African rangelands (Murphy et al., 2016 and references therein).

Key indicators for the extent of land degradation are the types of soil erosion that might be found in an area. For example, there is evidence that gully systems are cutting into urban environments in Angola (see SASSCAL task 171) or in agricultural fields in the Swartland region of South Africa (Olivier et al., 2018), while in Namibia, critical landscapes for livestock and wildlife have been lost as a result of erosion (Pringle et al., 2011). Key research related to this has focused on the efficacy of restoration from both ecological and socio-economic perspectives (Zimmerman et al., 2018).

There has also been a lengthy debate about the differences in water consumption of trees and grasses in savanna ecosystems. Discussions have centred on the degree of competition for water between trees and grasses under different environmental settings, as well as the consequences of bush encroachment on the water balance and especially groundwater recharge (e.g. Scholes & Archer, 1997; Scanlon et al., 2006; O'Connor et al., 2014). For southern African rangelands, with their widespread problem of bush encroachment, robust information is missing about the interaction of bushes and trees with the lower layer of grasses, herbs, and dwarf shrubs, and how this might affect the dynamics of water in plants and in the soil (Christian, 2010). Thus, SASSCAL studied these interactions with different methodological approaches. Using field monitoring techniques, measurements were taken of the soil water dynamics of bush-encroached areas as well as de-bushed areas since 2007 on a commercial farm in the central Namibian thorn-bush savanna and, since 2014, on two other farms (Groengroeft et al., 2018).

Rangelands are thought to have been highly productive before modern humans disrupted their efficient water and nutrient cycles. The appropriate management of herbivores, to provide sufficient rest for grazed grasses to regain their vigour, can go a long way towards recovering water and nutrient cycles over extensive areas of rangeland. Intensive management can also be applied on a few small areas, such as rain water harvesting measures to enhance infiltration into the ground and thereby support the growth of natural grasses and planted trees. This was attempted at three sites by digging contour ditches, and by constructing ponding banks at one of those sites. Earth-moving machinery was used at the 30 ha rural site, while contour ditches were manually dug with pick and spade at the two smaller urban sites. Diverse tree species were planted below contour ditches for different functions and products, including chop-and-drop mulching, tall protective canopies, and edible leaves, fruits and pods (Zimmerman et al., 2018).

Drought as a consequence of climate change causes devastating problems for rangelands and livestock production systems in Africa. The occurrence of drought limits the carrying capacity of rangelands and the number of animals that can be kept on them. Livestock mortality is often relatively high during drought periods. This has important implications for the livelihoods of local communities because of the loss of employment, production, and income (Tambo et al. 2017). Careful management is necessary to balance human demands and landscape capacities to avoid overexploitation. An assessment of rangeland condition, through the identification of key indicators associated with vegetation, soil, and water, is necessary in order to inform decision-makers on the planning and management of rangelands.

What are the key indicators for assessing rangelands?

Vegetation composition is the overarching key factor that determines rangeland quality. The presence of palatable food plants and the abundance of unpalatable plant species determine the carrying capacity of a landscape for all herbivores. The composition of the vegetation is mainly driven by the existing soil characteristics (geology), water availability, geographical features, and prevailing climatic conditions. Vegetation composition, and consequently food plant availability, is affected by changes in temperature and/or rainfall. In order to describe the overall quality of a given landscape, different indicators are used. For example, biomass is used as an indicator of productivity, while digestibility or biochemical concentrations (e.g. protein, nitrogen, lignin, fibre) are used as indices of plant quality. However, other factors, such as the presence of chemical and mechanical defences in plants (e.g. toxic food compounds or thorns and hairs), are often not included in these assessments and might lead to misunderstanding of the productivity and quality of a given landscape. The parameters describing the overall quality of a given rangeland are also not in a steady state and will always change with land use and climate. A description of these dynamic interactions is provided in the following sections.

Influence of large herbivores on vegetation

Since the evolution of large herbivores, terrestrial ecosystems have been highly influenced in shape and function by browsing and grazing animals, which modify primary production, nutrient cycles, soil properties, and fire regimes, with subsequent impacts on other biota (McNaughton et al., 1988; Pastor & Naiman, 1992; Olff & Ritchie, 1998; Wardle et al., 2004; Archibald et al., 2005). The distribution of large herbivores determines the vegetation composition of terrestrial ecosystems due to, for example, feeding damage (Rooney, 2001; Bobrowski et al., 2015) and trampling (Van der Wal et al., 2001; Cumming & Cumming, 2003), but also seed dispersal (Gill & Beardall, 2001; Hülber et al., 2005; Benthien et al., 2016). Additionally, plant chemical composition, morphology, and fertility change in response to feeding damage (Stolter et al., 2005; Stolter, 2008). The key factor behind this ecosystem modification is simply the food selection patterns of animals.

Biodiversity, chemical diversity, resource availability, and feeding decisions of large herbivores

In terms of plant biodiversity in Africa, most people will immediately think of the closed canopy tropical forests. Although the tropical grassy biomes, including savannas, are lower in plant diversity than the tropical forests (Kier et al., 2005; Barthlott et al., 2007; Harris et al., 2014), they also comprise a high number of species (Murphy et al., 2016). Depending on annual rainfall, species richness of vascular plants reported from the observatories of SASSCAL (http://www.sasscalobservationnet.org/; Jürgens et al., 2018) may be as high as 45.1 species per ha for the woodland savanna, 57.9 for thorn-bush savanna, 26.4 for dwarf shrub savanna, and 61.1 for the succulent karoo (in areas with high annual rainfall). Due to their long co-existence with wild, free-ranging herbivores and the natural, frequent occurrence of fire, these ecosystems are to some extent adapted to both forms of disturbance (Ratnam et al., 2011). They are also characterised by a large number of different life forms (e.g. woodland and thorn-bush savanna have as many as 11 different life forms; Jürgens et al., 2010). While woodland savanna is characterised mainly by a grassland-tree community, there is a shift to a grassland community interspersed with a relatively high proportion of different dwarf shrubs and small bushes in the thorn-bush savanna. In the thorn-bush savanna the diversity of grasses is also extraordinarily high. However, small shrubs and herbs, such as *Monechma genistifolium* and different wild legumes, often serve as food for wild herbivores. They can also be an additional, supplementary, alternative food resource for livestock, for example in the dry season when food availability is restricted (Madibela et al., 2018). Their utilisation by herbivores, as well as their general nutritional quality, is poorly known. More than 150 trees, bushes, and shrubs and more than 30 herbs and forbs in Namibia alone are reported to serve as food plants (Le Roux et al., 2009, and Stolter, unpublished data). Within SASSCAL, we aim to produce a database of nutritional values including these important but often neglected food plant species (Stolter 2018a).

However, when viewed from the perspective of a herbivore, we would like to extend the concept of "plant diversity" to also include "plant chemical diversity". Plants consist of a high number of different plant compounds such as proteins, amino acids, lipids, fibre fractions, and plant secondary metabolites. The chemical composition of a plant is species-specific, but also changes in response to external factors. For example, plants react to damage caused by herbivory, but also to enhanced UV radiation, drought stress, etc. When subjected to such stressors, changes occur in the concentration of nutritional compounds (e.g. protein) but also in specific defence compounds such as plant secondary metabolites (PSM) (Tegelberg et al., 2003; McKiernan et al., 2014). Thousands of different PSMs have evolved in plants and the composition varies between plant species (e.g. Stolter et al., 2005). Even within each single chemical class of PSM (e.g. tannins, terpenoids) there can be thousands of compounds (Iason et al., 2012) differing in their mode of action as a deterrent. Furthermore, the relative concentrations of specific compounds differ between individual plants of the same species growing on different sites (Stolter et al., 2010). There are also differences between different plant parts (e.g. twigs and leaves; Stolter, 2008) and differences between seasons (Stolter et al., 2013). This high variability (only demonstrated here for PSMs) co-varies with other compounds, for example different fibre fractions. Hence, the large number and variety of different plant compounds contributes to a multidimensional feeding environment for herbivores (Villalba et al., 2002), where the animals have to choose for each bite which plant or plant part to ingest. The impact of different factors on food quality and food availability for large herbivores will be further discussed in the subsequent chapter (Stolter et al., 2018a).

Bush encroachment

Bush encroachment is often seen as a sign of unsustainable land use caused by different factors. One driver of the transformation of the savanna ecosystem is habitat utilisation. In this respect, overgrazing, as well as the shift from wild herbivores to cattle, might be an important factor. Within SASSCAL, we investigated the effect of herbivore damage on plant and the associated consequences on food selection of livestock. Furthermore, we conducted standardised experiments and field surveys investigating the habitat utilisation of, and feeding damage caused by, different large herbivores. Knowledge on habitat utilisation, food selection of different herbivores, and the consequent plant response might help to understand how herbivores influence the vegetation, and therefore aid in the development of appropriate management strategies to prevent or defend bush encroachment (Stolter et al., 2018b).

Fire

In addition to the factors mentioned above, fire can have severe impacts on the vegetation, for example by slowing down the successional processes through which grassland is converted to forest vegetation (Backéus, 1992; Bond & Keeley, 2005). Therefore, fire can also have a regulatory function as it is crucial in interrupting the transition processes from one vegetation state to another (Joubert et al., 2012). By influencing the light, vegetation, and soil characteristics of rangelands, fires can lead to severe changes, not only in vegetation composition but also in the chemical make-up of plants. In consequence, this also affects the feeding decisions of the associated herbivore community as well as biodiversity. Therefore, all human-induced changes to the natural fire regime, including the use of fire for management purposes, influences the natural dynamics of savanna vegetation and causes changes in the composition, biodiversity, and function of terrestrial ecosystems (Bond & van Wilgen, 1996; Bird & Cali, 1998; Guyette et al., 2002).

Fire is often used extensively as a management tool for rangelands. One reason for using fire is to maintain productive grassland by removing moribund, poor-quality grasses. It is also used because of the "fertilising" effects of fire (Hobbs & Schimel, 1984; Ojima et al., 1994; Úbeda et al., 2005), which can lead to increased plant growth immediately after its occurrence (Van de Vijver et al., 1999; Giardina & Rhoades, 2001; Rieske et al., 2002). Furthermore, plants have to compensate for the lost, burnt tissue. Similar to the response that plants have to herbivory (Stolter, 2008), and depending on the plant species affected, this might lead to improved plant quality after a fire has passed through, for example the presence of a greater concentration of protein. However, depending on the frequency and severity of fire, essential nutrients such as nitrogen will be lost during the burning process either due to volatilisation or to their conversion into inorganic compounds. The latter will be lost by leaching processes during the first rainfall after the fire has occurred (Knicker, 2007). Therefore, we investigated the effect of naturally occurring fires on different parameters (e.g. vegetation composition and changes in forage quality, soil characteristics, biodiversity, abundances of mammals and insects, and large herbivore distribution; Joubert et al., 2018).

Nevertheless, naturally occurring fires are often suppressed by policy or their appearance is limited due to a serious reduction of fuel loads caused by overgrazing. Consequently, this reduction of fire is a major factor for the transition of grassland into bushy areas (Joubert et al., 2008).

Rangeland assessment and monitoring

There are two main techniques for assessing rangeland extent, condition, and quality: conventional field data collection and remote sensing. Conventional techniques are often tedious and laborious. On the other hand, remote sensing techniques provide a bird's-eye view of landscapes with measurements that can be repeated on a regular basis. For remote sensing techniques, field data is often required to calibrate and validate prediction models, although this does not necessarily need to be extensive. The chapter on rangelands in this volume shall present various in situ and remote sensing data collection techniques for the assessment of rangeland condition and health.

In situ based assessments

Conventionally, the assessment of rangeland has been done using field-based or in situ measurements. The field-based methods are used to collect information about the state or condition of soils, vegetation, and water. In the rangeland chapter, the use of a series of in situ methods is described in several articles, focusing on forage quality, landscape function, rangeland rehydration, fire, and bush encroachment.

While remote sensing can give large-scale overviews across landscapes, field studies are needed for concrete management, calibration, and validation ("ground truthing") of the resulting products. For example, habitat utilisation by large herbivores does not exclusively depend on biomass, protein, or fibre concentration. Factors like social behaviour (e.g. home ranges and territories) and geographical features (e.g. proximity to water holes), but also climatic conditions (e.g. temperature), influence the habitat utilisation of animals. Furthermore, predation risk and hunting pressure have an enormous impact on the distribution of animals. We discuss this in more detail in the article on bush encroachment management. Furthermore, details about plant quality can only be measured in the field, because we are not able to translate every plant characteristic into a spectral signal measurable from satellites. For grazers, the sole use of remote sensing to provide an estimate of habitat quality might be less problematic, as these animals feed mainly on grass, which is not highly defended, either mechanically or chemically. However, mechanical defences (e.g. the length of thorns) can only be seen in the field and the presence of some poisonous plant compounds, which might correlate with high nutritional quality (e.g. such as is frequently found in plants of the Fabaceae family), can unfortunately not yet be captured by remote sensing. Therefore, in-situ (field-based) studies are of

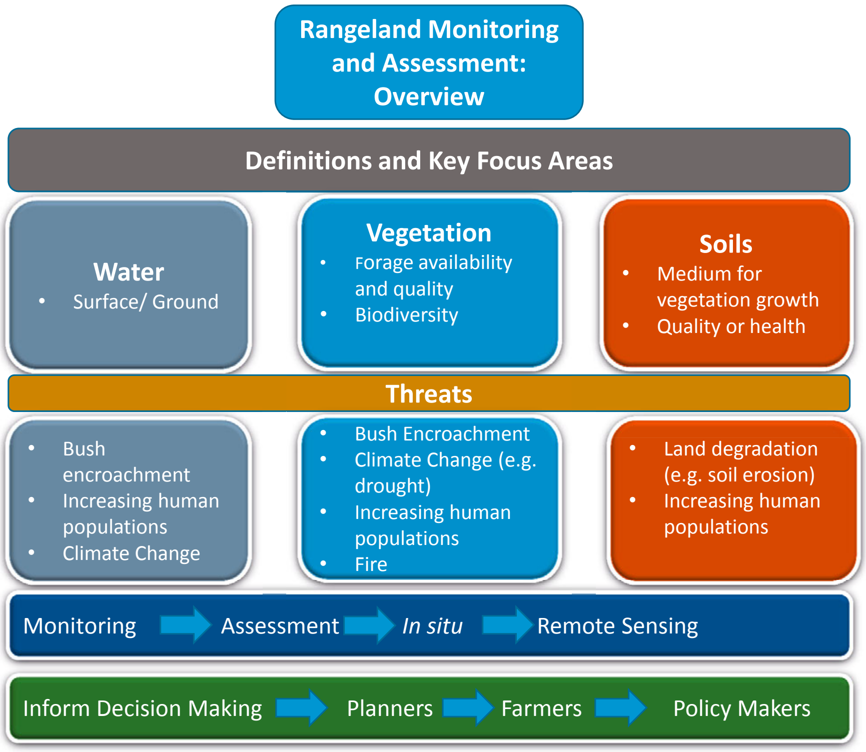

Figure 1: Schematic representation of the rangeland chapter.

high importance to confirm plant chemical composition, food utilisation, and habitat utilisation in order to understand habitat quality for different herbivores in the landscape. Due to the reasons mentioned above, we used different techniques to determine habitat utilisation of different animals in the field. Those methods can range from the use of photo traps and animal counts (observation) to GPS-collared animals and faecal dung counts (see article on fire and bush encroachment). Different methods are also available to study food utilisation, such as the estimation of damage caused by herbivory, analyses of rumen and faeces content, as well as personal observations. A brief description on the analyses concerned with nutritional quality can be found in the corresponding infobox by Stolter (2018b).

Remote sensing techniques

Satellite remote sensing provides an alternative approach for mapping vegetation cover, state, and condition for wider geographic areas and over relatively long time periods (Harris et al., 2014). The estimation of vegetation indicators in rangelands has been successfully applied using hyperspectral data, both field spectrometer and airborne data (Mutanga & Skidmore, 2004; Skidmore et al., 2010; Knox et al., 2012; Ramoelo et al., 2013), as well as satellite multispectral data (Harris et al., 2014; Schucknecht et al., 2017). Empirical statistical methods are used to achieve this, often using vegetation indices. The approach involves the determination of the relationship between in situ measured vegetation condition indicators, such as quality and availability (biomass, dry matter mass per unit area), and the vegetation indices such as the normalised difference vegetation index (NDVI; Rouse et al., 1974) and a second generation of vegetation indices such as the red edge position (REP) (Curran et al., 1991; Cho & Skidmore, 2006) and narrow band indices (Mutanga & Skidmore, 2004; Mutanga & Skidmore, 2007; Ramoelo et al., 2012; Ramoelo et al., 2015a; Ramoelo et al., 2015b). The next generation of satellite constellations incorporate the red edge band strategically, which enables forage quality estimation using nitrogen concentrations (N) as an indicator. For example, the Sentinel-2 satellite developed and launched by the European Space Agency (ESA) provides freely-available images that – like Landsat and MODIS – could be useful to improve the assessment of vegetation and crop productivity. In this study, the Sentinel-2 data (red edge based indices) were used to estimate leaf N concentrations, while a MODIS-based leaf area index model was used to estimate regional and time-series products for herbaceous vegetation (Task 229) (Stolter et al. 2018a).

Conclusions

It is evident that rangelands are under pressure due to ever-changing climate events and increasing human populations. As a result, threats such as bush encroachment and land degradation (e.g. soil erosion) are evident. Nevertheless, there was significant progress in SASSCAL in assessing the status or condition, extent, and quality of rangelands using both in situ and spatially-explicit remote sensing approaches. Key issues addressed in this chapter focused on rangeland quality – grass, trees and legumes, fire impact, bush encroachment, and creative use of rangelands – and finally, on rangeland management and dehydration processes (Fig. 1). Future research should focus on a collaborative development of a regional, integrated, and seamless rangeland monitoring framework for southern Africa.

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