THE EFFECT OF SHEEP FARMING ON THE LONG-TERM DIVERSITY OF THE VEGETATION OF THE KAROO – A REVIEW

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INTRODUCTION

South Africa is recognized for its species diversity and endemism as well as its diversity of ecosystems. With only 2% of the planet's land area, the country is home to 6% of the world's plant and mammal species, 8% of bird species and 5% of reptile species, many of which are found only in South Africa (Driver et al., 2012). With nine biomes ranging from Desert to Grassland to Forest, South Africa has a huge range of habitats, ecosystems and landscapes. These diverse ecosystems deliver ecosystem services that are of benefit to people including the provision of basic services and goods such as clean air, water, food, medicine and fibre.

The pressure on biodiversity continues to increase. Globally, habitat loss and degradation from agriculture and infrastructure development, over-exploitation, pollution and invasive alien species remain the predominant threats. The drivers of loss of biodiversity and degradation of vegetation vary across the different ecological areas in South Africa, but the major drivers at a national level include overgrazing in terrestrial and wetland ecosystems, invasive alien species in terrestrial and freshwater ecosystems and mining in all ecosystems to name but a few (Pimm & Raven, 2000; Laurance & Cochrane, 2001; Tscharntke et al., 2002; MA, 2005; UNEP, 2012).

The effect of grazing on vegetation diversity is well-documented throughout the world but a general understanding of grazing effects (especially with regards to wool sheep farming) is still lacking, despite the extensive theoretical background. Together with historic data, current data on veld and vegetation change can provide a good assessment of the present state of vegetation diversity in the wool production areas of the Karoo.

BIODIVERSITY

What is biodiversity?

The official definition of biological diversity (i.e. biodiversity) is captured in Article 2 of the "Convention on Biological Diversity", signed by 156 nations and the European Community at the United Nations Conference on the Environment and Development, "The Earth Summit" in 1992:

"Biological diversity means the variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic systems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems" (Convention on Biological Diversity, 1992).

Biodiversity forms the backbone of healthy ecosystems, which in turn is important for providing us with invaluable ecosystem goods and services. These ecosystem goods and services, which include clean air, food, drinking water, energy resources, biological control, climate regulation, recreation, tourism, and protection from natural disasters, amongst many others, are considered to be vital to human well-being, health, and economic livelihoods (Biggs et al., 2006; Brownlie et al., 2013).

Biodiversity and farming

Biodiversity in farming is useful to people in three broad ways: it has consumptive use value (in that nature provides products that can be consumed); it has productive use value (in that nature provides products that may be commercially harvested) and it has non-consumptive use value (in that indirect benefits may be derived from biodiversity, such as ecosystem functions).

Oldfield & Alcorn (1991) and Götmark (1992) argued that an important component of biodiversity is maintained by farming techniques. For example, by consuming biomass, by controlling shrub growth and by dispersing seeds through their hooves and manure, sheep can contribute to plant diversity (Steinfeld et al., 2006). Controlled grazing activity of sheep could certainly favour the biodiversity of an ecosystem (Montserrat, 1991).

Threats to biodiversity

At present, the earth is experiencing an accelerated loss of biodiversity (Sodhi & Ehrlich, 2010). Habitat loss and fragmentation, climate change, overexploitation, pollution and the spread of invasive alien species are widely accepted drivers of biodiversity loss (Pimm et al., 1995; Wilcove et al., 1998; Walker & Steffen, 1999; Pimm & Raven, 2000; Laurance & Cochrane, 2001; Tscharntke et al., 2002; Millennium Assessment, 2005; United Nations Environment Programme, 2012).

Agricultural practices often seek to transform landscapes to increase productivity in terms of marketable commodities. Sustainable agriculture has received increasing attention because expanding agriculture is globally the principal driver of biodiversity decline (Brussaard et al., 2010; International Assessment of Agricultural Knowledge, Science and Technology for Development, 2009; Millennium Assessment, 2005). Biggs et al. (2004) stated that "the largest immediate threat to biodiversity is the expansion of degraded lands into areas currently under sustainable use". According to Olivier et al. (2009), plant diversity in South Africa is heavily impacted upon by agriculture in the form of farming and overgrazing.

The major threats to biodiversity in the Karoo are posed by pastoralism, exotic plants, mining and agriculture (Lovegrove, 1993). Changes in land uses are predicted to exert the largest impact on biodiversity. Both alone, and compounded with nitrogen deposition, atmospheric CO_2, climate change and biological invasions, land use change exerts significant effects on global and local biodiversity (Sala et al., 2000). Livestock grazing is one of the major threats to biodiversity in the Karoo (Davis & Heywood, 1994). It has been suggested that the threat to biodiversity from overgrazing is most severe on continuously grazed lands (Cowling & Hilton-Taylor, 1999). Although well managed livestock grazing is compatible with biodiversity conservation, poor grazing management can lead to degradation and significant biodiversity loss at the landscape scale. Changes in vegetation composition associated with grazing are frequently not obvious and as a result, grazing as a threat to biodiversity is frequently underestimated or overlooked. Furthermore, despite being reported as a threat to many vegetation types, the actual impact of livestock grazing is very difficult to quantify at a broad scale and most assessments rely on remote sensing or anecdotal evidence to gauge grazing consequences.

DEFINING THE AREA FOR REVIEW

For the purpose of this review the Nama-Karoo Biome, as defined by Mucina et al. (2006), was used as study area (Figure 1). The Nama-Karoo is an arid continental high altitude plateau, experiencing hot summers and cold winters (frosts occur often) as the entire region is situated between 800m and 1 600m above sea level, as a consequence of continental upliftment. The Nama-Karoo appears uniform, but the wide variety of parent materials and diversity of topographical features such as plains, dongas (erosion trenches), koppies (buttes) and flat-topped mountains (mesas) (Ellis & Lambrechts, 1986), contribute dramatically to landscape heterogeneity (Pienaar et al., 2004).

The vegetation of the Nama-Karoo combines elements from the desert, arid and moist savannas, grasslands and, in sheltered sites, from the forest. It is normally a treeless environment (Mucina et al., 2006). Dwarf shrubs dominate the Karoo vegetation but the diversity in topography and climate has resulted in considerable variation in vegetation types in the region. Mucina et al. (2006) described three broad vegetation units, i.e. Bushmanland & West Griqualand, Upper Karoo and Lower Karoo which includes 16 veld types. In this review, diversity of vegetation will be used as a surrogate for the broader term ‘biodiversity’.

Rainfall has a key influence on the amount of plant material produced per hectare. In the Nama-Karoo rainfall decreases uniformly westwards from the eastern escarpment across the plateau and also from north to south (Palmer & Hoffman, 1997; Desmet & Cowling, 1999). In the southwest, rain is brought by unpredictable late summer thunderstorms and occasional inland intrusions of winter high-pressure systems from the west, whereas convectional thunderstorms and southerly movement of the intertropical convergence zone bring reliable summer rain to the northeast of the region (Desmet & Cowling, 1999).

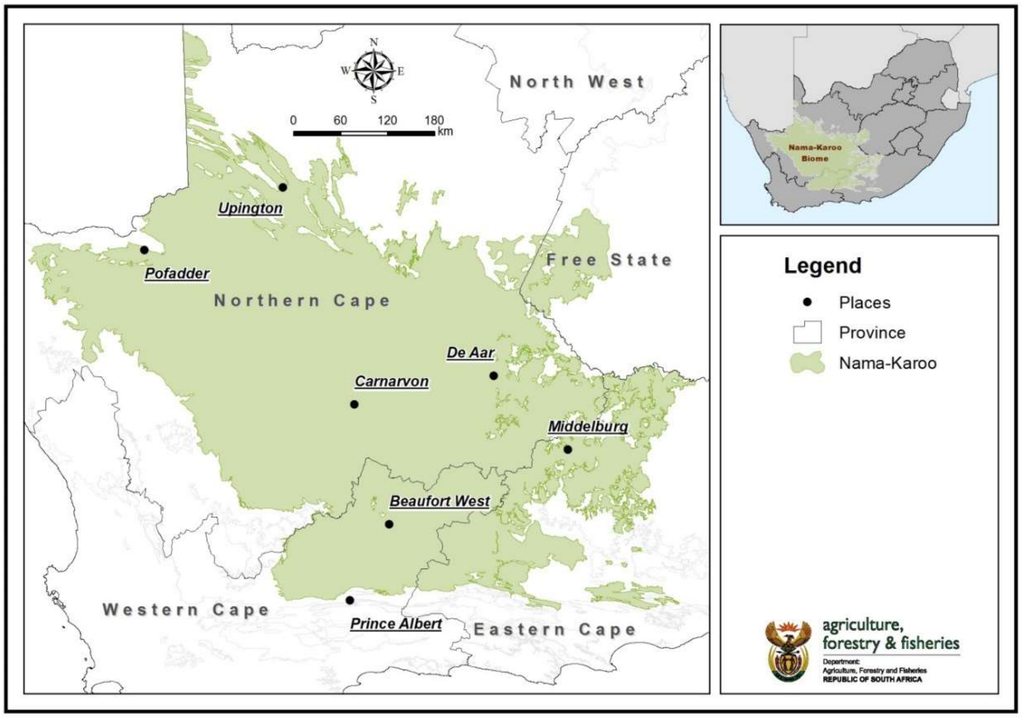

Figure 1. Nama-Karoo Biome of South Africa (Mucina et al., 2006)

Rainfall is highly seasonal (Hoffman & Cowling, 1987), peaking between December and March (Palmer & Hoffman, 1997) and the area experiences a broad range in annual rainfall between 100 and 500 mm. The low rainfall is unreliable and droughts are unpredictable and sometimes prolonged (Booysen & Rowswell, 1983).

THE NAMA-KAROO AND VEGETATION DIVERSITY

There is little published data regarding species richness or endemism for the Nama-Karoo flora, but floristic diversity was described for the Nama-Karoo by Cowling et al. (1994) and Cowling & Hilton Taylor (1999). The Karoo region (which includes the Succulent and Nama-Karoo) has a rich floristic diversity, consisting of up to 7000 different species (White, 1983; Cowling, 1986; Hilton-Taylor, 1987; Cowling & Hilton-Taylor, 1999), but Gibbs Russell (1987) estimated the number of plant species in the Nama-Karoo at only 2 147. There is however still no reliable estimate of the size of its flora. Cowling et al. (1989) and Cowling & Hilton-Taylor (1999) found the diversity of the Nama-Karoo Biome to be the lowest, on a biome scale, in South Africa.

Despite relatively low floristic diversity, the Nama-Karoo vegetation has a high diversity of plant life forms. These include coexisting ephemerals, annuals, geophytes, C_3 and C_4 grasses, succulents and deciduous and evergreen trees (Mucina et al., 2006). Communities in the Nama-Karoo constitute a matrix of long-lived shrubs, which are then interspersed by shorter-lived species such as grasses. Overgrazing may lead to a reduction or elimination of certain species or growth forms, thereby further reducing species richness (Hoffman, 1988).

The state of Nama-Karoo vegetation, prior to the colonial introduction of domestic stock, is unclear but theories considering pre-degradation environments have evoked controversy (Hoffman, 1995) with some regarding the Nama-Karoo as a perennial grassland (Acocks, 1953, Roux & Vorster, 1983a). There is generally a lack of appreciation for how climate and land use change will affect major growth forms or biodiversity occurring within specific parts of the Nama-Karoo landscape in the future (Dale et al., 2011; Verburg et al., 2012).

WOOLLED SHEEP FARMING

The nineteenth century was a pivotal period in the history of the Nama-Karoo and the livestock changed from indigenous sheep breeds to introduced breeds and wool production was added to the farming focus (Maree & Plug, 1993). Woolled sheep have been the most important grazing animals since 1870. Dual purpose wool and mutton breeds have also been developed to exploit both the wool and meat markets and to suit production systems and variable ecological conditions (Van Niekerk & Schoeman, 1993).

Although sheep number records only exist from 1855, sheep numbers within colonial boundaries were estimated at perhaps 1.5 million when the British took control of the Cape in 1806. These sheep were mostly fat-tailed, non-woolled sheep adopted from indigenous Khoisan people. Prior to the Union of South Africa coming into existence in 1910 the sheep population statistics were recorded by each of the four Colonies. The limited statistics that were found reflect that in 1841 there were 1 million sheep in the Western Province and 2 million in the Eastern Province. In 1890 the sheep population in the Orange Free State was 5 million and in Natal 798 681. The total sheep population of South Africa in 1891 was 13.5 million and by 1904 it had reached 16.3 million (Beinart, 2003).

Generally stock numbers were low in the Karoo areas between 1838 and 1904. During the period following the Great War of 1914 – 1918, wool prices were attractive and in consequence Merino sheep farming was extensively undertaken at the time. During the subsequent depression, attempts were made to reduce the numbers of sheep or to cross-breed for mutton production (Van Rensburg, 1939).

Stock numbers were lower in 1924 than in 1923 due to the drought of 1922 which killed over six million sheep, reducing the strain on the land from overstocking (Anon, 1926a). In 1926 in most cases veld was grazed all year round with many farms being overstocked (Anon, 1926b).

The number of woolled sheep in the Cape increased from 13.3 million in 1918 to 27.6 million in 1927, a period which coincided exactly with the jackal campaign, although it also marked major successes in scab eradication (Beinart, 2003). By 1933 the density of woolled sheep had increased to the highest in history. After the peak in 1933 livestock numbers declined, with a slight peak in the early 1960s. It has been argued that these livestock declines were driven by a reduction in forage availability (Dean et al., 1995), rather than by a decline in the market for wool and meat or by stock reduction policies. In the late 1960s extended droughts together with State intervention schemes such as the Stock Reduction Scheme (1969 – 1978) reduced animal numbers even further (Hoffman et al., 1999).

According to the Abstract of Agricultural Statistics (Department of Agricultural Economics and Marketing, 1985; Department of Agriculture, Forestry and Fisheries, 2013) the South African sheep flock underwent a structural change during the second half of the twentieth century. Between 1965 and 2012 the national woolled sheep flock (mostly Merinos) declined at a rate of 2.05% per annum, while the mutton sheep flock (mostly Dorpers) grew at a rate of 1.06% per annum. The change in the composition of the flock was driven by a change in the relative prices of mutton and wool. Estimates of woolled sheep numbers from 2005 – 2017 show that the numbers have remained constant at approximately 10 million (Figure 2).

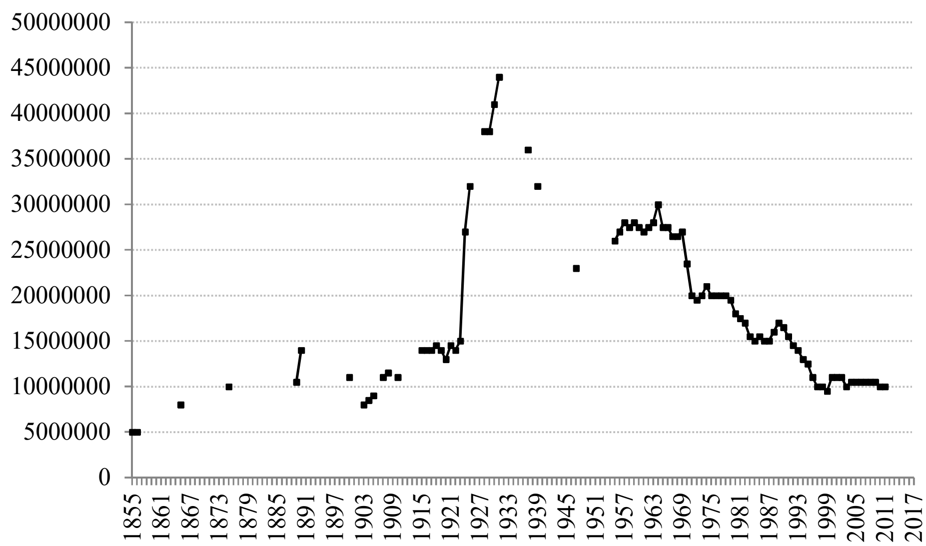

Figure 2. Woolled sheep numbers from 1855 to 2012 (Beinart, 2008; Department of Agricultural Economics and Marketing, 1985; Department of Agriculture, Forestry and Fisheries, 2013)

GRAZING AND DIVERSITY

Small stock production systems in the Nama-Karoo rely heavily on the natural rangelands as a vital, and in some cases the only, source of forage (Palmer & Ainslie, 2002; Reynolds et al., 2003). Grazing practices not only affect vegetation diversity through the direct utilization of useful plants, forage and browse to sustain domestic livestock populations, but also indirectly cause changes to other ecosystem functions or services. Negative changes in the Karoo and declining agricultural productivity have been attributed directly to overgrazing (Acocks, 1953; Acocks, 1979; Dean & Macdonald, 1994). Grazing- and livestock-induced disturbance is a complex and composite factor, with both direct and indirect impacts on plants (O'Connor &

Roux, 1995; Ledergerber et al., 1997). The impacts consist principally of defoliation, trampling, defecation and urination, and the associated modification to soil structure, nutrient status, food supply, shelter and microclimate (Taboda & Lavado, 1993; Maliha et al., 2000).

Influence of grazing on diversity

The influence of grazing on diversity, however, is notoriously complex. In some cases, high diversity has been attributed to heavy grazing pressure (Naveh & Whittaker; 1979; Peet et al., 1983), while in others, diversity has been found to decrease under sustained grazing (Johnson, 1956; Looman, 1983; Collins & Barber, 1985) or diversity has shown little change (Van der Merwe et al., 2018). In a six-year long experiment in tall grass prairie grazed pastures showed significantly higher plant species diversity than the ungrazed pastures (Hickman et al., 2004). Herbivores are generally thought to enhance plant diversity by their direct consumption of competitively dominant plant species and indirect effects on plant competition (McNaughton, 1985; Milchunas et al., 1988; Huntley, 1991; Belsky, 1992; Crawley, 1997).

Both plant and animal diversity depends on the level of grazing. Not only is the level of grazing important, but also the timing and the animal species involved (Grant et al., 1996; Hulme et al., 1999; Humphrey & Patterson, 2000). Light grazing may result in an increase in species richness, most probably as a result of reduced competition (Whittaker, 1975; Naveh & Whittaker, 1979; Waser & Price, 1981; Noy-Meir et al., 1989). At the community level it is widely accepted that intermediate levels of disturbance lead to the highest levels of species richness (Connell, 1978; White & Picket, 1985; Lawton & Jones, 1995; Hobbie et al., 1994; Dodson et al., 2000; Grime, 2001; Hickman et al., 2004). Some studies have reported an increased diversity of annual species and a lowered diversity of perennial species for areas with high grazing pressure (Todd & Hoffman, 1999).

More commonly found is that increased grazing intensity can lead to a decrease in species richness (Waser & Price, 1981; Milchunas et al., 1988; Bakker, 1989; Noy-Meir et al., 1989; Hobbs & Huenneke, 1992; Olsvig-Whittaker et al., 1993; Palmer & Cowling, 1994; Ali et al., 2000; Zhao et al., 2006; Haarmeyer et al., 2010). Several studies have found reduced vegetation diversity under heavy grazing (West, 1993; Milton et al., 1994; Ritchie & Olff, 1999). Grazing may promote diversity at small scales but diminish diversity at larger scales (Chaneton & Facelli, 1991; Landsberg et al., 2002). Hoffman (1989) documented patterns of local diversity in well managed and overgrazed vegetation from dwarf karroid shrublands (c. 200 mm y^{-1}) to succulent thorn thickets (c. 450 mm y^{-1}). He found that diversity was not significantly related to either rainfall or growth form, but overgrazed vegetation was significantly poorer in species than well-managed rangelands.

Species compositional changes

The plant species composition of the Karoo has reportedly changed over the last 200 years in response to settled pastoralism with domestic small stock (Shaw, 1875; Talbot, 1961; Downing, 1978; Roux & Theron, 1987). Both climate and grazing influence species composition and function in the Nama-Karoo (Milton & Hoffman, 1994; O'Connor & Roux, 1995; Van der Merwe et al., 2018). There is considerable evidence that prolonged herbivory cause changes in species composition (O'Connor, 1991; Roux, 1967; Meyer, 1992; Du Toit & Blom, 1995; Tainton, 1981; Stokes, 1994, Van der Merwe et al., 2018). Any changes in the vegetation composition also result in changes in the diversity and abundance of wildlife communities (Roux & Voster, 1983a; Hoffman & Cowling, 1990; Dean & MacDonald, 1994).

The structure of Karoo vegetation is a matrix of longer-lived perennial grasses and dwarf shrubs, within which dramatic variation in the abundance of annual grasses, ephemeral forbs and prostrate perennial grasses takes place (O'Connor & Roux, 1995). Over-utilization due to cultivation and overgrazing of the natural resources has resulted in the decrease, and in some cases the endangerment, of a number of natural flora and fauna within Karoo areas (Lovegrove, 1993). Compositional changes and local extinction of palatable grass species such as *Themeda triandra* following drought are greater under heavy grazing than under light or no grazing (O'Connor, 1995; Fynn & O'Connor, 2000).

The introduction of domestic livestock into sensitive arid and semi-arid areas has played a major part in altering the vegetation composition (Cowling & Roux, 1987). Traditional livestock breeds are often recommended for grazing management to meet conservation objectives as, in addition to their adaptation to harsh environmental conditions, it has been suggested that more developed commercial breeds may threaten plant diversity because of their ill-adapted dietary choices. Diet selection studies have indicated that livestock strongly differentiates among plant species, with some species preferred above others and some species being avoided (Du Toit & Blom, 1995; Du Toit et al., 1995). The most palatable plants are usually grazed first, which results in their dying out while inferior types are given the chance to develop and invade the veld (Morris & Smuts, 1932).

Effect of grazing on phenology (flowering, seed production etc.)

The phenological stage of a plant plays a very important role in the diet selected by sheep. The growth stage of a plant is a factor that influences the palatability of a plant. Animals prefer younger growth to older growth. Flower buds, flowers, fruits and seeds are important to grazers because they contain much more crude protein, fats and carbohydrates than the leaves and stems (Botha, 1979). With the maturation of grass the fibre and lignin content increases and makes the grass less acceptable to sheep. Sheep and cattle also concentrate more on eating leaves and fruit than stems (Heady & Torrel, 1959).

Plants are more sensitive to grazing during their active growing period and, since there are differences in the phenology of plant components, the time of the year when a camp is grazed will favour some components more than others. Most shrub species flower and/or fruit in autumn and spring (Roux, 1966). It can be reasoned that by knowing the phenological cycles of the key plants in a region, certain grazing treatments or adjustments can be implemented (Roux, 1968).

Herbivores feeding on foliage and flower buds may reduce the production of viable seed (Hendrix, 1988; Milton & Dean, 1990; Wiegand et al., 1995). In selectively grazed natural rangelands, preferred forage species suffer repeated reproductive failure and are often gradually replaced by less palatable plants (O'Connor, 1991; Milton, 1994). Where grazing prevents annual production of seed, forage species decrease in density (Milton & Dean, 1993).

Selective grazing

Free ranging livestock are highly selective during foraging and the primary cause of changes in Karoo vegetation is attributed to the impact of the extensive small stock industry (Roux & Vorster, 1983b; Roux & Opperman, 1986; Roux & Theron, 1987) through the agent of selective grazing (Roux & Theron, 1987). According to Botha (1981) sheep, as well as goats, are very selective and have preferences. The more palatable plant species are usually grazed more heavily than less palatable plant species (Provenza, 1995). As a consequence of selectivity, livestock grazing patterns are often uneven with some areas of landscapes receiving little use and others sometimes receiving moderate or heavy use (Senft et al., 1985; Bailey, 2005; DelCurto et al., 2005). Local disturbances and selective grazing can enhance diversity at local scales, but strong selection for grazing tolerant plant species within the species pool might reduce diversity at larger scales (Provenza et al., 2003).

STRATEGIES IMPLEMENTED TO CURB LAND/VELD DEGRADATION

Soil Conservation Schemes (1929 – 1969)

The Karoo emerged from a period of very high stocking levels between 1920–1940, which had seen much of the area lose plant cover and topsoil. One of the main resolutions of the Soil Erosion Conference held in November 1929 was that public bodies or farmers' organisations appoint erosion committees, with a view of having its share in the combating of soil erosion.

Leading from the Soil Erosion Conference, soil erosion conservation schemes were introduced by the State in 1933 for the purpose of granting reasonable facilities to individual landowners to undertake reclamation work in respect of the damage already caused to the soil by erosion. Scheme A provided for the payment of a bonus of 33.5% upon satisfactory completion of approved works. Scheme B granted a loan with a subsidy of 25%. Scheme C provided for subsidised labour. Supplement to Scheme C was Scheme D under which a loan of 50 pounds was granted for the purchase of implements, building materials, etc. Scheme E facilitated the fencing in of eroded areas and the planting of trees.

The seriousness of the soil erosion situation was evident from the legislation that was deemed necessary to control soil erosion. The first substantial legislation aimed at combating soil erosion was the Forest and Veld Conservation Act 13 of 1941. This was followed by the Soil Conservation Acts of 1946 and 1969. The Soil

Conservation Act (No 45 of 1946) provided for applications to the Soil Conservation Board for the proclamation of the catchment areas as soil conservation districts. "District committees" were appointed and were responsible to prepare a comprehensive "soil conservation scheme" for districts as a whole. These schemes were submitted to the Soil Conservation Board and to the Minister for approval. The 1946 Soil Conservation Act also sought to restrict the number of animals on the veld and in 1948 under the Act there were subsidies for internal fencing and watering of stock.

Veld Reclamation Scheme (1966)

The Veld Reclamation Scheme was introduced to encourage farmers to withdraw a portion of the pasture on their land for the duration of at least a full growing season. Where withdrawal was essential for the recovery of the veld, financial assistance would be provided in terms of the Soil Conservation Act provisions. This scheme concluded in 1973.

Stock Reduction Scheme (1969)

A stock reduction scheme ran for a decade from 1969 (Pringle et al., 1982). About 7 000 farmers, including nearly half of those in the Karoo, participated. Participation in the scheme was voluntary (Cooper, 1996). Farmers were paid compensation for reducing their livestock to one-third less than the carrying capacity recommended by the Department, and resting one-third of their land each year. It was implemented in an attempt to allow the natural vegetation to recover and reduce the process of soil erosion. The Stock Reduction Scheme also required farmers to reduce stock numbers by a third before they were able to qualify for state subsidy during the drought of the 1960's (Van der Merwe, 1974). It was followed by a National Grazing Strategy, aimed at longer-term voluntary participation.

National Grazing Strategy (1985)

The National Grazing Strategy was formulated and mooted in 1985 (Du Toit et al., 1991). The broad and all-encompassing objective of the Strategy was to reclaim, develop and stabilise the natural and cultivated pastures in South Africa, through proper management, as to yield the greatest sustainable benefit for the present generation, while maintaining the production potential for the benefit of future generations.

South African Agricultural Production Strategy (2011 – 2025)

The South African Agricultural Production Strategy seeks to position primary agriculture by targeting subsistence, smallholder and commercial production for the purpose of improving national food safety and security and agricultural economic output in a profitable and sustainable manner. This will be attained through the qualitative and quantitative improvement of South Africa's agricultural productivity, production efficiency and trade and regulatory environment for all commodity groups. It furthermore seeks to stimulate rural economic growth and development (Department of Agriculture, Forestry and Fisheries, Anon).

CONCLUSION

In conclusion it is evident that vegetation diversity is influenced by a large variety of factors. The precise (quantitative) effect on diversity of vegetation in a specific area would be extremely difficult to calculate as complete counts of organisms are impractical and almost impossible. There is also no way to quantitatively compare diversity of vegetation at present with that of the past.

Grazing practices not only affect vegetation diversity through the direct utilization of useful plants and forage to sustain domestic livestock populations, but also indirectly cause changes to other ecosystem functions or services. Defoliation, trampling, defecation and urination represent the main impacts of grazing, while the associated modification to soil structure, nutrient status, food supply, shelter and microclimate is seen as one of the most important types of disturbances altering natural processes and affecting the structure and composition of plant communities.

The influence of grazing on vegetation diversity however, is notoriously complex. In some cases, high diversity has been attributed to heavy grazing pressure, while in others, diversity has been found to decrease under sustained grazing. The impact of livestock grazing on the less common species that constitute the bulk of the biodiversity of the Karoo remains poorly understood.

Many studies have projected a future warming over southern Africa resulting in a projected drier condition of many areas of the country. Under future climate change projections, the Nama-Karoo Biome is predicted to be reduced in area, but exactly how these climate-driven changes are likely to manifest themselves in the context of the complex range of land-use activities in the Karoo remains unclear.

Past grazing and management strategies can however not be regarded as the sole driver of vegetation diversity changes in the Karoo. Factors such as droughts, fires, alien invasive species, the migration of large herds of springbuck, brown locust swarms and Karoo caterpillar infestations during the past 100 years should also be taken into consideration.

REFERENCES

Abensperg-Traun, M., Smith, G.T., Arnold, G.W. & Steven, D.E., 1999. The effect of habitat fragmentation and livestock grazing on animal communities in remnants of gimlet *Eucalyptus salubris* woodland in the Western Australia wheatbelt. 1. Arthropods. Journal of Applied Ecology. 33, 1281-1301.

Acocks, J.P.H., 1953. Veld types of South Africa. Memoirs of the Botanical Survey of South Africa. 28, 1–192.

Acocks, J.P.H., 1979. The flora that matched the fauna. Bothalia. 12, 673–709.

Ali, M.M., Dickinson, G. & Murphy, K.J., 2000. Predictors of plant diversity in a hyperarid desert wadi ecosystem. Journal of Arid Environments. 45, 215-230.

Anon., 1926a. Improved sheep farming methods. Farming in South Africa. 1(6), 19.

Anon., 1926b. Pasture management. Farming in South Africa. 1(6), 214.

Bailey, D.W., 2005. Identification and creation of optimal habitat conditions for livestock. Rangeland Ecology & Management 58, 109 - 118.

Bakker, J.P., 1989. Nature management in cutting and grazing. Kluwer.

Beinart, W., 2003. The rise of conservation in South Africa: Settlers, livestock, and the environment 1770 – 1950. Oxford University Press: Oxford.

Belsky, A.J., 1992. Effects of grazing, competition, disturbance and fire on species composition and diversity in grassland communities. Journal of Vegetation Science. 3, 187–200.

Biggs, R., Bohensky, E., Desanker, P.V., Fabricius, C., Lynam, T., Misselhorn, A.A., Musvoto, C., Mutale, M., Reyers, B., Scholes, R.J., Shikongo, S. & Van Jaarsveld, A.S., 2004. Nature supporting people: The Southern African Millennium Ecosystems Assessment. http://www.millenniumassessment.org/ documents_sga/ SAfMA_Integrated_Report.pdf

Biggs, R., Reyers, B. & Scholes, R.J., 2006. A biodiversity intactness score for South Africa. South African Journal of Science. 102, 277-283.

Booysen, J. & Rowswell, D.I., 1983. Die droogteprobleem in die Karoogebiede. Proceedings of the Grassland Society of southern Africa. 18, 40–45.

Botha, P., 1979. Factors influencing the palatability of herbage and species selection by the animal. Karoo Agric. 1(2), 13 - 18.

Botha, P., 1981. The influence of species-selection by sheep, cattle and goats on the floristic composition of mixed Karooveld. D.Sc. thesis, University of Potchefstroom, Potchefstroom, South Africa.

Brownlie, S., King, N. & Treweek, J., 2013. Biodiversity trade-offs and offsets in impact assessment and decision making: can we stop the loss? Impact Assessment and Project Appraisal. 31(1), 24-33.

Brussaard, L., Caron, P., Campbell, B., Lipper, L., Mainka, S., Rabbinge, R., Babin, D. & Pulleman, M., 2010. Reconciling biodiversity conservation and food security: scientific challenges for a new agriculture. Current Opinion in Environmental Sustainability. 2(1–2), 34–42.

Convention on Biodiversity (CBD)., 1992. Convention on Biological Diversity. United Nations.

Chaneton, E.J. & Facelli, J.M., 1991. Disturbance effects on plant community diversity: spatial scales and dominance hierarchies. Vegetatio. 93, 143–155.

Collins, S.L. & Barber, S.C., 1985. Effects of disturbance on diversity in mixed-grass prairie. Vegetatio. 64, 87-94.

Connell, J.H., 1978. Diversity in tropical rain forests and coral reefs. Science. 199, 1302-1310.

Cooper, A., 1996. Soil conservation policy in South Africa, 1910 – 1992: The 'human dimension'. Ph.D. Thesis. University of Natal. Durban.

Cowling, R.M., 1986. A description of the Karoo Biome Project. South African National Programmes Report No. 122. Council for Scientific and Industrial Research, Pretoria, South Africa.

Cowling, R.M. & Hilton-Taylor, C., 1999. Plant biogeography, endemism and diversity. IN: Dean, R.J. & Milton (eds). The Karoo: Ecological patterns and processes. Cambridge University Press: Cambridge, UK.

Cowling, R.M. & Roux, P.W., 1987. The Karoo Biome: A preliminary synthesis. Part 2, Vegetation and History. Foundation for Research Development, Council for Scientific and Industrial Research, Pretoria, South Africa.

Cowling, R.M., Esler, K.J., Midgley, G.F. & Honing, M.A., 1994. Plant functional diversity, species diversity and climate in arid and semi-arid southern Africa. Journal of Arid Environments. 27, 141–158.

Cowling, R.M., Gibbs Russel, G.E., Hoffman, M.T. & Hilton-Taylor, C., 1989. Patterns of plant species diversity in southern Africa. IN: Huntley, B.J. (ed). Biotic diversity in southern Africa. Concepts and conservation. Cape Town: Oxford University Press.

Crawley, M.J., 1997. Plant-herbivore dynamics. IN: Crawley, M.J. (ed). Plant Ecology. Blackwell.

Dale, V.H., Efroymson, R.A. & Kline, K.L., 2011. The land use – climate change – energy nexus. Landscape Ecology. 26, 755-773.

Davis, S.D. & Heywood, V.H., 1994. Centres of plant diversity: a guide and strategy for their conservation, Vol.l. Oxford University Press: Oxford.

Dean, W.R.J. & Macdonald, I.A.W., 1994. Historic changes in stocking rates of domestic livestock as a measure of semi-arid and arid rangeland degradation in the Cape Province, South Africa. Journal of Arid Environments. 26, 281–298.

Dean, W.R.J., Hoffman, M.T., Kerley, G.I.H. & Milton, S.J., 1995. Desertification in developed countries: in search of the silver bullet. South African Journal of Science. 91, 213–215.

DelCurto, T., Porath, M., Parsons, C.T. & Morrison, J.A., 2005. Management strategies for sustainable beef cattle grazing on forested rangelands in the Pacific Northwest. Rangeland Ecology & Management. 58, 119-127.

Department of Agriculture, Forestry and Fisheries (DAFF). 2013. Abstract of Agricultural Statistics. Pretoria.

Department of Agriculture, Forestry and Fisheries (DAFF). Anon. South African Agricultural Production Strategy. www.daff.gov.za/doaDev/doc/IGDP/AGRIC_PRODUCTION_STRATEGY_FRAMWK.pdf

Department of Agricultural Economics and Marketing (DAEM). 1985. Abstract of Agricultural Statistics. Pretoria.

Desmet, P.G. & Cowling, R.M., 1999. The climate of the Karoo – a functional approach, IN: Dean, R.J. & Milton (eds). The Karoo: Ecological patterns and processes. Cambridge University Press: Cambridge, UK.

Dodson, S.I., Arnott, S.E. & Cottingham, K.L., 2000. The relationship in lake communities between primary productivity and species richness. Ecology. 81, 2662–2679.

Downing, B.H., 1978. Environmental consequences of agricultural expansion in South Africa since 1850. South African Journal of Science. 74, 420–422.

Driver, A., Sink, K.J., Nel, J.L., Holness, S., Van Niekerk, L., Daniels, F., Jonas, Z., Majiedt, P.A., Harris, L. & Maze, K. 2012. National Biodiversity Assessment 2011: An assessment of South Africa's biodiversity and ecosystems. Synthesis Report. South African National Biodiversity Institute and Department of Environmental Affairs. Pretoria.

Du Toit, P.F., Aucamp, A.J. & Bruwer, J.J., 1991. The National Grazing Strategy of the Republic of South Africa. Objectives, achievements and future challenges. Journal of the Grassland Society of southern Africa. 8, 126–130.

Du Toit, P.C.V. & Blom, C.D., 1995. Diet selection by sheep and goats in the Noorsveld. African Journal of Range and Forage Science. 12, 27–37.

Du Toit, P.C.V., Blom, C.D. & Immelman, W.F., 1995. Diet selection by sheep and goats in the Arid Karoo. African Journal of Range and Forage Science. 12, 16–26.

Ellis, F. & Lambrechts, J.J.N., 1986. Soils. in the Karoo Biome: a preliminary synthesis. Part 1. Physical environment. IN: Cowling, R.M., Roux, P.W., Pieterse, A.J.H. (eds), South African National Scientific Programmes Report 124, p 18-38.

Fynn, R.W.S. & O'Connor, T.G., 2000. Effect of stocking rate and rainfall on rangeland dynamics and cattle performance in a semi-arid savanna, South Africa. Journal of Applied Ecology. 37, 491–507.

Gibbs Russell, G.E., 1987. Preliminary floristic analysis of the major biomes in southern Africa. Bothalia. 17, 213–227.

Götmark, F., 1992. Naturalness as an evaluation criterion in nature conservation: a response to Anderson. Conservation Biology. 6, 455–458.

Grant, S.A, Torvell, L. & Common, T.G., 1996. Controlled grazing studies on *Molinia* grassland: effects of different seasonal patterns and levels of defoliation on *Molinia* growth and responses of swards to controlled grazing by cattle. Journal of Applied Ecology. 33, 1267-1280.

Grime, J.P., 2001. Plant strategies, vegetation processes and ecosystem properties. John Wiley and Sons: Chichester. UK.

Haarmeyer, D.H., Schmiedel, U., Dengler, J. & Bösing, B.M., 2010. How does grazing intensity affect different vegetation types in arid Succulent Karoo, South Africa? Implications for conservation management. Biological Conservation. 143, 588–596.

Heady, H.F. & Torrel, D.T., 1959. Forage preferences exhibited by sheep with oesophageal fistulus. Journal of Range Management. 12, 25-43.

Hendrix, S.D., 1988. Herbivory and its impact on plant reproduction. IN: Lovett Doust, J. & Lovett Doust, L. (eds). Plant reproduction ecology: pattern and strategies. Oxford University Press: New York.

Hickman, K.R., Hartnett, D.C., Cochran, R.C. & Owensby, C.E., 2004. Grazing management effects on plant species diversity in tallgrass prairie. Journal of Range Management. 57, 58–65.

Hilton-Taylor, C., 1987. Phytogeography and origins of the Karoo flora. IN: Cowling, R.M. & Roux, P.W. (eds). The Karoo Biome: A preliminary synthesis. Part 2 – Vegetation and history, South African

National Programmes Report No. 142. Council for Scientific and Industrial Research, Pretoria, South Africa, p. 70-95.

Hobbie, S.E., Jensen, D.B. & Chapin, F.S., 1994. Resource supply and disturbance as controls over present and future plant diversity. p. 385 – 408. IN: Schulze, E.D. and Mooney, H.A. (eds). Biodiversity and ecosystem function. Springer-Verlag, Berlin.

Hobbs, R.J. & Huenneke, L.F., 1992. Disturbance, diversity and invasion: implications for conservation. Conservation Biology. 6, 324–337.

Hoffman, M.T., 1988. The rationale for Karoo grazing systems: criticisms and research implications. South African Journal of Science. 84, 556-559.

Hoffman, M.T., 1989. Vegetation studies and the impact of grazing in the semi-arid Eastern Cape. PhD Thesis. University of Cape Town. Cape Town.

Hoffman, M.T., 1995. Desertification of the Karoo, South Africa: a review of the recent research and current status of the debate. IN: Badenhorst, N. (ed). Proceedings of the National Research and Development workshop on the assessment and monitoring of desertification in South Africa. Agricultural Research Council, Pretoria.

Hoffman, M.T. & Cowling, R.M., 1987. Plant physiognomy, phenology and demography. IN: Cowling, R.M. & Roux, P.W. (eds). The Karoo Biome: a preliminary synthesis. Part 2 – vegetation and history. South African National Scientific Programmes Report. 142, 1–34.

Hoffman, M.T. & Cowling, R.M., 1990. Vegetation change in the semi-arid Karoo over the last 200 years: An expanding Karoo – fact or fiction? South African Journal of Science. 86, 286–294.

Hoffman, M.T., Cousins, B., Meyer, T., Petersen, A. & Hendricks, H., 1999. Historical and contemporary land use and the desertification of the Karoo. IN: Dean, R.J. & Milton, S. (eds). The Karoo: Ecological patterns and processes. Cambridge University Press: Cambridge, UK.

Hulme, P.D., Pakeman, R.J., Torvell, L., Fisher, J.M. & Gordon, I.J., 1999. The effects of controlled sheep grazing on the dynamics of upland *Agrostis-Festuca* grassland. Journal of Applied Ecology. 36, 886–900.

Humphrey, J.W. & Patterson, G.S., 2000. Effects of late summer cattle grazing on the diversity of riparian pasture vegetation in an upland conifer forest. Journal of Applied Ecology. 37, 986–996.

Huntley, N.J., 1991. Herbivores and the dynamics of communities and ecosystems. Annual Review of Ecological Systems. Ecol. Syst. 22, 477–503.

International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD)., 2009. Agriculture at a Crossroads. Synthesis Report (eds. McIntyre, B.D., Herren, H.R., Wakhungu, J. & Watson, R.T.). International Assessment of Agricultural Knowledge, Science and Technology for Development. Island Press, Washington, DC.

Johnson, W.M., 1956. The effect of grazing intensity on plant composition, vigor and growth of pine-bunchgrass ranges in Central Colorado. Ecology. 37, 790-798.

Landsberg, J., James, C.D., Maconochie, J., Nicholls, A.O., Stol, J. & Tynan, R., 2002. Scale-related effects of grazing on native plant communities in an arid rangeland region of South Australia. Journal of Applied Ecology. 39, 427–444.

Laurance, W.F. & Cochrane, M.A., 2001. Special section: synergistic effects in fragmented landscapes. Conservation Biology. 15, 1488-1489.

Lawton, J.H. & Jones, C.G., 1995. Linking species and ecosystems: organisms as ecosystem engineers. p. 194–208. IN: Jones, C.G. & Lawton, J.H. (eds). Linking species and ecosystems. Chapman and Hall, New York.

Lawton, J.H. & May, R.M., 1994. Extinction Rates. Oxford University Press. Oxford: UK.

Ledergerber, S., Thommen, G.H. & Baur, B., 1997. Grazing damage to plants and gastropod and grasshopper densities in a $C0_2$-enrichment experiment on calcareous grassland. International Journal of Ecology. 18, 255-261.

Looman, J., 1983. Grassland as natural or semi-natural vegetation. IN: Holzner, W., Werger, M.J.A. & Ikusima, I. (eds). Man's impact on vegetation. Junk, The Hague. p. 173-184.

Lovegrove, B., 1993. The living deserts of southern Africa. Fernwood Press. Cape Town.

Millennium Assessment (MA)., 2005. Ecosystems and Human Well-being: Wetlands and Water Synthesis. Millennium Ecosystem Assessment. World Resources Institute. Island Press, Washington, DC.

Maliha, S.N., Waiter, G.W., Justin, V.Z. & Kris, H., 2000. Ant (Hymenoptera: Formicidae) responses to environmental stressors in the northern Chihuahuan desert. Environmental Entomology. 29, 200-206.

Maree, C. & Plug, I., 1993. Origin of southern African livestock and their potential role in the industry. IN: Maree, C. & Casey, N.H. (eds). Livestock Production Systems: Principles and practices. Agri Development Foundation: Pretoria.

McNaughton, S.J., 1985. Ecology of a grazing ecosystem: the Serengeti. Ecological Monographs. 53, 291–320.

Meyer, T.C. , 1992. Weidingskapasiteitstudies op veld in die dorre Karoo. MSc Thesis. University of the Orange Free State. Bloemfontein.

Milchunas, D.G., Sala, O.E. & Lauenroth, W.K., 1988. A generalized model of the effects of grazing by large herbivores on grassland community structure. American Naturalist. 132, 87–106.

Milton, S.J., 1994. Growth, flowering and recruitment of shrubs in grazed and in protected rangeland in the arid Karoo, South Africa. Vegetatio. 111, 17–27.

Milton, S.J. & Dean, W.R.J., 1990. Seed production in rangelands of the southern Karoo. South African Journal of Science. 86, 231–233.

Milton, S.J. & Dean, W.R.J., 1993. Selection of seeds by harvester ants (*Messor capensis*) in relation to condition of arid rangeland. Journal of Arid Environments. 24, 63–74.

Milton, S.J. & Hoffman, M.T., 1994. The application of state-and-transition models to rangeland research and management in arid succulent and semi-arid grassy Karoo, South Africa. African Journal of Range and Forage Science. 11(1), 22.

Milton, S.J., Dean, W.R., Du Plessis, M.A. & Siegfried, W.R., 1994. A conceptual model of arid rangeland degradation. BioScience. 44(2), 70-76.

Montserrat, P., 1991. Forest evolution in the grazed mountains of the Pyrenees. Botanica Chronica. 10, 359–366.

Morris, I.J. & Smuts, I.J., 1932. Sheep farming. II. Nutritive value and management of the veld. Farming in South Africa. 6(70), 421–422.

Mucina, L., Rutherford, M.C., Palmer, A.R., Milton, S.J., Scott, L., Lloyd, J.W., Van der Merwe, Hoare, D.B., Bezuidenhout, H., Vlok, J.H.J., Euston-Brown, D.I.W., Powrie, L.W. & Dold, A.P., 2006. Nama-Karoo Biome. IN: Mucina, L. & Rutherford, M.C. (eds). The vegetation of South Africa, Lesotho and Swaziland. Strelitzia 19, South African National Biodiversity Institute, Pretoria.

Naveh, Z. & Whittaker, R.H., 1979. Structural and floristic diversity of shrublands and woodlands in Northern Israel and other Mediterranean areas. Vegetatio. 41, 171–190.

Noy-Meir, I., Gutman, M. & Kaplan, Y., 1989. Responses of Mediterranean grassland plants to grazing and protection. Journal of Ecology. 77, 290–310.

O'Connor, T.G., 1991. Local extinction in perennial grasslands, a life history approach. American Naturalist. 137, 753–773.

O'Connor, T.G., 1995. Transformation of a savanna grassland by drought and grazing. African Journal of Range and Forage Science. 12, 53–60.

O'Connor, T.G. & Roux, P.W., 1995. Vegetation changes (1949 – 71) in a semi-arid, grassy dwarf shrubland in the Karoo, South Africa: influence of rainfall and grazing by sheep. Journal of Applied Ecology. 32, 612–626.

Oldfield, M.L. & Alcorn, J.B., 1991. Conservation of traditional agroecosystems. IN: Oldfield, M.L. & Alcorn, J.B. (eds). Biodiversity: culture, conservation and ecodevelopment. Westview Press: Boulder, Colorado.

Olivier, N.J.J., Myakayaka, A.G. & Richards, R.L., 2009. Indigenous Plants. IN: Strydom, H.A. & King, N.D. (eds). Environmental Management in South Africa. Cape Town: Juta, p. 344

Olsvig-Whittaker, L.S., Hosten, P.E., Marcus, I. & Shochat, E., 1993. Influence of grazing on sand field vegetation in the Negev Desert. Journal of Arid Environments. 24, 81–93.

Palmer, A.R. & Cowling, R.M., 1994. An investigation of topo-moisture gradients in the eastern Karoo, South Africa, and the identification of factors responsible for species turnover. Journal of Arid Environments. 26, 135–147.

Palmer, A.R. & Hoffman, M.T., 1997. Nama-Karoo. IN: Cowling, R.M., Richardson, D.M. & Pierce, S.M. (eds). Vegetation in Southern Africa. Cambridge University Press. Cambridge.

Palmer, T. & Ainslie, A., 2002. South Africa, IN: Grassland and Pasture Crops: Country Pasture / Forage Resource Profiles. (F.A.O. Online database, F.A.O. South Africa) Forestry and Agroforestry Organisation. www.fao.org/ag/agp/agpc/doc/counprof/ southafrica/southafrica.htm

Peet, R.K., Glenn-Lewin, D.C. & Wolf, J.W., 1983. Prediction of man's impact on plant species diversity. IN: Holzner, W., Werger, M.J.A. & Ikusima, I. (eds). Man's impact on vegetation. Junk: The Hague. p 41-54.

Pienaar, E., Esler, K.J. & Mucina, L., 2004. Vegetation of mesas and surrounding plains in the southeastern Nama-Karoo, South Africa. South African Journal of Botany. 70(4), 540–558.

Pimm, S.L. & Raven, P.H., 2000. Biodiversity: extinction by numbers. Nature. 403, 843-845.

Pimm, S.L., Russel, G.J., Gittleman, J.L. & Brooks, T.M., 1995. The future of biodiversity. Science. 269, 347-350.

Pringle, J.A., Bond, C. & Clark, J., 1982. The conservationists and the killers. The story of game protection and the Wildlife Society of southern Africa. Cape Town: T.V. Bulpin and Books of Africa.

Provenza, F.D., 1995. Postingestive feedback as an elementary determinant of food preference and intake in ruminants. Journal of Range Management. 48, 2–17.

Provenza, F.D., Villalba, J.J., Dziba, L.E., Atwood, S.B. & Banner, R.E., 2003. Linking herbivore experience, varied diets, and plant biochemical diversity. Small Ruminant Research. 49, 257–274.

Rahlao, S.J., Milton, S.J., Esler, K.J., Van Wilgen, B.W. & Barnard, P., 2009. Effects of invasion of fire-free arid shrublands by a fire-promoting invasive alien grass (*Pennisetum setaceum*) in South Africa. Austral Ecology. 34(8), 920-928.

Reynolds, J.F., Stafford-Smith, D.M. & Lambin, E., 2003. Do Humans cause Deserts? An old problem through the lens of a new framework: The Dahlem Desertification Paradigm (DDP). IN: Allsopp, N., Palmer, A.R., Milton, S.J., Kirkman, K.P., Kerley, G.I.H., Hurt, C.R. & Brown, C.J. (eds.), Proceedings of the VIIth International Rangelands Congress 26th July – 1st August, Durban, South Africa. p. 2042-2048.

Ritchie, M.E & Olff, H., 1999. Herbivore diversity and plant dynamics: compensatory and additive effects. IN: Olff, H., Brown, V.K. & Drent, R.H. (eds). Herbivores: Between Plants and Predators: the 38th symposium of the British Ecological Society in cooperation with the Netherlands Ecological Society, held at Wageningen Agricultural University, The Netherlands, 1997, pp. 175-204. Blackwell Science Ltd: Oxford. 639 pp.

Roux, P.W., 1966. Die uitwerking van seisoensreënval en beweiding op gemengde karooveld. Proceedings of the Grassland Society of southern Africa. 1, 103–110.

Roux, P.W., 1967. Die onmiddelike uitwerking van intensiewe beweiding op gemengde Karooveld. Proceedings of the Grassland Society of southern Africa. 2, 83–90.

Roux, P.W., 1968. Principles of veld management in the Karoo and adjacent dry sweet-grassveld. IN: Hugo, W.J. (ed). The small stock industry. Government Printer: Pretoria.

Roux, P.W. & Opperman, D.P.J., 1986. Soil Erosion. IN: Cowling, R.M., Roux P.W. & Pieterse A.J.H. (eds). The Karoo Biome: A Preliminary synthesis. Part I - Physical Environment. South African National Scientific Programmes Report 124, 92-108

Roux, P.W. & Theron, G.K., 1987. Vegetation change in the Karoo Biome. IN: Cowling, R.M. & Roux, P.W. The Karoo Biome: a preliminary synthesis. Part 2 – vegetation and history. South African National Scientific Programmes Report. 142, 50–69.

Roux, P.W. & Vorster, M., 1983a. Vegetation change in the Karoo. Proceedings of the Grassland Society of South Africa. 18, 25–29.

Roux, P.W. & Vorster, M., 1983b. Development of veld management research in the Karoo Region. Proceedings of the Grassland Society of southern Africa. 18, 30–34.

Sala, O.E., Chapin, F.S., Armestro, J.J., Berlow, E., Bloomfield, J., Dirzo, R., Huber-Sanwald, E., Huenneke, L.F., Jackson, R.B., Kinzig, A., Leemans, R., Lodge, D.M., Mooney, H.A., Oesterheld, M., Poff, N.L., Sykes, M.T., Walker, B.H., Walker, M. & Wall, D.H., 2000. Global biodiversity scenarios for the year 2100. Science. 287, 1770–1774.

Senft, R.L., Rittenhouse, L.R. & Woodmansee, D.R.G., 1985. Factors influencing patterns of cattle grazing behavior on shortgrass steppe. Journal of Range Management 38, 82-87.

Shaw, J., 1875. On the changes going on in the vegetation of South Africa through the introduction of the Merino sheep. Journal of the Linnaen Society. 14, 202–208.

Sodhi, N.S. & Ehrlich, P.R., 2010. Conservation Biology for All. Oxford University Press, Oxford.

Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M. & De Haan, C., 2006. Livestock's long shadow: Environmental issues and options. FAO. Rome.

Stokes, C.J., 1994. Degradation and dynamics of succulent Karoo vegetation. MSc Thesis. Botany. University of Natal. Pietermaritzburg.

Taboda, M.A. & Lavado, R.S., 1993. Influence of cattle trampling on soil porosity under alternate dry and ponded conditions. Soil Use Management. 9, 139-153.

Tainton, N.M., 1981. The ecology of the main grazing lands of South Africa. IN: Tainton, N.M. (ed). Veld and Pasture Management in South Africa. Shuter and Shooter: Pietermaritzburg.

Talbot, W.J., 1961. Land utilization in the arid regions of southern Africa. Part I. South Africa. IN: Stamp, L.D. (ed). A history of land use in arid regions. Arid Zones Research. 17. Paris: UNESCO.

Todd, S.W. & Hoffman, M.T., 1999. A fence-line contrast reveals effects of heavy grazing on plant diversity and community composition in Namaqualand, South Africa. Plant Ecology. 142(1/2), 169–178.

Tscharntke, T., Steffan-Dewenter, I., Kruess, A. & Thies,, C. 2002. Characteristics of insect populations in habitat fragments: a mini review. Ecological Research. 17, 229-239.

United Nations Environment Programme (UNEP)., 2012. Global Environmental Outlook 5. Part 1: State and trends of the environment. in United Nations Environmental Programme. http://www.unep.org/geo/geo5.asp

Van der Merwe, H., Du Toit, J.C.O., Van den Berg, L., O'Connor, T.G., 2018. Impact of sheep grazing intensity on vegetation at the Arid Karoo Stocking Rate Trial after 27 Years, Carnarvon, South Africa. Journal of Arid Environments. 155: 36-45.

Van der Merwe, I. du T., 1974. Results of the stock reduction scheme. Karoo Regional Newsletter. June. 1974: 20.

Van Niekerk, W.A. & Schoeman, S.J., 1993. Sheep and goat production. IN: Maree, C. & Casey, N.H. (eds). Livestock Production Systems: Principles and practices. Agri Development Foundation: Pretoria.

Van Rensburg, G.T., 1939. Sheep farming in the Transvaal. I. History and general problems. Farming in South Africa. 14(161), 309–311.

Verburg, P.H., Van Asselen, S., Van der Zanden, E.H. & Stehfest, E., 2012. The representation of landscapes in global scale assessments of environmental change. Landscape Ecology. 24, 1167–1181.

Walker, B.M. & Steffen, W.L., 1999. Interactive and integrated effects of global change on terrestrial ecosystems. IN: Walker, B., Steffen, W.L., Canadell, J. & Ingram, J. (eds). The Terrestrial Biosphere and Global Change Implications for Natural and Managed Ecosystems. Book Series 4. Cambridge University Press, Cambridge, UK. p. 329-375.

Waser, N.M. & Price, M.V., 1981. Effects of grazing on diversity of annual plants in the Sonoran Desert. Oecologia. 50, 407–411.

West, N.E., 1993. Biodiversity of rangelands. Journal of Range Management. 46(1), 2-13.

White, F., 1983. The vegetation of Africa. A descriptive memoir to accompany the UNESCO/AETFAT/UNSO vegetation map of Africa. United Nations Educational, Scientific and Cultural Organization, Switzerland.

White, P.S. & Picket, S.T.A., 1985. Natural disturbance and patch dynamics: an introduction. p. 3-13. IN: Picket, S.T.A. & White, P.S. (eds). The ecology of natural disturbance and patch dynamics. Academic Press, New York.

Whittaker, R.H., 1975. Communities and Ecosystems. Macmillan Publishing Company: New York, p. 385.

Wiegand, T., Milton, S.J. & Wissel, C., 1995. A simulation model for a shrub ecosystem in the semi-arid Karoo, South Africa. Ecology. 76, 2205–2221.

Wilcove, D.S., Rothstein, D., Dubow, J., Phillips, A. & Losos, E., 1998. Quantifying threats to imperilled species in the United States. BioScience. 48, 607-615.

Zhao, W.Y., Li, J.L. & Qi, J.G., 2006. Changes in vegetation diversity and structure in response to heavy grazing pressure in the Northern Tianshan Mountains, China. Journal of Arid Environments. 68, 337–508.