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Review Paper

Drivers and trajectories of social and ecological change in the Karoo, South Africa[§]

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This review article explores past, present and possible future drivers of change in Karoo social-ecological systems. Biogeographically, the Karoo comprises the arid Succulent Karoo and Nama-Karoo biomes covering significant portions of the Northern Cape, Eastern Cape and Western Cape provinces and a smaller part of the Free State. Despite the Karoo's specific environment and spatial importance nationally (covering some 30% of South Africa), no government structures address its needs holistically. Today it is a politically and economically marginalised region; perceptions of it as a desert easily morph into perceptions of it as deserted and ripe for exploitation for the benefit of external constituencies, whether in the name of astronomy, shale-gas and uranium mining or renewable energy. To manage the Karoo better for present and future generations, it is clearly desirable for social and natural scientists to work collaboratively, yet there is relatively little interdisciplinary work to date. Against this background this review article provides an overview of social and ecological changes historically and in the present, and offers some cautious reflections concerning climate change, changing land use and governance as key drivers affecting trajectories of change into the future.

Keywords: change, interdisciplinary research, Nama-Karoo, social-ecological systems, Succulent Karoo

Introduction

This review article explores broad drivers and trajectories of change in Karoo social-ecological systems, setting the context for the more focused case studies that follow. By social-ecological systems (SES) we refer to the complex interaction of social and ecological dynamics in the environment on which life depends; this perspective locates humans within nature, rather than standing outside of it (Berkes and Folke 1998). Given that SES are complex, they are inherently unpredictable and difficult to manage. Biggs et al. (2015) suggest that a combination of approaches is thus needed to address the sustainability challenges that society is now facing, particularly in low-productivity ecosystems and marginal economies such as the Karoo. Environmental management needs to be adaptive where there is evidence that it is failing to achieve its goals, and to integrate different perspectives in decision-making around land and resources use, while establishing safe boundaries for environmental change that avoid reaching thresholds of system failure or irreversibility. At the same time, integrating social concerns and environmental management necessarily involves grappling with issues of poverty,

inequality and power relations within society, including in the determination of societal priorities.

The Karoo as a geographical region covers much of the interior plateau of South Africa. Biogeographically, it comprises the arid and semi-arid winter-rainfall Succulent Karoo and summer-rainfall Nama-Karoo biomes, stretching from the northern West Coast across the interior plateau and together making up some 30% of the country's land area (Mucina and Rutherford 2006; Figure 1). Both biomes extend into neighbouring Namibia but the focus of this article is on the South African Karoo. In terms of politico-administrative boundaries, the region occupies significant portions of three of the four largest provinces of South Africa (Northern Cape, Eastern Cape and Western Cape) and a small part of a fourth (Free State).

Aligning social and ecological considerations with administrative boundaries, we have identified five overlapping Karoo subregions, each with a particular mix of social, economic and ecological features and blurring into the biomes on their borders: Namaqualand in the west, the Great Karoo in the centre, the Northern Karoo in the north, the Little Karoo in

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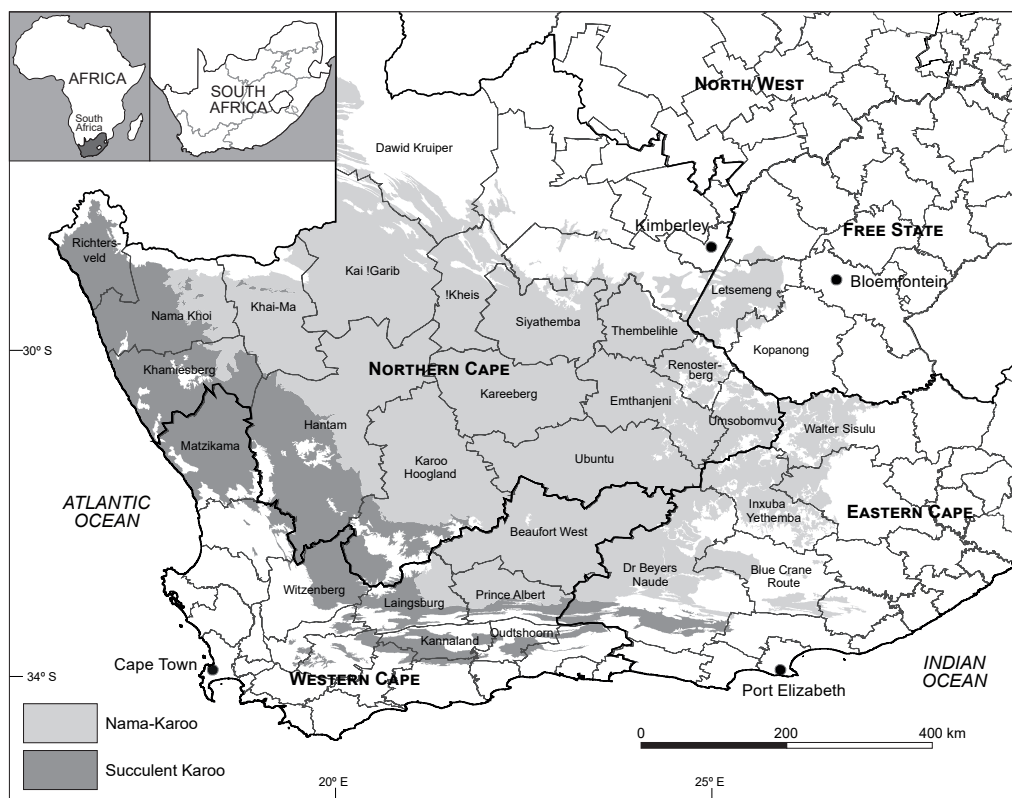


Figure 1: Succulent Karoo biome (dark grey) and Nama-Karoo biome (light grey), showing provincial (bold) and local municipality (light grey) borders. Sources: Biome map from Mucina and Rutherford (2006), and municipal and provincial boundary shapefiles from the Municipal Demarcation Board of South Africa (<https://www.demarcation.org.za/site/shapefiles/>)

the south and the Grassy Karoo in the south-east (Table 1). We have excluded the northern Gariiep (Orange) River valley from our analysis, because it supports a relatively distinct social-ecological system, although we recognise its importance for adjacent Karoo (and savanna) areas.

The entire region receives a rainfall of less than 400 mm per annum (much of it below 250 mm) and supports biological productivity of under 2 t ha^{-1} (Pan et al. 2015; DEA 2016); the aridity of the Karoo is one of its defining features, shaping its biodiversity as well as prospects for human livelihoods throughout history. The Succulent Karoo is unparalleled among the arid regions of the world for its spectacular plant diversity and high endemism, particularly among succulent plants (Cowling and Hilton-Taylor 1999). The larger Nama-Karoo region, which combines elements of the adjacent Savanna, Grassland and Succulent Karoo biomes, has relatively low diversity and endemism (Cowling and Hilton-Taylor 1999). One of the proposed drivers of differences in biodiversity patterns in the two biomes is the coefficient of variation in rainfall and temperature, both of which are lower in the Succulent Karoo compared with the Nama-Karoo (Cowling and Hilton-Taylor 1999), as well as with comparably arid inland shrublands in North America (Esler et al. 1999), South America, north Africa, central Asia, and central and Western Australia (Cowling and Hilton-Taylor 1999).

While livestock farming at different scales has dominated the landscape for centuries, during the second half of the twentieth century most Karoo residents became clustered

in small urban centres where today over 75% of the population resides (Hill and Nel 2018). Karoo towns and villages are far apart and poorly resourced in terms of educational and health facilities. Many have been in a state of economic decline in recent decades, although 'enterprise diversity' in terms of commercial activity remains high (Atkinson et al. 2017; Toerien 2017). At the same time, and despite the Karoo's regionally specific natural environment and spatial significance within South Africa, there is no one government structure that examines the needs of the region or plans policies for it as a whole – a major impediment to its holistic management. The Karoo is a marginalised region, not only politically and economically but also in the imaginary of most South Africans. Perceptions of the Karoo as a desert region easily morph into perceptions of it as a deserted region – a non-place, a non-region, with few permanent residents of voting age. This has, in turn, animated external perceptions of it as essentially empty space in which its physical resources, including minerals, clear skies and abundant sunlight, are ripe for exploitation for the benefit of constituencies beyond its borders (Milton and Dean 2015; Walker and Chinigò 2018).

Adding to the challenge of holistic management is the dearth of scientific treatments of the Karoo across disciplinary boundaries. Important books that focus on ecological processes and management include Dean and Milton (1999) and Esler et al. (2006). Beinart's (2003) history of conservation addresses the political and economic significance of the Karoo within the history of modern South

Table 1: Selected biogeographic and demographic features of 26 Karoo local municipalities (race and language percentages rounded). Sources: Statistics South Africa (n.d.), Municipalities of South Africa (n.d.), Dr Beyers Naude Local Municipality (2017), ECSECC (2017). LM = Local Municipality

Local Municipality	Biome	District Municipality and Province	LM area (km ²)	LM population 2011	LM population km ⁻² 2011	LM population growth 2001–2011 (%)	Main town, population 2011	LM race 2011 (%) ^a	LM language 2011 (%) ^b
Namaqualand Subregion									
Richtersveld	Succulent Karoo	Namakwa Northern Cape	9 608	11 982	1.25	1.68	Port Nolloth 6 092	co 77 bA 13 wh 9	Afr 84 Xh 6 Eng 3
Nama Khoi	Succulent Karoo; Nama-Karoo	Namakwa Northern Cape	17 990	47 041	2.61	0.47	Springbok 12 790	co 88 bA 4 wh 7	Afr 93 Xh 1 Eng 1
Kamiesberg	Succulent Karoo	Namakwa Northern Cape	14 208	10 187	0.88	0.54	Garies 2 105	co 86 wh 8	Afr 92 Eng 1
Matzikama	Succulent Karoo	West Coast Western Cape	12 981	67 147	5.17	2.14	Vredendal 18 170	co 75 bA 9 wh 15	Afr 89 Xh 3 Eng 2
Northern Karoo Subregion (incorporating historical Bushmanland)									
Khai-Ma	Nama-Karoo	Namakwa Northern Cape	15 715	12 465	0.79	0.83	Pofadder 3 287	co 75 bA 18 wh 6	Afr 81 Xh 2 Eng1 Sets 11
Kai !Garib	Nama-Karoo	ZF Mgcau Northern Cape	26 377	65 869	2.5	1.16	Keimoes 12 000	co 62 bA 28 wh 6	Afr 71 Xh 1 Eng 1 Set 24
IKheis	Nama-Karoo	ZF Mgcau Northern Cape	11 107	16 637	1.5	0.06	Groblershoop 4 938	co 85 bA 7 wh 5	Afr 93 Eng 1 Sets 2
Siyathemba	Nama-Karoo	Pixley ka Seme Northern Cape	14 727	21 591	1.47	1.57	Prieska 14 246	co 80 bA 12 wh 8	Afr 92 Xh 3 Eng 1
Thembelihle	Nama-Karoo	Pixley ka Seme Northern Cape	8 023	15 701	1.96	0.82	Hopetown 10 259	co 71 bA 15 wh 13	Afr 89 Xh 5 Eng 1
Letsemeng	Nama-Karoo	Xhariep Free State	9 828	38 628	3.93	-1.08	Koffiefontein 10 402	co 23 bA 68 wh 8	Afr 61 Xh 10 Eng 1 Sets 9 Ses 12
Great Karoo Subregion (incorporating historical Hantam, Nieuweveld, Roggeveld and Upper Karoo)									
Hantam	Succulent Karoo; Nama-Karoo	Namakwa Northern Cape	39 085	21 578	0.55	0.59	Calvinia 9 680	co 82 bA 4 wh 12	Afr 93 Eng 1
Karoo Hoogland	Nama-Karoo; Succulent Karoo	Namakwa Northern Cape	30 230	12 588	0.42	1.8	Williston 3 368	co 78 wh 15	Afr 90 Eng 1
Kareeberg	Nama-Karoo	Pixley ka Seme Northern Cape	17 701	11 673	0.66	2.07	Carnarvon 6 612	co 85 bA 5 wh 9	Afr 94 Eng 1
Ubuntu	Nama-Karoo	Pixley ka Seme Northern Cape	20 393	18 601	0.91	1.27	Victoria West 8 254	co 70 bA 21 wh 8	Afr 81 Xh 12 Eng 2
Emthanjeni	Nama-Karoo	Pixley ka Seme Northern Cape	13 472	42 536	3.16	1.69	De Aar 23 760	co 58 bA 33 wh 8	Afr 69 Xh 23 Eng 2
Renosterberg	Nama-Karoo	Pixley ka Seme Northern Cape	5 529	10 978	1.99	1.91	Petrusville 5 211	co 57 bA 33 wh 7	Afr 71 Xh 24
Laingsburg	Succulent Karoo	Central Karoo Western Cape	8 784	8 289	0.93	2.16	Laingsburg 5 667	co 82 bA 8 wh 9	Afr 94 Xh 2 Eng 2

Table 1: (cont.)

Local Municipality (LM)	Biome	District Municipality and Province	LM area (km ²)	LM population 2011	LM population km ⁻² 2011	LM population growth 2001–2011 (%)	Main town, population 2011	LM race 2011 (%) ^a	LM language 2011 (%) ^b
Prince Albert	Nama-Karoo; Succulent Karoo	Central Karoo Western Cape	8 153	13 136	1.61	2.23	Prince Albert 7 054	co 85 bA 3 wh 12	Afr 92 Eng 4
Beaufort West	Nama-Karoo	Central Karoo Western Cape	21 917	49 586	2.26	1.36	Beaufort West 20 066	co 74 bA 16 wh 9	Afr 82 Xh 10 Eng 2
Grassy Karoo Subregion									
Dr Beyers Naude ^c	Nama-Karoo; Succulent Karoo	Sarah Baartman Eastern Cape	28 653	79 292	2.77	0.82	Graaff-Reinet 26 585	co 65 bA 25 Wh 10	Afr 78 Xh 14 Eng 3
Blue Crane Route	Nama-Karoo	Sarah Baartman Eastern Cape	11 069	36 002	3.25	0.04	Somerset East 13 619	Co 33 bA 59 wh 7	Afr 42 Xh 50 Eng 3
Inxuba Yethemba	Nama-Karoo	Chris Hani Eastern Cape	11 663	65 560	5.62	0.83	Cradock 36 671	co 32 bA 56 wh 11	Afr 44 Xh 49 Eng 3
Walter Sisulu ^c	Nama-Karoo; Grassland; Albany Thicket	Joe Gqabi Eastern Cape	13 269	87 263	6.57	2.70	Burgersdorp 5 241	Co 12 bA 80 Wh 8	Afr 19 Xh 65 Eng 2 Ses 12
Umsobomvu	Nama-Karoo	Pixley ka Seme Northern Cape	6 813	28 376	4.16	1.83	Colesberg 16 869	co 31 bA 62 wh 6	Afr 38 Xh 54 Eng 2
Little Karoo Subregion									
Kannaland	Succulent Karoo	Eden Western Cape	4 765	24 767	5.20	0.33	Calitzdorp 4 284	co 85 bA 5 wh 10	Afr 93 Eng 3
Oudtshoorn	Succulent Karoo	Eden Western Cape	3 540	95 933	27.10	1.25	Oudtshoorn 29 143	co 77 bA 9 wh 13	Afr 89 Xh 5 Eng 2
Totals			385 600	993 406	2.57				
South Africa			122 million	51.77 million	47		co 9 bA 79 wh 9 Afr 14 Xh 16 Eng 10		

^a co = coloured; bA = black African; wh = white

^b Afr = Afrikaans; Xh = isiXhosa; Eng = English; Sets = Setswana; Ses = Sesotho

^c Dr Beyers Naude was established in 2016 through the amalgamation of the former Baviaans, Camdeboo and Ikwezi local municipalities; Walter Sisulu was also established in 2016 through the amalgamation of the former Gariep and Maletswai local municipalities

Africa, through the lens of environmental history. In terms of more specialist studies, the Karoo region has long been of interest to palaeo-ecologists and geologists because of its fossiliferous mudstones (Meadows and Watkeys 1999), to ecologists because of the diversification in certain plant, invertebrate and reptile taxa and the anthropogenic decimation of mammalian fauna (Cowling et al. 1999; Dean and Milton 1999), and to archaeologists and historians concerned with the fate of southern Africa's 'First People' (Smith 1995, 1999; Hall and Mazel 2005) as well as the colonisation of what Penn (1995, 2005) has described as South Africa's 'forgotten frontier'; major concerns here have included the fate of its indigenous hunter-gatherer and herder societies (Adhikari 2010), contestations over resources and the emergence of new identities (Penn 2005; Legassick 2010, 2016). A relatively small number of social scientists have researched social conditions and livelihoods in the contemporary Karoo (Atkinson 2007; Nel et al. 2007).

To understand and manage the Karoo better for future generations, it is clearly desirable for social and natural scientists to share insights and transcend disciplinary barriers. The importance of interdisciplinary collaboration in dealing with complex problems is widely recognised; in South Africa it has been applied to the Working for Water invasive-alien plant management and job creation project (Biggs et al. 2015). However, there are few examples of interdisciplinary work at a conceptual level. Land and livelihoods research has perhaps come closest (for instance, Rohde et al. 2003). Hoffman et al. (2007) assembled a journal special issue on land use in Namaqualand that focused on interdisciplinary debates around 'sustainability' and the significance of history, policy, politics and economics in shaping land use and its consequences for natural and social systems. Recent internationally-driven interest in the potential for shale-gas and uranium mining in the Karoo, together with the promotion of radio

astronomy through the Square Kilometre Array (SKA) project (Walker and Chinigò 2018) and rapid expansion of renewable energy projects (Milton and Dean 2015), has led to a proliferation of environmental impact assessments and related cross-disciplinary research, much of it confined to grey literature (CSIR 2016; Kirsten 2016; Scholes et al. 2016; Atkinson et al. 2017; Bluff et al. 2017). Yet publications that attempt to link natural and social science perspectives into a coherent treatment of the complex 'development path' of the Karoo over time are still, regrettably, scarce. In important multidisciplinary treatments of the potential impacts of proposed shale-gas mining (Glazeweski and Esterhuyse 2017) and international astronomy (CSIR 2016), studies from various disciplines tend to sit alongside each other, rather than being integrated conceptually.

Some of the challenges of interdisciplinary collaboration are that researchers in different disciplines receive unidisciplinary training (Max-Neef 2005), draw on different literatures, use terminology that may be misinterpreted outside their disciplines, obtain data at incompatible spatial scales, focus on different aspects of problems, and work with very different understandings of methodology and epistemology. While all may agree that the state of the natural environment affects livelihoods, understandings of the concept of sustainable development differ across and within disciplines (Hoffman et al. 2007). Life-science research focuses on factors such as land use, climate change and substrates that affect the abundance and distribution of living organisms. In the social sciences typical concerns include power, social inequality, household dynamics, livelihoods, political economy and scale, but researchers working in such seemingly related fields as political ecology, critical development studies and environmental sociology do not all agree on methodology and theoretical frameworks.

Against this background, this review attempts to develop an integrated overview of social and ecological drivers of change in the past and the present, and their impact on trajectories of change into the future, one that is comprehensible across a wide range of disciplines. It is presented as a step towards the goal of a deeper interdisciplinary account, rather than itself a fully developed synthesis. It comprises three main sections: (1) a broad historical overview to approximately 1994, (2) an analysis of contemporary dynamics (the main body of the article) and (3) some cautious reflections on three major drivers of change into the future (climate change, land use and governance).

Section one: Broad historical overview

The periodisation adopted for this overview works with major shifts in the political economy of the region that have profoundly affected relationships between humans and the natural environment. For the purposes of this article three main periods have been identified: (1) the precolonial era up to the advent of European colonisation in the late seventeenth century, (2) the early colonial period until the mid-nineteenth century, characterised by the entry of Dutch *trekboers* (nomadic pastoralists) into the Karoo and the uneven assertion of colonial authority over the region's northern and eastern frontiers, and (3) the period of settled livestock farming on extensive, mostly white-owned farms

from the mid-nineteenth century to the mid-1990s. Although there are important continuities between the apartheid and post-apartheid eras, 1994, the year of South Africa's transition to formal democracy, has been selected for the end of the historical overview because it heralded a significantly new political era in the country and, by extension, the Karoo.

A comment on the contested issue of terminology for social groups is appropriate here. As far as possible we have favoured 'herders' and 'hunter-gatherers' for the precolonial and colonial periods but where necessary we have used 'Khoekhoen' (adjective Khoekhoe) and San to distinguish between these two groups, along with the linguistically clumsy but commonly used generic term 'Khoisan' when referring to these two groups collectively. We have also adopted the terms used by Statistics South Africa to identify the four main 'population groups' or 'races' in apartheid and contemporary South Africa, where this is required by the context, i.e. black African, coloured, white and Indian/Asian. In the apartheid era the descendants of the Khoekhoen and San were classified as 'coloured', although, as discussed further below, today some are challenging this appellation.

The precolonial era: hunter-gatherers and herders

The Karoo preserves an extremely long record of first hominin and then human occupation, archaeological evidence attesting to a tool-using hominin presence from the Early Stone Age about 1.6–2 million years ago (Beaumont et al. 1995; Smith 1995; Sampson 1986, 2010). Archaeological and recent genetic evidence makes it clear that the original human occupiers of the Karoo and surrounding areas were the ancestors of the San hunter-gatherers who were living there at the start of the colonial period; their physical and cultural presence has been dated back to around 20 000 years BP (Smith 1999; Parkington and Dlamini 2015; Morris 2018).

Having established a presence over most of the African subcontinent over millennia, San lifeways were disrupted some 2 000 years ago by the arrival from the north of the Khoekhoen, transhumant pastoralists with fat-tailed sheep (Elphick 1985; Smith 2005). The origin and ingress routes of these pastoralists are still the subject of debate (Sadr 1998, 2008, 2015); evidence points to Khoekhoe cattle arriving in the subcontinent some centuries after sheep (Sadr 2008, 2015). Thereafter Khoekhoe herders co-existed with the San but also competed for key resources: watering points, pasture (for their livestock), game animals and plant foods, as well as for favourable settlement sites (Elphick 1985). Archaeological evidence suggests that some time before the arrival of the Dutch at the Cape in 1652 the San had been driven from the coastal regions and Gariep riverine zone (regions favourable to pastoralists) into the more mountainous and arid areas of the interior (Beaumont et al. 1995; Parkington 2003). Here the main hunter-gatherer group in the colonial period was the !Xam.

The presence of predators in the Karoo made *kraals* (enclosures into which livestock were herded at night) essential for pastoralists, and explains the stone-built hyaena traps still seen on many local farms and attributed to the Khoekhoen by Pringle in 1821 (Wahl 1970; Maguire 2017). The recent discovery of Khoekhoe pottery at Prince

Albert (Maguire 2015) and the presence of typical Khoekhoe graves in this district extend their known presence in the Karoo to the Swartberg. It now seems that a pan-Karoo presence of herders is indicated wherever it was possible to pasture and water livestock, even if only seasonally.

While it would be a mistake to think of the precolonial era as a time of stasis, the rate of social and ecological change was slow. Before the colonial period the natural system of the Karoo was exposed to a very low density of usage by herbivores, except at very small spatial scales (for example, the herder livestock *kraals*) or for only brief periods, such as during the extremely intense but episodic springbok migrations (*treks*) (Roche 2004). Hunter-gatherer and herder societies were very small in scale and mobile, meeting the vicissitudes of a highly variable climate by moving over vast areas.

The early to mid-colonial period

The advent of the colonial era, conventionally dated to the establishment of the Dutch East India Company (DEIC) refreshment station at the Cape in 1652, marks the beginning of a far-reaching period of change in which the Karoo was slowly drawn into an unfolding global capitalist order. Over time the locus of power shifted increasingly to the new settlers and the colonial powers behind them (first the Dutch, then the British from the start of the nineteenth century). The impacts on Karoo society and biodiversity were profound. By the early nineteenth century the independent way of life of the San and Khoekhoen had all but been destroyed and the area 'made safe' for permanent settlement by Dutch-speaking farming households and a

growing underclass of Khoisan servants, labourers and dependants. The gradual evolution of this colonial society involved both the destruction of the precolonial order and the creation of new, hybrid identities, along with a racialised social hierarchy that persists, albeit in attenuated form, into the present.

This period can be divided into two overlapping phases. The first involved early incursions by Dutch-speaking settlers into the areas that came to be known as the Hantam (around the Hantamsberg), the Roggeveld and the Nieuweveld from the 1740s to the 1830s (see Figure 2), during which time settlement was seasonal and precarious. Like the early livestock herders who had no option but to camp near water and lead nomadic lives, the early European settlers depended on surface water; conflict over access to reliable water thus characterised the colonisation of the region (Marks 1972; Guelke and Shell 2007). The second phase, between approximately 1830 and 1850, saw the establishment of settled livestock farming across much of the Great Karoo and the imposition of stronger government authority from Cape Town. In this time the foundations of the contemporary social geography of the Karoo were laid down, with the establishment of many of the small towns of today, alongside a scattering of Christian mission stations for Khoisan people striving to retain some degree of autonomy.

The impact of Dutch incursions into their territory was felt first by the Khoekhoe people closest to the Cape. The DEIC's primary concern was the provisioning of passing ships sailing to and from the Dutch East Indies. This involved bartering with the Khoekhoen for cattle on the harshest and most unequal of terms. Khoekhoe herds

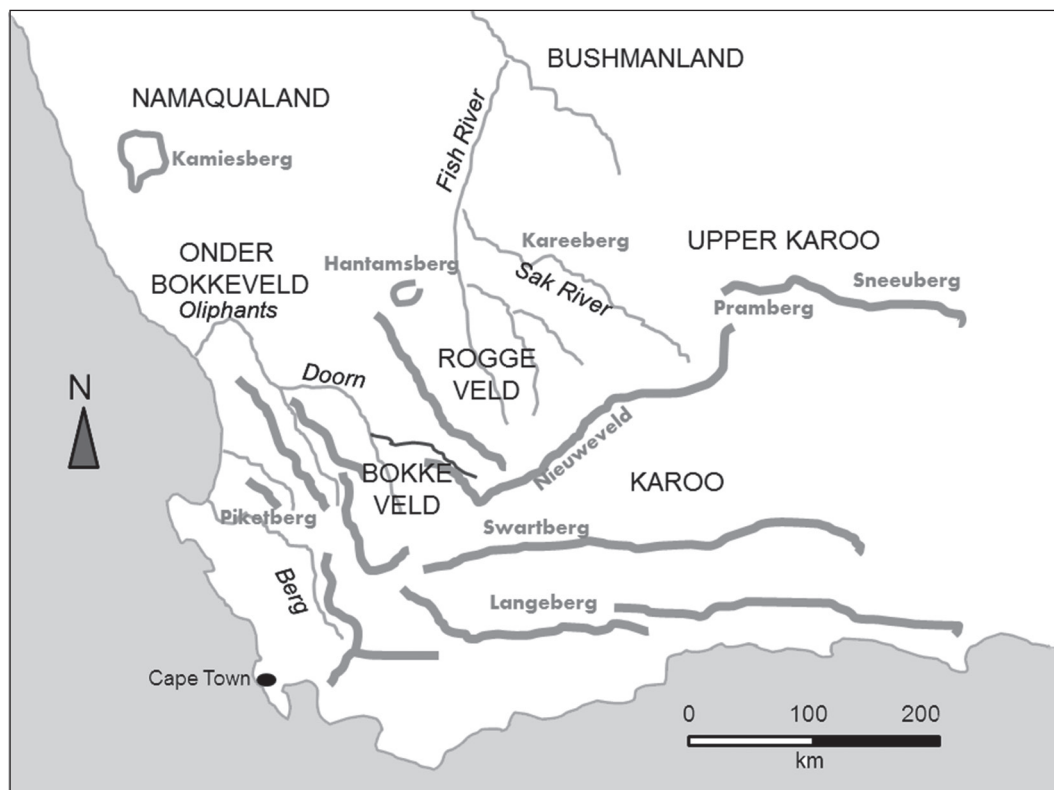


Figure 2: Historical regions of the Karoo, modified from Penn (1986)

were a cultural expression of status and personal wealth rather than a commercial utility: trading for desirable goods transformed cattle into a commodity (Toerien 2010), which influenced Khoekoe behaviour and changed their transhumance patterns. Over time this led to the unravelling of the Khoekhoe way of life and their gradual incorporation as servants and labourers on the lowest rungs of colonial society.

By 1720 there were no more cattle for bartering in close proximity to the Cape, requiring DEIC expeditions to distant Namaqualand; by 1740 the Dutch controlled all the coastal lands south of Namaqualand, the first settlers entering the areas later named Leliefontein and Groene Rivier in 1750 (Penn 1995). Similar expeditions in search of cattle were sent along the southern Cape coast. These trading frontiers were soon followed by a *trekboer* frontier, the DEIC having started to issue grazing licences to Dutch colonists as early as 1713 (Penn 1995). The term *trekboer* refers to Dutch-speaking farmers who practised the transhumant pastoralism they copied from their Khoekhoe servants, and was applied mainly to the settlers who infiltrated the Karoo via the northern route, rather than to the southern settlers who moved into the better-watered midlands of the Grassy Karoo in the east. This region was better able to support cattle (acquired from the amaXhosa on the eastern Cape frontier) than the Great Karoo.

In 1779 explorer-soldier Robert Gordon noted that few traditional Khoekhoe *kraals* were to be seen in Namaqualand (Raper and Boucher 1988), with most Khoekhoen by then in the employ of the colonists. During this same journey Gordon noted that the majority of Dutch settlers in Namaqualand had a 'Hottentot wife or two'. The offspring of these unions, along with runaway slaves and other outcasts from colonial society, came to constitute a new social group, the Bastards. Initially, the Bastards were able to find independent lifeways amongst 'white' settlers, but in time they lost their lands and social status and were obliged to move further north, across the Sak River (the colonial boundary from 1804–1847) and into what was then known as Bushmanland.

Trekboer incursions into the Hantam and Roggeveld began in the 1740s, with the first farm in the Roggeveld registered in 1746 (Hopkins and Marais 2005; Amschwand 2010). The hunter-gatherer groups living there resisted the penetration of the colonists into their land but were met with merciless reprisals in the form of the armed commando system. Captured women were kept as bounty to work on farms, as were children until age 25. Ongoing bloodshed resulted in the 'general commando' of 1774, which set out to remove the San from the Hantam in the north to the Swartberg in the south and the Sneeuberge in the east. Oral testimonies collected by Wilhelm Bleek and Lucy Lloyd in the 1870s from !Xam prisoners from the Brandvlei and Vanwyksvlei areas describe how their immediate ancestors still retained a viable hunter-gatherer way of life in the area known as Bushmanland into the nineteenth century (Deacon and Skotnes 2014). However, by about 1830 the commando system had finally broken all Khoisan resistance (Kotze 1951; Scholtz 1976). This process of at times genocidal subjugation (Adhikari 2010) took almost 100 years.

In this time competition for land was exacerbated by the increased pressure of amaXhosa groups moving into

the Karoo from the Cape's yet more contested eastern frontier from the 1790s (Kallaway 1980; Anderson 1985). This added to the hostilities that made the Hantam, Roggeveld, Nieuweveld and Upper Karoo unfavourable for permanent colonial settlement until around 1830. Van der Merwe (1937) mentions that in 1826 there were only four permanently inhabited farms between the Riet and Sak rivers. Still more pastoralist amaXhosa were settled by the authorities at Prumberg in 1809 and then, in 1830, as a buffer against the San on a major land grant at Schietfontein, the site of present-day Carnarvon (Anderson 1985). This largely submerged history resulted in Carnarvon being an ethnically mixed and predominantly black town when formally proclaimed in 1847 (Chinigò 2018).

By 1840 much of the Great Karoo, up to the Sak River in the north and the edge of the lands retained by the amaXhosa in the east, was settled by the colonists. The rapid rate of advance is borne out by the frequent shifts of the as yet unsurveyed colonial boundary, first from Riet River, the colonial boundary from 1759 (Scholtz 1976), to the Sak River in 1804 (Boeseken 1948), culminating in the annexure of all the land from there to the Gariep (Orange) River in 1847 (Amschwand 2017).

A mission station meant for the embattled San was established at the Sak River in 1799 – the first of several (Schoeman 2002, 2005). It was a failure, but gradually mission stations acquired indigenous followers whose main purpose may not have been religious redemption but a modicum of safety, stability and status, plus access to goods from the Cape, especially guns. These stations became the nucleus of the six 'coloured' reserves that were formally proclaimed in the Northern Cape in 1909 in terms of the Mission Stations and Communal Reserves Act of the Cape legislature – Richtersveld, Steinkopf, Concordia, Komaggas, Leliefontein and Pella (Rohde et al. 2003). Along with administrative centres such as Graaff-Reinet (est. 1786) and Beaufort West (1820), the earliest towns were mission stations (Phillippolis 1822, Colesberg 1830, Amandelboom [Williston] 1845, Schietfontein [Carnarvon] 1847 and Calvinia 1847). They were followed by the first church towns and their subsequent sister congregations (Fraserburg, Sutherland, Murraysburg, Jansenville, Aberdeen, Pearston and others, all in the 1850s), and finally by transport route towns and railway settlements in the 1870s (De Aar 1872 and Laingsburg 1878) (Erasmus 1995). Areas dependent on groundwater were settled last, once deep drilling technology and wind pumps had been introduced in the late nineteenth century (Talbot 1961).

Early settled farming involved heavy stocking of grazing lands because the 'carrying capacity' of the land (a concept that had not yet come into use) was over-estimated. The impact of settlement on the biodiversity of these regions was enormous: on wildlife (e.g. the extinction of the quagga [*Equus quagga quagga*] in the late 1870s [Flower and Lydekker 1891] and eventual local extinction of livestock predators, such as wild dog [*Lycaon pictus*], lion [*Panthera leo*] and brown hyaena [*Hyaena brunnea*]), the almost total extinction of the wild rye grass (*Secale africanum*) after which the Roggeveld is named (Zacharias 1990), and the near extinction of the sterboom (*Cliffortia arborea*), bundled for sale as firewood in centres such as Calvinia.

The consolidation of settled livestock farming from the mid-nineteenth century

The consolidation of colonial settlement after 1840 was underpinned by significant economic changes, building on the technological advances of the industrial revolution, centred on the colonial power, Great Britain. These developments saw farming in the Karoo become increasingly market-oriented, with major implications for its social-ecological system. Important technological innovations included drilling machines, wind pumps, wire fencing, jackal-proof fencing, new knowledge about stock diseases and the advent of the railway in the late nineteenth century. Also significant were the development of land surveying, linked to the history of astronomy in South Africa (Dubow 2018), and the imposition of new ideas around privatised land as itself a commodity to be bought and sold.

The rapid spread of deep drilling technology in the early 1900s allowed permanent settlement far from surface water, thus radically altering grazing patterns and the distribution of livestock (Archer 2000). As discussed further in the section on contemporary dynamics, this had major implications for land cover, biodiversity and settlement patterns. The discovery of diamonds to the north of the Karoo (1866), followed by gold on the Witwatersrand (1886), provided an eager market for Karoo mutton farmers, while the introduction of ostrich farming and a new breed of wool sheep, the merino, tied settler farming in the Karoo firmly to global markets. The late nineteenth century was not only a time of growing prosperity for an emerging white elite in the Karoo but also one when the pastoral economy of this region contributed strongly to the political and economic life of the Cape Colony more broadly – a development that Beinart (2003) argues has not been sufficiently appreciated by many historians. In this time the Karoo became an important site for the development of the natural sciences in southern Africa (Beinart 2003, 2018).

The first ostrich boom (late 1860s to early 1890s) brought improved prosperity to Karoo farmers, with kilometres of ostrich walls built to create camps for domesticated birds. The ostrich industry crashed in 1914 with the onset of World War 1 and changes in the market but the environmental damage it caused has persisted. The introduction of the merino breed of sheep was even more significant. Initially introduced into South Africa by Gordon in 1790, farming with merino sheep began to establish itself first in the Grassy Karoo from the 1820s and 1830s (Scholtz 1976; Beinart 2003). While it took some time before their numbers exceeded those of the fat-tailed Cape sheep, by 1855 three-quarters of the 6.5 million sheep in the Cape Colony were merino and by 1891 they numbered some 12 million (Beinart 2003). The adoption of lucerne in 1861 as a supplement fodder improved wool yields (Beinart 2003) but the accompanying irrigation caused salinisation of heavily irrigated land. Merino wool remained the prime agricultural product of the Karoo into the late 1950s, culminating in the 'wool boom' of 1951 in the wake of the Korean war. Stock numbers peaked at over 23 million in the 1930s but thereafter decreased, in part in response to government policy that rewarded stock reduction to restore poor rangeland condition (Beinart 2003). In the 'coloured reserves' a much higher stocking rate has persisted,

particularly in lowland areas, resulting in reduced cover and shifts in species compared with similar, privately owned rangeland (Hoffman 2014).

In the twentieth century the mining industry established itself as a significant economic player in parts of Namaqualand, with major consequences for the environment in affected areas. Commercial mining of copper and other base metals began in the 1850s in the Springbok region. Diamond mining along the Namaqualand coast commenced in the 1920s, eventually affecting much of the coastline between the Olifants River mouth and Alexander Bay (Viljoen and Reimold 1999). Mining of diamonds through open-cast methods on the coastal plains and in deposits within the Gariep River channel from the 1950s mostly pre-dated environmental legislation, with the consequence that mined areas were left ecologically transformed and degraded.

No new economic drivers emerged within the Karoo in the decades leading up to South Africa's democratic transition, with little urban or rural investment taking place (Nel et al. 2007). After wool prices dropped, many farmers shifted from merinos back to meat-producing sheep breeds, such as the locally bred dorper, which needed less labour. Some farmers began to turn their attention to game farming, although the main impetus around this new land use came in the 1990s, after the passage of the Game Theft Act of 1991 gave private landowners rights of ownership over the wildlife on their land (Carruthers 2008). A process of consolidation of farm holdings got underway from the 1970s, which has continued into the present (Hill and Nel 2018). White migration to larger urban centres beyond the Karoo increased while financially stronger farmers bought out weaker farmers, not only adding to the decline in the white population but precipitating a movement of redundant farmworkers off the land and into nearby small towns. After 1948 apartheid policies enforced racial segregation in Karoo towns, while the National Government's Coloured Labour Preference Area policy attempted to 'freeze' the number of black African families allowed to live and work west of a line drawn through the eastern Karoo to the southern coast.

The transition to formal democracy in 1994 involved major changes to the political geography of South Africa, as the post-apartheid state moved to dismantle the spatial architecture of the apartheid era, by reincorporating the 10 former African 'homelands' in South Africa's rural periphery into the core state and redrawing provincial and municipal boundaries. This process saw the division of the former Cape Province, in which most of the two Karoo biomes were located, into three smaller provinces (Western Cape, Eastern Cape and Northern Cape). Local government was also redesigned through the integration of rural and urban areas within a system of tiered local and district municipalities. In the Karoo, given its size and small-town settlement pattern, this has resulted in very large local municipalities, each comprising a number of widely separated towns or villages and their rural hinterlands. An unintended consequence of this larger national restructuring process has been administrative fragmentation and the weakening rather than enhancement of official commitments to integrated development planning and sustainable resource management for this ecologically sensitive region as a whole.

Section two: Social-ecological dynamics in the present

Our discussion of contemporary social-ecological dynamics spans four key aspects: first, an overview of the physical environment of the Karoo, followed by assessments of social dynamics, changes in land use and changes in biodiversity.

Trends in climate, hydrology, soils and vegetation

Rainfall in the Karoo is highly variable between years, but long-term rainfall records for the southern and eastern Karoo demonstrate multi-decadal (in the order of 20 or 50 years) rainfall cycles. Both unpublished data from Prince Albert and an analysis of 123 years of data from Middelburg (Eastern Cape) reveal wet periods from 1870–1898, 1937–1952, 1986–2014 and dry periods from 1899–1936, 1953–1985, and from 2015 onwards. The likelihood is that eastern Nama-Karoo areas will experience a dry cycle over the next 20 years (du Toit and O'Connor 2014); however, as these authors point out, the high inter-annual variation makes it difficult to discriminate between natural variation and possible effects of global climate change on rainfall.

Temperatures have increased throughout South Africa over the past 30 years (Davis-Reddy and Vincent 2017). Data from the Tierberg Long-term Ecological Research (LTER) site near Prince Albert show an increase in the frequency of extremely high (>42 °C) temperatures as well as a steep increase in mean daily minimum and maximum temperature in all seasons (Figure 3). The incidence of high and low temperature extremes in the Karoo may be either cyclic or episodic, and data runs of more than 40 years may be required to detect trends in this region (du Toit and O'Connor 2017). However, what is clear is that regardless of the causes, the climate in the next two decades is likely to be challenging for those whose livelihoods depend on using natural vegetation in the Karoo (Hoffman 2014), whether farming with domestic livestock or wildlife.

Surface water in the Karoo is ephemeral. There are few permanent springs and no perennial rivers apart from the Gariep River in the north. In the Northern and Great Karoo, pans (shallow ephemeral lakes) flood occasionally but not predictably or seasonally. When they do, their nutrient-rich waters team with invertebrates, attracting thousands of nomadic water-birds. Water was certainly a major factor in the evolution of dormancy and water storage in Karoo plants, and aestivation and nomadic lifestyles among animals. Access to water has also been critical for human settlement and livelihoods. As already noted, the advent of deep drilling technology from the late nineteenth century allowed permanent settlement far from surface water, thus radically altering grazing patterns and the distribution of livestock. However, access to surface water remained essential for growing subsistence crops. Clearing of alluvial vegetation and flood irrigation led to erosion and salinisation of deeper soils along river courses, and such areas have shown little passive recovery since subsistence cropping ceased in the early twentieth century (Macdonald 1989). Reduction in vegetation cover also appears to have led to high rates for soil loss. Decker et al. (2011) suggest that the rate of soil loss in the Karoo during the twentieth century was twice as fast as soil production. Transport of nutrient-rich sediments from uplands, together with water extraction for irrigation,

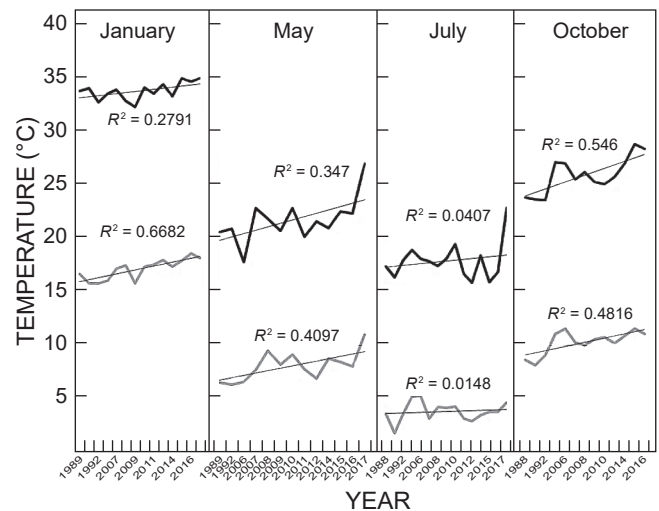


Figure 3: Trends in mean daily minimum and maximum temperatures at Tierberg LTER, Prince Albert, Great Karoo in months representing four seasons, 1988–2017. Source: unpublished data owned by SAEON

has changed the hydrology of some of the few perennial Karoo rivers and resulted in a decrease in tall riparian woodland but an increase in both indigenous (*Phragmites australis*) and alien (*Arundo donax*) reeds (Hoffman 2014).

Another critical hydrological feature is the proportion of precipitation that finds its way into underground reservoirs versus runoff. These reservoirs have driven the windmill-based livestock ranching of the Karoo for one-and-a-half centuries but will face threats of pollution and depletion if shale-gas extraction ('fracking'), uranium mining and/or geothermal energy production proceed (Dhansay et al. 2017; Glazewski and Esterhuysen 2017).

Social dynamics

A challenge for social research is that there is no definitive data set on the sociology of 'the Karoo' as a whole, or of the Succulent Karoo and Nama-Karoo biomes individually. As already noted, the administrative boundaries of Karoo municipalities, the units around which much statistical and other social information is organised, do not map neatly onto the two Karoo biomes. The following discussion draws on composite data from 26 local municipalities that are deemed to fall either entirely or predominantly within the Nama-Karoo and Succulent Karoo biomes, supplemented by other sources of data, with the Northern Cape province at times used as a proxy for 'the Karoo'. Table 1 provides demographic and economic details for each municipality, grouped in terms of the five overlapping social-ecological subregions we have identified (Namaqualand, Northern Karoo, Great Karoo, Grassy Karoo and Little Karoo).

This composite data makes it clear that sociologically, as ecologically, the Karoo is not a simple, homogeneous region. However, some common features inform not only the lived experience of those living in the contemporary Karoo, but also the dominant idea of the Karoo held by the great majority of South Africans who do not live there, including the all-important political elites who drive policy. Together these features reinforce the relative political and

economic marginalisation of the Karoo within the political economy of South Africa as a whole, a condition that can itself be seen as one of its defining features. Looking forward, unless local people themselves become more empowered to shape a future that is socially as well as ecologically sustainable, the prospects for tackling the significant challenges they face appear poor.

As discussed further in the next subsection, most of the Karoo is still given over to ranching on private, predominantly white-owned land (Snijders 2015). Given their aridity, the two Karoo biomes are very sparsely populated compared with the remainder of the country; while together accounting for nearly one-third of the land area of South Africa, they hold under 2% of the total population, with an average population density of 2.57 people per square kilometre compared with the national average of 47 (Table 1). However, the Karoo average masks important differences among the subregions. Thus the local municipalities of the Great Karoo are considerably more sparsely populated, at less than one person per square kilometre, than the better-watered and economically more favoured Grassy Karoo and Little Karoo; in the latter subregion the population density in the Oudtshoorn local municipality is nearly 10 times the regional average. Overall, the rate of population growth is both slow and uneven, with a number of municipalities showing static or extremely low growth rates since the mid-1990s (Hill and Nel 2018). An analysis of migration trends in the Northern Cape by Eigelaar-Meets (2018) also shows that between 1996 and 2011 the province demonstrated a 'persistent negative net migration' overall, driven mainly by out-migration among the white and coloured populations.

At the same time, the very low population density of the Karoo as a whole does not adequately reflect the importance of its distinctive small-town environment in shaping the life experience and development aspirations of the majority (73% by 2004) (Hill and Nel 2018) of its residents. In a study of the small-town 'habitus' of Carnarvon, Butler (2018) identified the following as major themes: a strong sense of place in which the intimacy of small-town life is significant; Christianity and concerns around social justice; being down-to-earth and content with little as important values, along with major concerns around the vulnerability of the youth and uncertainty about the future. Large distances between towns, poor road infrastructure and the absence of public transport limit social and economic connectivity between towns.

Also significant is the distinctive demographic profile of the Karoo in terms of 'race' and language compared with the remainder of the country, which contributes to its political marginality nationally. This is a space where people classified as 'coloured' rather than 'black African' (in the still influential lexicon of apartheid) form the majority of the population, the predominance rising noticeably as one moves from east to west. Thus the 2011 national census classified fully 88% of the population of the Nama Khoi local municipality in the Northern Cape (around Springbok) as coloured, compared with 65% in the Dr Beyers Naude Local Municipality in the Eastern Cape (Table 1). Nationally, the percentage of people classified as coloured is under 10%. As already indicated, 'coloured' identity is a product of the

region's complex history and, while it has become largely naturalised in people's understandings of themselves and others, it is neither a sufficient nor static frame of reference. Recent work by folklorist de Prada-Samper (2017) suggests that aspects of |Xam cultural heritage continue to inform 'coloured' identity in the present, while there is growing evidence of older Khoisan identities being revalorised and reframed (Besten 2013).

At the same time, the racial hierarchy of white over black that apartheid social engineering cemented is still strongly evident in the economy as well as socially, in racially specific church congregations and 'white flight' from public schools. However, the change in government has seen the emergence of a small black middle class, mainly located in government and the teaching and health professions (Nel et al. 2007; Atkinson 2018), while the white population has continued to decline in both absolute and relative terms; by 2011 people classified as white accounted for only 7.1% of the population of the Northern Cape (Statistics South Africa 2011; see also Hill and Nel 2018).

Afrikaans is the dominant language, albeit shading into an increasingly stronger presence of isiXhosa as one moves eastwards (Table 1). Both Afrikaans and Christianity are widely shared cultural resources, serving to mediate the racial hierarchy of white over black and provide some basis for common understandings about local challenges across racial lines. This was evident at public consultations held in conjunction with the Environmental Impact Assessments around shale-gas mining and the SKA in 2016, where external experts' use of English (often of a highly technical nature) was a source of frustration for local participants (Borchardt 2016).

The Karoo also has distinctive social challenges. As a region it shares many of the problems of other non-metropolitan regions in South Africa in terms of high levels of poverty and unemployment as well as heavy dependence on social grants and generally low education levels. Social development agencies in local municipalities identify teenage pregnancy and high dropout rates from school as major concerns that both reflect and perpetuate social dysfunctions. Thus in 2015 the delivery rate to women under the age of 18 in the Central Karoo District Municipality was 13.3%, which was significantly higher than the Western Cape provincial rate of 5.5% (Central Karoo District 2016). In addition, the Karoo faces particularly serious challenges around substance abuse, with disturbingly high levels of alcohol abuse and associated social and health concerns that demand urgent attention. Levels of Foetal Alcohol Syndrome recorded in some districts are the highest reported in the world (Olivier et al. 2016). The emergence of *tik* (crystal methamphetamine) addiction in the last decade is adding to the problem (SACENDU 2016). Intervention programmes of non-governmental organisations, such as the Foundation for Alcohol Related Research (FARR), based in De Aar, and the Hantam Community Education Trust, situated outside Colesberg, are commendable but many more such programmes are needed across the region; research into the neglected history of alcohol and alcohol abuse in the Karoo is also urgently needed, to better understand the drivers of this regional pandemic.

The pattern of uneven economic decline described in the previous section has persisted into the post-apartheid era but the tourism industry has become a much more prominent sector and an important source of employment in a job-challenged region (Ingle 2010; Toerien et al. 2016); this has been underpinned in part by a large increase in the conservation estate (discussed below). Residents in different centres have sought benefit from this economic opportunity, with a few favourably located towns (such as Prince Albert and Graaff-Reinet) experiencing something of a 'post-productivist' boom among the Karoo's small middle class (du Rand et al. 2016). The Namaqualand flower spectacle in spring now attracts visitors from around the globe. However, many small towns continue to experience economic decline (Nel et al. 2007; Hill and Nel 2018). Also impacting on social dynamics are major changes in land use, the focus of the next section.

Land-use changes

As already discussed, livestock production has underpinned the economy of the Karoo since the mid-nineteenth century. For much of the twentieth century, the tenure, production and settlement patterns laid down in the late colonial period appeared relatively stable but more recently this order has come under pressure. The hegemony of white commercial farming is being challenged nationally by demands for the speeding up of the country's sluggish land reform programme and an end to the inequitable distribution of land between black and white. The nature of commercial farming in the Karoo is itself changing, while there are calls for the region's fragile biodiversity to be better protected through the extension of the conservation estate. In addition, major new non-agricultural land uses are bringing powerful external actors into the picture, variously promoting astronomy, renewable energy and possible shale-gas and uranium mining as the answer for the development challenges facing the Karoo.

The three main forms of land tenure in South Africa (private, communal and state) are all present in the Karoo but to very different degrees compared with the remainder of the country. Communal areas (the former coloured reserves) occupy around 3% of the Karoo (our estimate) in the north-west. Protected areas make up a yet smaller (though growing) fraction (Table 2). For the most part, however, the Karoo is privately owned. Of relevance for national debates on land reform, by far the greatest extent of privately owned commercial farm land of any province is found in the arid Northern Cape (here being used as a proxy for the Karoo); at just under 30 million ha, commercial farms constitute over 80% of this province and fully 36% of all commercial farmland in South Africa by area, but account for only some 13% of farm units nationally (Statistics South Africa 2013). As already noted, average Karoo farm sizes are increasing and the number of commercial farms declining, leading to reduced employment opportunities. By way of example, of 348 farms with resident owners and farmworker families in the Carnarvon/Vanwyksvlei/Brandvlei area in 1960, by 2015 only 56 (16%) still had permanent residents (Nel 2015). The Agricultural Census of 1991 recorded a total of 6 593 'commercial farming units' in the Northern Cape; by 2007 the number had dropped to 5 128 (Statistics South Africa

2013). While farmers' concerns around land reform, farm security and stronger state regulation of labour conditions have all been implicated in this trend, it also reflects a longer history of concentration in commercial agriculture that predates the transition to democracy. Nationally, the number of farming units decreased from some 117 000 in 1950 to 66 000 in 1980, with a concomitant decline in farm worker numbers (Beinart 1994).

Another important development within commercial agriculture involves the shift towards more wildlife-based enterprises. The move from livestock production has been attributed to falling profits, increased stock theft, changes in labour legislation as well as foreign investment (ABSA Group Economic Research Department 2003; Brandt and Spierenburg 2014; Snijders 2015). Game farming for venison production and hunting was already in evidence in the Karoo in the 1960s (Berry 1986), but the industry has grown exponentially since the 1990s. More recently, professional urban 'lifestyle farmers' have converted livestock farms to game farms as investments or for personal enjoyment (Reed and Kleynhans 2009; Wessels and Willemsse 2013). According to data collected by Ramsay (2016), by 2016 almost 6 million ha (equivalent to almost one-sixth of the Karoo) were allocated to game farms in the Eastern, Northern and Western Cape provinces (including but not exclusively in the Karoo). Wildlife-based enterprises serve to maintain natural habitat but may have negative consequences for biodiversity in the long term (Hayward and Kerley 2009) and can also be responsible for habitat degradation. Some wildlife-related enterprises involve animal species with no conservation value, such as alien mammals for hunting (e.g. fallow deer) or potentially damaging indigenous species that are out of range in the Karoo, e.g. giraffe (Vorster 2017).

There is no up-to-date study of land reform in the Karoo as a whole but the available information points to the state-run programme being mired in problems around governance, reach and productivity that are similar to those

Table 2: Increase in the area committed to conservation in the Karoo within the past century. NP = National Park; NR = Nature Reserve; WHS = World Heritage Site. Sources: compiled from open-access sources

Park	Year initiated	Original area (ha)	Area in 2018 (ha)
Akkerendam NR	1962	2 750	2 750
Anysberg NR	1988	62 500	62 500
Augrabies Falls NP	1966	<10 000	55 383
Camdeboo NP	1979	14 500	19 405
Gamkaberg NR	1974	10 430	10 430
Goegap NR			7 000
Karoo NP	1979	7 209	76 800
Mountain Zebra NP	1937	1 712	28 400
Namaqua NP	1988		70 000
Oorlogskloof NR			4 776
Richtersveld NP	1991	162 445	162 445
Richtersveld WHS	2007	160 000	160 000
Rolfontein NR	1970	8 000	8 000
Square Kilometre Array	2017	130 000	130 000
Tankwa NP	1986	27 064	146 373
Total			~944 262

reported nationally (Cousins and Walker 2015). To date the total hectareage involved is small and the impact on racially skewed land ownership patterns very modest. The state has transferred ownership of the former coloured reserves to local municipalities or trusts through the Transformation of Certain Rural Areas Act of 1999, while significant land restitution claims have included the Richtersveld and Riemvasmaak. The latter case saw the transfer of 74 000 ha of land (including 4 000 ha of Augrabies National Park) to local communities who had been displaced from their land in the 1970s. However, the re-instatement of a communal grazing system without strong management institutions resulted in chronic overgrazing, such that grazing capacity was reduced within a decade (Hoffman 2014).

More work is needed to map land redistribution projects across the Karoo itself, but in the Northern Cape a total of 1 469 100 ha – approaching 5% of commercial farmland in the province – was transferred to black beneficiaries between 1994 and 2016 through this subprogramme of land reform (DRDLR n.d.). Of note is that half of this land has involved leaseholds to black livestock farmers under the Municipal Commonage Programme. Historically, most Karoo towns had publicly owned commonage lands attached to them that came to be leased to white commercial graziers. After 1994 this category of land was identified as an important vehicle for land reform (Atkinson et al. 2012; Atkinson and Ingle 2018). When first developed in the late 1990s, the municipal commonage programme was regarded as innovative, with the potential to serve both aspirant full-time black farmers and part-time farmers looking to supplement livelihoods. However, effective management has proved elusive in many commonage projects, undermining their potential (Atkinson and Ingle 2018; Davids 2018).

The emergence of new, non-agricultural land uses in the Karoo since the early 2000s is reducing the social and economic authority of the farming sector and unleashing new dynamics in the region. Astronomy is increasingly prominent here, with the Karoo identified by the national government and its international partners as a prime site for investment in astronomy because of its dry climate, clear skies and, crucially, low population (Walker and Chinigò 2018). In order to protect this investment the whole of the Northern Cape, excluding the Sol Plaatje Municipality around Kimberley, has been declared an astronomy advantage area in terms of the Astronomy Geographic Advantage Act of 2007 (South African Government 2008; SKA n.d.). This gives the Minister of Science and Technology considerable power to regulate land use in the interest of astronomy, the long-term implications of which for other land users have yet to become clear. In addition to its optical astronomy site outside Sutherland, the state is committing heavily to the SKA, a major international radio astronomy project being developed on a core site some 80 km from Carnarvon. This has involved purchasing over 30 farms (130 000 ha), which have since been declared a special nature reserve dedicated to the promotion of science. Radio astronomy has particularly onerous requirements for minimum radio frequency interference, which is impacting negatively on farming activities in neighbouring areas, for instance through restrictions on the use of cell phones and electric fences (Kirsten 2016; Atkinson et al. 2017). Many farmers

and residents in nearby towns resent 'The Game Reserve for the Stars' and the fact that an international bid was made without local people being properly informed about the full implications of this global science project on their doorstep (Butler 2018; Gastrow and Oppelt 2018).

The renewable energy sector has also developed at a rapid rate, with 6 328 MW of energy capacity already procured between 2011 and 2016 (Energy Research Centre, CSIR, IFPRI 2017), the majority of this from solar and wind projects located within the Karoo and adjacent areas. Energy projects are widely spread across the Karoo and across individual vegetation types. Individual developments entail a relatively small transformation of habitat, with a total of 40 000 ha expected to have been transformed by 2030. While livestock farming has been displaced on solar power projects, it has usually continued on wind farms. The energy sector has contributed to employment during the establishment phase, but the operational phase relies primarily on skilled people from outside and the economic proceeds flow to corporate headquarters located elsewhere. The electricity generated also flows into the national grid, without (at this stage) offering local residents the benefit of cheap, renewable power.

The prospect of shale-gas and uranium mining is, arguably, casting an even deeper shadow over large swathes of the Great Karoo. The effects of exploiting potential shale gas reserves through hydraulic fracturing ('fracking') are considered in detail in Glazewski and Esterhuysen (2017). Development of this industry is not yet confirmed, but if it proceeds its impact on ground and surface water supplies will threaten both social and ecological systems in this arid region. Furthermore, although the footprint at the individual point of extraction is small, once transport infrastructure (roads and pipelines) is factored in, the cumulative environmental impact is not inconsiderable. If fracking is pursued, its contribution to the Karoo's economy is expected to mirror that of the renewable energy sector in terms of very limited local employment opportunities once the construction phase is over and the flow of profits to external investors (Glazewski and Esterhuysen 2017). Application for exploration and mining of uranium over a large portion of the central Karoo (centred on Beaufort West) has been made but mining has yet to commence; recent reports indicate that international investors are withdrawing from this development, citing unfavourable global market conditions and uncertainty around 'mineral retention rights' in South Africa (Cramer 2018). Open-cast uranium mining, if pursued, would also pose major threats to human health and to the environment (Wassenaar et al. 2013).

In Namaqualand open-cast mining of dune sands bearing titanium heavy minerals has been developed on the coast since the 1990s (Rozendaal et al. 2009). Mining of dune sands has affected <50 km of coastline; further expansion is likely dependent on trends in commodity prices. Overall, mining ventures have had a substantially negative impact on coastal Succulent Karoo vegetation in affected areas. Rehabilitation efforts aim to re-establish a multi-species vegetation cover, including indigenous species, but previous levels of biodiversity are not recovered, with geophytes and slow-growing shrubs lost in the mining process (Pauw et al. 2018). Further inland, Aggenys was established in

the 1970s to service the mining of zinc, lead, copper and silver (Viljoen and Reimold 1999). Ores containing these base metals are concentrated in space; while the mined area becomes completely transformed, the extent of the impact depends in part on the total area affected. Outwash from tailings and rock dumps into drainages may contain high, potentially harmful, levels of the mined heavy metals (Syakalima et al. 2001), but the risk of water pollution is partly offset by the arid climate of the Karoo.

Conservation is another non-agricultural land use that has become more prominent in recent decades. Since the 1960s, a considerable increase in the extent of state lands has occurred, with the conversion of private land to conservation estate administered mainly by the South African National Parks (SANParks). Non-SANParks conservation areas cover a comparatively small area (Table 2). National Parks (NP) have increased in size since their proclamation, by 16.6-fold in the case of Mountain Zebra NP. To this must now be added the SKA core site, which will be managed by SANParks as a 'special nature reserve' to which the general public will not have access; land of the Sutherland Observatory also functions as a nature preserve. Expansion may continue; for example, the Department of Environment Affairs (DEA) has approved the Karoo Corridor Park plan, incorporating state and private land and linking the Camdeboo and Mountain Zebra NPs to create a 520 000 ha megapark. Creation of conservation areas has recreated facsimiles of previous natural systems, through the replacement of livestock with a complement of indigenous wildlife species. The Richtersveld NP and the neighbouring Richtersveld World Heritage Site provide an interesting exception, with the potential for wider application – the former a contractual park between SANParks and the local Nama community and the latter created by the Nama community in order to protect an integrated botanical and cultural landscape. Here traditional land-use practices of raising livestock are allowed to continue.

In summary, the combination of state-owned land committed to conservation and astronomy and communal land with conservation as an aim has resulted in some 932 000 ha – an area about half the size of the Kruger NP – currently set aside for conservation. While this represents a major increase since the 1970s, it is still a small percentage of the Karoo. Evaluation of the loss of agricultural production and associated employment against the opportunities offered directly by these conservation areas, as well as indirectly through associated tourism, is beyond the scope of this review. However, of concern is that most of the revenue derived from national parks goes to central coffers. Similarly, the development of the SKA, while hugely significant for building national science and technology capacity within South Africa, is likely to make a negligible contribution to the economy of the Kareeberg Local Municipality and the Karoo more generally. Expansion of state land in the Karoo over the past 50 years thus appears to have weakened, rather than strengthened, the previously tight coupling between land use and local livelihoods.

Changes in biodiversity

The Karoo-Namib region of southern Africa is rich in plant and animal species, with high levels of endemism in plants

(Cowling and Hilton-Taylor 1999) and animals (Vernon 1999). Steep altitudinal gradients and heterogeneous surfaces, all of which are present in the Karoo, tend to be species-rich. Patchiness and beta diversity in relatively homogeneous landscapes are maintained by inequitable water distribution (small drainage lines), biogenic activities such as patch grazing, ant nests and termitaria, as well as by patchy disturbances caused by hail storms, lightning strike fires and differential erosion rates and episodic flooding. Some Karoo-endemic plants and animals are confined to exposed sandstone bedrock that outcrops on the edges of scarps, where soil erosion is rapid and safe sites in rock crevices confined enough to limit competition from non-specialists. The Karoo is a dynamic landscape (Meadows and Watkeys 1999) leading to speciation in plants, such as Aizoaceae with short-distance seed dispersal, and animals, such as scorpions, with movements restricted geographically by fold mountains and other barriers (Prendini 1995).

In the past, large herbivores (antelope and equids) would have used the Karoo in the good times, retreating back to higher rainfall areas during the dry times (Smith 1999). In the case of springbok, the available evidence suggests that the start of the major movements by this species was the slow concentration of animals in areas where there were still some resources. As numbers grew, so resources became scarce and this precipitated the *treks* that were a thing of the past by the early 1900s (Roche 2004). The advent of livestock keeping by colonists precipitated substantial environmental change, including degradation caused by more or less continuous grazing and browsing of the shrublands (see, for example, Burchell 1822). Karoo shrublands cannot carry a large biomass of herbivores for extended periods (Esler et al. 2006). These concerns were noted as early as the late 1800s (Shaw 1875). While livestock density declined from the 1930s in response to droughts, wool prices and government policy that rewarded stock reduction (Beinart 2003), many parts of the Karoo, and indeed many rangelands in southern Africa, still show signs of persistent degradation (Downing 1978; Hoffman 2014). Some areas have reduced ability to carry livestock sustainably (Dean and Macdonald 1994).

Hoffman (2014) presents evidence that the Nama-Karoo biome has seen some reversal in degradation and a significant increase in grassiness since the 1960s, in response to reduced livestock numbers and a shift in rainfall seasonality from winter to summer (du Toit et al. 2018; Hoffman et al. 2018). Increased grassiness has led to fire occurrences as far west as Loxton, which is a new phenomenon (du Toit et al. 2015a, 2015b) with unknown implications for biodiversity. Hoffman (2014) has also pointed out that vegetation can become severely degraded over a single decade under heavy stocking. Productivity of degraded vegetation declines through the replacement of palatables with unpalatable perennials and annuals that provide no grazing during drought (Rutherford and Powrie 2013; Hoffman 2014). Although potentially reversible, such recovery is delayed by the absence of seed banks and competition from long-lived dominants (Wiegand and Milton 1996; Seymour et al. 2010). Apart from losses of palatable primary production, and the disappearance of a large native

animal component, these changes suggest that processes in the arid rangelands are no longer functioning as they did in the precolonial era (Talbot 1961).

The legacy of change manifested in the present state of the rangelands of the Karoo has had important consequences for biodiversity. However, the situation is complex. Although the heavy stocking rates imposed on rangelands by the early settlers took their toll, many other factors have contributed to changes in biodiversity; these include hunting, the control of predators, the disruption of nomadic movements by large herbivores through fencing, the perturbation of waterways and their concomitant vegetation (Acocks 1976), road construction, and the development of farms with their oases of green around farmhouses and water points. Collectively, these have led to many changes in the original fauna and flora and the disruption of ecological processes (Milton and Dean 2015). Historically, locust (*Locustana pardalina*) outbreaks, mainly in the Nama-Karoo, provided a source of food for many species of predator, including mammals, birds, reptiles and invertebrates (Erasmus 1988). With fluctuating outbreaks of locusts, the food-webs become dynamic (Henschel 2015) and predator populations would similarly rise and fall. Control of past locust outbreaks using chemicals must have had a major influence on local biodiversity, but there are no studies that address this aspect.

The increase in the abundance of woody plants along many of the non-perennial river courses, especially *Acacia karroo* (*Vachellia karroo*), has been a particularly conspicuous change (Acocks 1976; Hoffman and Rohde 2010; Hoffman 2014). The expansion of their distribution range by greater kudu (*Tragelaphus strepsiceros*) and vervet monkeys (*Cercopithecus pygerythrus*) can be linked to the encroachment of trees along drainage lines (Macdonald 1992). The expansion of *A. karroo* alone has surely benefitted vervet monkeys, with the trees providing a constant source of food products that has allowed the monkeys to reach high densities in places (Pasternak et al. 2013). Similarly, Namaqua Warblers (*Phragmacia substriata*) are now more widely distributed in the Karoo than formerly; this expansion is also thought to be linked to the increase in trees along drainage lines and in farmhouse oases (Vernon 1999). However, overall the populations of many species of plants and animals have been seriously reduced through changing land use. The historical transformation of alluvial terraces along drainage lines for subsistence crops has led to the demise of the riverine rabbit (*Bunolagus monticularis*) in many parts of its former range (Macdonald 1992). Populations of two dwarf tortoise species, Karoo dwarf tortoise (*Chersobius boulengeri*; Near Threatened) and the speckled dwarf tortoise (*Homopus signatus*; Vulnerable), both endemic to the Karoo and Red Data listed, have been seriously reduced, probably although not entirely because of land use (Bates et al. 2014). The development of buildings, roads and water extraction in remote and scenic parts of the Karoo as a consequence of the increase in tourism is also likely to affect the status and distribution of species with limited distribution ranges. One such example is Braack's dwarf leaf-toed gecko (*Goggia braacki*), which has a Near-Threatened status and is thought to have a declining population because of increased

tourist activity and grazing by livestock (Bates et al. 2014).

Formerly, large mammals, their predators and associated fauna (such as avian and mammal scavengers and a diversity of smaller animals that feed on carrion) occurred over much of the Karoo. Direct observations and travellers' reports (Rookmaaker 1989; Skead 2011), along with the evidence from the distribution of epizoochoric plant species (Milton et al. 1990) and place names (Dean and Milton 2003), all suggest that large mammals were present, at least sporadically, throughout much of the Karoo. Reasons for their demise are well known (Skead 1980, 1987) and include hunting, fencing that disrupted nomadic movements (Dean et al. 2018), the rinderpest epidemic of the late 1800s and early 1900s (Stevenson-Hamilton 1957) and loss of grazing resources. While on-going predator control has failed to reduce sheep losses or black-backed jackal (*Canis mesomelas*) and caracal (*Caracal caracal*) populations, it has reduced populations of Cape leopard (*Panthera pardus*) (Devens et al. 2018). By-catch in traps and poisoning are potentially threatening populations of bat-eared foxes (*Otocyon megalotis*) and aardwolf (*Proteles cristatus*) but leading to increases in meso-predators such as mongooses; this in turn increases predation impacts on ground-nesting bird populations (Lloyd 2007).

The historical distribution of the avifauna is similarly fairly well known, and the reasons for the disappearance of certain species, mostly the large raptors and vultures, are clear. Factors influencing changes in the distribution of other Karoo bird species are clear in some cases but less clear in others. Local increases in temperature will play a part in re-organising bird distributions, but knowledge of distribution shifts as a result of climate change is still at the stage of modelling (Simmons et al. 2004) and not yet supported by field data. Using contemporary survey data, Cunningham et al. (2016) have suggested that the increase in abundance and distribution of Pied Crows (*Corvus albus*) in south-western South Africa (including the Karoo) is in response to climate change, but this is complicated by other factors. Pied Crows commonly nest on pylons and other man-made steel structures (Madden 2013; Cunningham et al. 2016), so the increase in power lines and thus available nest sites has also influenced population dynamics.

One of the factors that has changed bird distribution in the Karoo is the widespread planting of alien trees in towns and at farmhouses and roadside pull-offs. Alien trees in the Karoo provide potential nest sites for several bird species (Macdonald et al. 1986; Macdonald 1986, 1990; Hockey et al. 2005; Dean and Milton 2008) that were probably previously excluded from the region by the lack of suitable trees. Land-use changes, such as irrigated crop lands, impoundments and roads have increased habitat or foraging opportunities for a number of bird species (Hockey et al. 2005), with some local changes in avian diversity (Schwarzenberger and Dean 2003).

The increase in *Prosopis* spp. invasions in parts of the Karoo, such as along the Hantam River (Hoffman and Rohde 2011) and in the Kenhardt, Carnarvon, Vanwyksvlei and Britstown areas (Harding and Bate 1991), is almost certain to influence local biodiversity. For example, drainage lines invaded by *Prosopis* spp. in the arid savanna show some small differences in bird species assemblages (Dean

et al. 2002). In the same general area, dense *Prosopis glandulosa* stands influence the species assemblages of dung beetles, in particular by excluding some of the larger species (Steenkamp and Chown 1996). Alien plants may also play a role in the range expansion of some insects in the Karoo, as they have done in the Western Cape province (Geertsma 2000). There are few data sources on changes in distributions of invertebrate species in the Karoo, with the changes that have been reported largely anecdotal and probably due to land use. For example, livestock ranching can have marked changes in web spider populations in rangelands (Henschel and Lubin 2017, 2018). Populations of Karoo ruspers (caterpillars; *Loxostege frustalis*) are now larger than in the past, with a greater impact on shrublands, probably as a result of the expansion of *Pentzia* spp., particularly *Pentzia incana* (Möhr 1982), and this in turn through grazing and land management.

The shift to game farming discussed in the previous section is potentially disastrous for the continued well-being of karroid shrublands, unless carefully managed. This is because game is not easy to move and tends to overgraze patches in the landscape (Vorster 2017). Moreover, predators are controlled as much as they are on sheep farms while expensive game animals are being fed supplements during droughts and lean times but continue to take whatever they can in the way of forage from the shrublands, resulting in extreme overgrazing impacts (WRJ Dean pers. obs.). These are probably irreversible in the short term, and largely irreversible in the long term.

It is not possible to go back to the tightly coupled herbivore–carnivore–scavenger systems that formerly existed in the Karoo. However, for the biodiversity of the region to be conserved into the future, as many patterns and processes as possible must be conserved across the largest area possible.

Section three: Drivers of change into the future

Given the complexity and unpredictability of social-ecological systems referred to in our introduction, projecting trajectories of change in the Karoo into the future is a formidable task. The Karoo is not a closed system but interacts with and is impacted by multiple developments and events, across different domains and scales (local, national and global), the analysis of which is beyond the scope of this review. What we offer here are brief reflections on three cross-cutting and interacting drivers of social and ecological change that have emerged through our review of the region's history and contemporary dynamics as significant in shaping trajectories of change. Climate change is undoubtedly a key driver of change, along with changing land use. Also critical, but equally, if differently, difficult to predict, is the issue of governance, more particularly the role of the state with regard to policy direction and enforcement relating to the environment and economic and social development.

Notwithstanding the significance of the new land uses described above, livestock farming by both commercial and communal graziers is expected to remain the main land use across most of the Karoo into the foreseeable future. Understanding how it is likely to be impacted by climate

change and what mitigation or adaptation strategies are called for is thus of overriding importance. A suite of models all predict a warming climate for the Karoo (IPCC 2014). While the extent of this cannot be determined with accuracy, any increase in temperature will place an increasing evapo-transpirative demand on plants and is likely to have negative effects on endemic succulent plant species (Young et al. 2015). Importantly, however, changes in precipitation are not expected to be uniform across the west–east gradient of the Karoo. There is general agreement among climatologists that the winter rainfall region of the south-western Cape, that is the area containing the Succulent Karoo, will receive less rainfall (up to 20%) (Hewitson and Crane 2006; McKellar et al. 2007; Engelbrecht et al. 2009), consistent with the poleward retreat of rain-bearing mid-latitude cyclones (although an analysis of rainfall trends from 1900 to 2000 revealed no evidence of such a trend nor of an increasing incidence of drought over that period; Hoffman et al. 2009). At the same time, the eastern and north-eastern portion of the Karoo is predicted to receive a greater amount of summer and annual rainfall than historically, while rainfall for the central Nama-Karoo region is not expected to change much (Hewitson and Crane 2006; Engelbrecht et al. 2009). A pattern of increasing summer rainfall has been conspicuous for Middelburg in the eastern Karoo over the past 30 years (du Toit and O'Connor 2014). For the central Karoo increasing aridity would still be expected, owing to increasing temperatures.

A challenge for conservation will be to maintain a matrix of natural vegetation across which plant and animal species can adapt their distribution to an altered climate. This should be facilitated in the Karoo because livestock production ensures the predominance of natural vegetation. However, the impact of different grazing practices on biodiversity has generally been poorly investigated (O'Connor et al. 2010) and more than a century of livestock grazing may have already taken its toll on plant diversity in some regions, leaving only a grazing-resistant flora (Seymour et al. 2010; van der Merwe et al. 2018).

Change in temperature, amount and seasonality of precipitation could each on their own induce distributional changes in vegetation at the level of biomes, communities and individual species, with accompanying changes in faunal distribution; acting in concert, these changes may be substantial. A decrease in annual rainfall for the winter rainfall region (McKellar et al. 2007; Engelbrecht et al. 2009) would likely induce marked compositional changes in the Succulent Karoo, with leaf succulents benefitting at the expense of non-leaf succulents (Hoffman et al. 2009). An increase in summer rainfall for the eastern Karoo (Hewitson and Crane 2006; Engelbrecht et al. 2009) is predicted to benefit grasses at the expense of karroid shrubs (Roux 1966; O'Connor and Roux 1995). Increasing grassiness of the eastern Karoo is now well documented (Masubelele et al. 2014; du Toit et al. 2018; Hoffman et al. 2018) and may portend expansion of the Grassland biome at the expense of the Nama-Karoo biome (Masubelele et al. 2015). Graziers have already responded to an increased abundance of grass in the eastern Karoo by partially substituting cattle for small stock. The associated increased incidence of fire on the eastern Karoo plains has also

resulted in a substantial decline of reseeded dwarf shrub species (du Toit et al. 2015a, 2015b).

The Karoo has always been climatically unpredictable, but the original hunter-gatherer and herder societies, as well as the natural fauna, were able to accommodate this by moving over large areas in order to exploit the fleeting availability of resources. Transhumance grazing remains evident among the Nama graziers of the Richtersveld (Hendriks et al. 2005; Hempson et al. 2015), while some commercial graziers in the Karoo operate across multiple properties, allowing movement of stock from high to low altitude, or from summer to winter rainfall. Australian commercial graziers facing similar challenges also practise 'agistment' of stock between properties far removed from one another, in order to exploit spatial variation in resource conditions in response to climatic variation (Stafford-Smith and Cribb 2009). However, today the majority of both commercial and communal graziers outside the Richtersveld are based on relatively small properties, with closed boundaries. Even a well-managed farm is vulnerable to the impact of severe, extended drought, because growth is likely to be poor over the entire property and purchasing fodder supplies is not economically sustainable. Many commercial graziers are rendered insolvent during severe drought events in the Karoo (Wessels and Willems 2013), a pattern that is likely to be exacerbated in the future and lead to further economic hardship and an even greater concentration of land ownership, unless different approaches to the utilisation of space, farmer support and the conservation of biodiversity are developed.

How this might be achieved, including its articulation with a stronger land reform programme, is beyond the scope of this review but we put this forward as an important issue to explore further. Possibilities include building on existing experience in communal pastoralism and experimenting with different models of co-operative ventures in which livestock owners manage their herds together over extensive areas. A major challenge will be to build trust among farmers operating at different scales and to develop the policies and robust institutions necessary for such enterprises to work. One of the key lessons from the land reform programme to date is that effective governance institutions are essential if co-operative projects are to succeed.

There are many uncertainties surrounding the new land uses discussed in the previous section but cumulatively they represent a major shift in the political economy of the Karoo, from one dominated since the mid-nineteenth century by a resident white agrarian elite to one in which selected elements of the region's natural endowment are being targeted for exploitation by contending and largely non-resident interest groups. The impact on local economic development of the complex interplay of national development ambitions and environmental conservation in the promotion of astronomy across the region requires further investigation. If proposed shale-gas and uranium mining proceeds, they will displace commercial livestock farming and disrupt the environment in affected areas in far-reaching ways. Currently, it appears as if neither activity is being actively pursued but the possibility that interest in these extractive mining developments could revive, if more favourable investment conditions return, cannot be ruled

out. Whether mining of the large deposits of base metals in the Northern Cape or Namaqualand will expand is not clear, but the many small deposits scattered throughout the region may offer small-scale mining opportunities, further contributing to a loss of grazing lands. Continued mining of heavy mineral sands is expected to affect a restricted area along the west coast, although terrestrial diamond mining is on the wane.

What is clear is that in their current manifestations, none of these developments will address entrenched unemployment and poverty in the region at scale, and that without this the social and economic malaise evident in many small towns can be expected to persist. While ensuring sustainable livestock production on both private and communal land must be a major objective for government policy in the Karoo, long-term strategies for promoting economic development within its towns, where the great majority of its residents live, are urgently required if current levels of poverty and marginalisation are to be reversed. Of major concern here is the limited capacity of local people to participate meaningfully in determining what sustainable development in their particular contexts means, both now and for the future.

Clearly, the state has a critical role to play in maintaining the proper functioning of ecosystems as well as promoting human wellbeing, so how effectively national, provincial and local government carry out their responsibilities will affect the trajectory of change in the Karoo. Planning for future climate and land-cover change is critical within the land reform process because vegetation can be transformed over a single decade in overstocked Karoo rangeland. Hoffman (2014) and Hoffman et al. (2018) present evidence from the last 100 years showing that government policies have had both positive impacts on rangelands (through destocking) and negative impacts (through inappropriate irrigation schemes or resettlement of too many people on unproductive land, promoting land degradation). He further suggests that awareness of past trajectories and future scenarios should assist the state in meeting the challenges of land reform under a changing climate. However, this requires receptive officials. The fragmentation of the Karoo region across different politico-administrative boundaries complicates the task of managing this social-ecological space effectively (Atkinson 2018). The difficulties are compounded by the economic and political marginalisation of the region, reflected in the generally weak capacity of local government. South Africa's sophisticated constitutional dispensation of three cooperative 'spheres' (not levels) of government is particularly difficult to realise in a region as large and poorly served in terms of transport and communication infrastructure as the Karoo.

In a context of global uncertainty about the contours of change, the future of the uniquely endowed social-ecological system of the Karoo is thus fraught with particular uncertainties of its own. From one dominated by graziers for much of its history, the landscape is currently being transformed into one serving multiple land uses, shaped largely by external rather than internal interests. In this context pastoralism is unlikely to be as formative in shaping trajectories of social-ecological change as it has been in the past, even if pastoralism accounts for

most of the Karoo's land area for the foreseeable future. In our introduction we argued that effective management of complex social-ecological systems requires both establishing safe boundaries for environmental change and addressing poverty and inequality within society; the evidence presented in this review indicates that in the Karoo a great deal of challenging work remains to be done on both fronts.

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