Vegetation change (1988–2010) in Camdeboo National Park (South Africa), using fixed-point photo monitoring: The role of herbivory and climate

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Fixed-point photo monitoring supplemented by animal census data and climate monitoring potential has never been explored as a long-term monitoring tool for studying vegetation change in the arid and semi-arid national parks of South Africa. The long-term (1988–2010), fixed-point monitoring dataset developed for the Camdeboo National Park, therefore, provides an important opportunity to do this. Using a quantitative estimate of the change in vegetation and growth form cover in 1152 fixed-point photographs, as well as series of step-point vegetation surveys at each photo monitoring site, this study documented the extent of vegetation change in the park in response to key climate drivers, such as rainfall, as well as land use drivers such as herbivory by indigenous ungulates. We demonstrated the varied response of vegetation cover within three main growth forms (grasses, dwarf shrubs [< 1 m] and tall shrubs [> 1 m]) in three different vegetation units and landforms (slopes, plains, rivers) within the Camdeboo National Park since 1988. Sites within Albany Thicket and Dwarf Shrublands showed the least change in vegetation cover, whilst Azonal vegetation and Grassy Dwarf Shrublands were more dynamic. Abiotic factors such as drought and flooding, total annual rainfall and rainfall seasonality appeared to have the greatest influence on growth form cover as assessed from the fixed-point photographs. Herbivory appeared not to have had a noticeable impact on the vegetation of the Camdeboo National Park as far as could be determined from the rather coarse approach used in this analysis and herbivore densities remained relatively low over the study duration.

Conservation implications: We provided an historical assessment of the pattern of vegetation and climatic trends that can help evaluate many of South African National Parks' biodiversity monitoring programmes, especially relating to habitat change. It will help arid parks in assessing the trajectories of vegetation in response to herbivory, climate and management interventions.

Introduction

Preserving and conserving natural areas and reducing biodiversity loss are core principles of most protected area management programmes (Bruner *et al.* 2001; Ehrlich & Pringle 2008; Rodrigues *et al.* 2004). Protected areas managers across the world are confronted with a range of critical decisions in terms of assessing and anticipating climate change impacts as well as land use impacts on biodiversity (Maraiano, Falcucci & Boitani 2008). These management decisions and solutions, however, are best made if they are informed by reliable monitoring data which document the extent, nature and rate of environmental change over time as well as the key potential drivers of such change (Gitzen *et al.* 2012; Lindenmayer & Likens 2010; Scholes *et al.* 2008).

The Camdeboo National Park (CNP), which surrounds the town of Graaff-Reinet in the semi-arid Karoo Midlands, South Africa, achieved national park status in 2006 and conserves remnants of the main biomes in the region. For 27 years prior to this, the area was managed as a provincial nature reserve after it had been used as a communal grazing area for several decades (Burdett 1995). The impact of previous land uses has left a legacy of erosion and degradation in some parts of the landscape and active attempts have been made to restore these areas (CNP Newsletter 2011). Several studies document the natural resources of the CNP, particularly the vegetation (Palmer 1990). However, these studies were undertaken decades ago and critical issues such as the recent rate of spread and impact of alien plants within different vegetation types in the CNP is not known (CNP Management Plan 2006; Masubelele, Foxcroft & Milton 2009).

Outside the park, within the commercial livestock producing areas, the influence of rainfall and grazing by domestic animals has been well documented (Hoffman, Barr & Cowling 1990; O'Connor & Roux 1995). However, few studies have been conducted on the impact of wild herbivores on rangeland condition within either private or state-owned protected areas in the region. In the

Karoo National Park, about 150 km west of the CNP, a change in land use from small-stock farming to conservation and the reintroduction of wild ungulates resulted in an increase in perennial grass cover following a change in land use. However, rates of recovery were slower in areas exposed to heavy indigenous ungulate herbivory (Kraaij & Milton 2006). Whilst a census of indigenous ungulates within the CNP has been conducted since 1990 there has not been any synthesis of these data. Little is known, therefore, of the concentration and impact of indigenous ungulates within different vegetation types of the park. Without this information it is difficult to determine the impact of indigenous ungulate herbivory on the vegetation of the reserve.

Another major concern for the conservation of biodiversity in protected areas is the impact that future climate change will have on biodiversity and ecosystem function (Perrings *et al*. 2011). For example, rainfall is the key abiotic driver in the Karoo Midlands (O'Connor & Roux 1995) and extended droughts are common in the region. It is important for managers to understand the influence of periodic floods and droughts on vegetation structure and composition over time frames of several years and decades. An understanding of current rainfall–vegetation dynamics will enable conservation managers to plan more effectively for future changes in climate. Climate change projections for the region suggest that the area will become more arid with an increase in the occurrence of more extreme events such as drought (Department of Environmental Affairs 2010; Driver *et al.* 2012; Midgley *et al*. 2002). Thicket vegetation around Graaff-Reinet, for example, is expected to be amongst the worst affected of all Albany thicket types in the Eastern Cape (Robertson & Palmer 2002). Current projections also suggest an increase in shrub cover at the expense of grasses, with obvious knock-on effects for vegetation communities of the Nama-karoo biome, as well as for grazer–browser herbivore ratios in the CNP (Midgley *et al*. 2002; Rutherford, Powrie & Husted 2012a, 2012b).

Monitoring is an important tool for management as it helps in understanding how ecosystems are structured and how they function over time (Noss 1990). There has been a surge in development of long-term biodiversity monitoring programmes to address some of the millennium development goals and also to respond to climate change for most countries in the world (Scholes *et al*. 2008). According to Reyers and McGeoch (2007), southern Africa has responded with the initiation of the South African Earth Observation Network (SAEON), as well as Biodiversity monitoring transect analysis (BIOTA). Recently, South African National Parks (SANParks) has established a biodiversity monitoring framework (McGeoch *et al*. 2011), however, few national parks, not only in South Africa but indeed throughout the world, have a comprehensive, long-term monitoring programme in place, especially for the vegetation. Whilst the Kruger National Park burning plots represent an exception (Trollope *et al.* 1998), most studies on vegetation change in protected areas are of less than 20 years duration.

Repeat fixed-point photography offers an important tool for monitoring vegetation change, particularly because the spatial scale of analysis ranges from local to landscape scale and is of direct relevance to park managers (Hall 2000; Nichols, Ruyle & Nourbakhsh 2009; Turner *et al*. 2003). The potential of fixed-point photo monitoring has also never been explored as a long-term monitoring tool for use in the arid and semi-arid national parks of South Africa. Owing to the diversity of vegetation types in the CNP, it provides a useful case study to explore the potential of this technique for monitoring vegetation change. A repeat fixed-point photography monitoring programme was established in the CNP in 1988 but the efficacy and value of the results have not been assessed. This study is important because if it proves successful it will be recommended to SANParks as an appropriate monitoring tool for the assessment and monitoring of environmental change over long time frames.

The main objective of the study was to document the extent of vegetation change in the CNP in response to key climate drivers, such as rainfall, as well as land use drivers, especially herbivory by indigenous ungulates. A secondary objective was to evaluate the use of fixed-point photography as a monitoring tool for studying change in the main growth forms and vegetation types at the CNP. In this synthesis of 22 years of fixed-point monitoring data, we have addressed the following main questions, (1) 'How has growth form composition changed within different vegetation types and land forms?', (2) 'What influence have drought and flooding events as well as changes in seasonal rainfall patterns had on these patterns?', (3) 'How has herbivore density and concentration influenced vegetation cover and growth form composition?' and (4) 'Is fixed-point photography an appropriate monitoring tool for addressing key management concerns within SANParks' arid and semi-arid conservation areas?'.

Research method and design

Study area

The CNP surrounds the town of Graaff-Reinet (Figure 1), which is situated in the Camdeboo Municipality of the Eastern Cape Province of South Africa. The CNP is located between 32°18′14.83″S and 24°38′31.41″E and lies from 740 m.a.s.l. to 1480 m.a.s.l. at the foothills of the Sneeuberg range, with a small section of low-lying plains included within the park boundaries. The climate is semi-arid with 32.0% of the average annual total of 336 mm of rain (CV = 31.5%) falling during the hottest months of the year (February–April). The CNP also experiences snow, fog and frost, with maximum temperatures during summer of 43 °C and minimum temperatures of -3 °C in winter (CNP Management Plan 2006). The mean annual maximum temperature during the study period was 26 °C, whereas mean annual minimum temperature was 10 °C. The hydrology of the CNP is largely based on its location at the edge of the Great Escarpment, from which six seasonal rivers (Sundays, Gats, Melk, Camdeboo, Pienaars and Erasmuskloof) drain into the Nqweba Dam in the central area of the park (CNP Management Plan 2006).

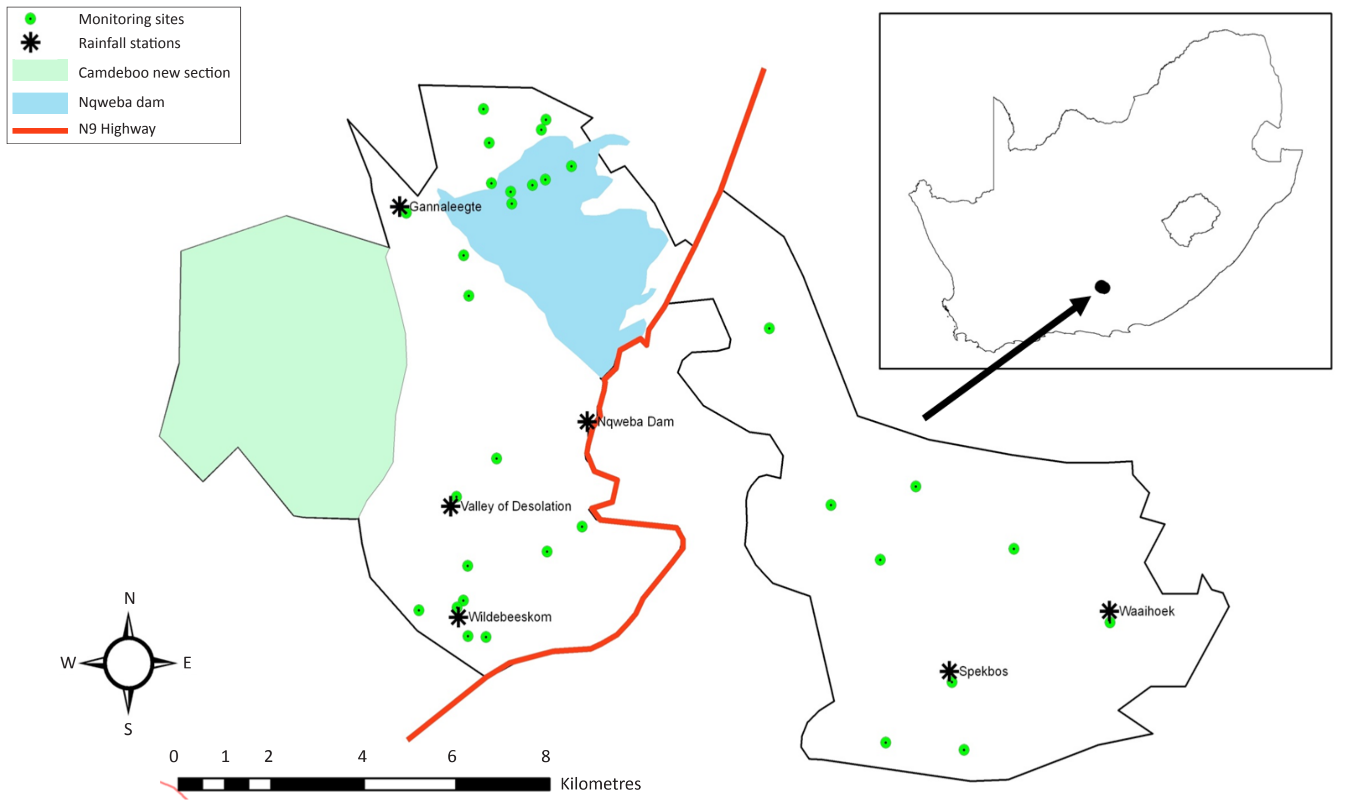


FIGURE 1: Location and extent of the Camdeboo National Park at Graaff-Reinet in the Eastern Cape Province of South Africa.

The geological system of the CNP consists of very thick layers of near-horizontal strata of sedimentary rocks of tertiary origin. Large areas of the park, however, are covered by alluvium, gravel, sand, mud and stone of more recent origin. Soils derived from these quaternary deposits have an important influence on the vegetation in the park because they represent the growth medium for many dwarf shrubs in the region (Lovegrove 1993). The soils are generally calcareous duplex forms of secondary nature having been deposited as alluvium on the impermeable sandstone. They are subject to sheet and gully erosion, which is aggravated when vegetation cover is reduced.

The vegetation of the CNP falls into three biomes, namely the Albany Thicket, Grassland and Nama-karoo biomes (Mucina & Rutherford 2006). Although Palmer (1990) provided a detailed phytosociological analysis of the former Karoo Nature Reserve, the main vegetation types currently recognised in the CNP follow Mucina and Rutherford's (2006) classification. These are: Camdeboo Escarpment Thicket (AT14), Karoo Escarpment Grassland (Gh1), Eastern Lower Karoo (NKl2), Upper Karoo Hardeveld (NKu2) and Eastern Upper Karoo (Nku4). Azonal vegetation also occurs around the Nqweba Dam, which is classified by Mucina and Rutherford (2006) as Southern Karoo Riviere (AZi6). In this study, the vegetation types outlined above have been grouped into three broad physiognomic classes for analysis. These classes are broadly reflective of the major biomes in the region. Grassy Dwarf Shrublands represent vegetation types within the Grassland biome, whilst Dwarf Shrublands comprise Nama-karoo biome vegetation types. Albany Thicket, which was called Succulent Thicket by Palmer (1990), represents vegetation associated with the Albany Thicket biome. In addition to the three physiognomic classes outlined above, a fourth Azonal unit located within the ephemeral rivers and Nqweba Dam flood plain was also recognised.

Although the CNP was first proclaimed and managed as a provincial reserve (called the Karoo Nature Reserve) in 1979, it became a national park in 2006 and is the 22nd protected area to fall under the management of SANParks. The area has a very long history of land use. Immediately prior to the proclamation of the Karoo Nature Reserve in 1979, the land was leased to tenant farmers who grazed their livestock on the property, thus contributing to overgrazing and the erosion of some areas (Burdett 1995; CNP Management Plan 2006).

Photo monitoring procedure

The fixed-point photo monitoring system used in this study was started in 1988 by the two nature reserve managers at the time (Ken Coetzee and Peter Burdett) with the establishment of initial 15 sites (Table 1). Additional sites were added in 1989 and 1992 by the current park manager (Peter Burdett) within each of the four main physiognomic classes, to reach a total of 32 sites. The main objective of the monitoring programme was to document the impact of herbivores on the different vegetation types of the reserve. Between 1988 and 2005 each site was photographed a total of 12 times.

After the proclamation of the CNP in 2006, the sites were not re-photographed until 2010 when this current study was undertaken. This was largely because of the time and effort required by the park manager to effect the transition of the Karoo Nature Reserve into the CNP and to align the newly acquired conservation area with broader SANPark's policies.

Each of the 32 sites was permanently marked with a 70 cm square concrete block set in the ground to a depth of about 50 cm. In the centre of the concrete block, a four-sided metal pole was fixed and allowed to protrude about 40 cm above the surface in such a way that each of the sides of the metal pole faced in one of four directions (north, east, south and west). This permanently fixed basal pole was used to position a removable 170 cm high metal pole with a slightly larger diameter which fitted securely over the basal pole. A flat plate, used to secure the camera was welded on the top of the removable pole.

A standard 50 mm lens mounted on a manual single lens reflex (SLR) camera loaded with 35 mm colour slide film was used for most of the years prior to 2010, except in 2003 when a wider-angle (35 mm) lens was used at some of the sites. To replicate this process in 2010, a 50 mm lens, mounted on a Minolta X300s manual SLR camera and loaded with Fujichrome Sensia 35 mm colour slide film, was used. However, because of the ease of postproduction processing and the saving in cost, a digital camera was also used (Canon Powershot Gll). All the original and 2010 colour slide images were scanned as TIFF images at 300 dpi, A3 output format using a high quality Nikon Coolscan 5000 scanner at the Plant Conservation Unit, University of Cape Town. This amounted to a total of 1152 images and an electronic copy of all of the photographs together with the metadata was sent to the CNP manager to whom the original material was also returned.

Repeat photos were matched as accurately as possible and analysed in Photoshop CS4. The cover of grasses, dwarf shrubs (< 1 m) and tall shrubs (> 1 m) were estimated using expert analysis for each individual image. Three ecologists, with field knowledge of the vegetation of the region, independently estimated the cover for each growth form on each of the images obtained in the different vegetation units. This was performed separately for the north, east, south and west directions and then averaged to provide an individual site value for each growth form. Values for similar vegetation units were then grouped together to get the average value for the vegetation unit at each time period.

Vegetation classification and the grouping of sample sites

Vegetation cover data were used to support the subjective grouping of sites into four vegetation units by the park manager. We used species composition and cover data collected using a step-point sampling technique during 2010. The step-point surveys were carried out along a 100 m transect along each direction (north, east, south, west) at a photo location. To show the grouping of these 128 transects (32 sites × four directions), a non-metric multidimensional scaling (NMS) ordination procedure using a Sorensen distance measure was undertaken within *PC-Ord* version 5.33 (McCune & Mefford 2006). This ordination technique is suitable for the representation of ecological data because it makes no assumptions of linearity or underlying models of species relationships. NMS iteratively searches for ordering or grouping of samples in multidimensional space that minimises the stress and number of dimensions in the solution. The stress value provides a measure of the goodness of fit of the data to the ordination solution and follows Kruskal's (1964) formula as rescaled by Mather (1976). Each of the 128 transects was also grouped subjectively into one of three landforms in which they occurred: rivers, plains and slopes. Change in the cover of different growth forms within each of these landforms was assessed over the sampling period.

Climate analysis

Annual (October–September) and monthly rainfall patterns were analysed from data collected at four weather stations established within different sections of the CNP since 1987 by the park manager (Figure 1). Change in annual rainfall was assessed using a Mann Kendall non-parametric test for trend in time series data (Modarres & Da Silva 2007). A standardised precipitation index (SPI) was also calculated to determine the change over time in the incidence of drought and wet periods (Mckee, Doesken & Kleist 1993). To assess the extent of change in rainfall seasonality, monthly rainfall data were grouped into two time periods (1990–2000 and 2000–2010). In addition, the average values for the months of December, January and February for the four stations were summed to represent early summer rainfall. These values were then compared for each decade and tested for significance using a univariate analysis of variance. This analysis was repeated for autumn (March–May), winter (June–August) and spring (September–November) time periods. Long-term A-Pan evaporation data obtained from the Department of Water Affairs' website for the period (1989–2008) for Nqweba Dam, as well as the average maximum and minimum temperature

TABLE 1: The total number of sites in each vegetation unit and the year in which sites were established by the park manager at the Camdeboo National Park.

Date that sites were established	Vegetation unit				Total number of sites
	Grassy Dwarf Shrublands	Dwarf Shrublands	Albany Thicket	Azonal	
1988	4	3	5	3	15
1989	0	1	4	0	5
1992	3	4	1	4	12
Total number of sites	**7**	**8**	**10**	**7**	**32**

for Graaff-Reinet obtained from the South African Weather Service (1992–2008) were also analysed. Changes in the temperature and A-Pan evaporation time series data were assessed using a Mann Kendall non-parametric test for trend (Modarres & Da Silva 2007).

Herbivore abundance

The location and abundance of different ungulate species were recorded annually by CNP field rangers from 1990 to 2010. Each species was converted to a large stock unit equivalent value (Furstenburg 2002; Meissner *et al*. 1983) and multiplied by the number of individuals recorded for each species during each census event. During the annual census the location of each species was undertaken in the field using a grid reference system created by the park manager. The GPS co-ordinates of the centre of each grid were subsequently determined from Google Earth. In this way each observation record was assigned a GPS coordinate. These GPS points were used to create a shapefile in DIVA-GIS which was then geo-referenced in ArcToolbox. Stocking density maps were then created for each annual census period in *ArcGIS* 9.3 (2008). The inverse distance weighted interpolation technique, which is a spatial analysis tool, was then used to create a grazing impact surface for the CNP (Murwira & Skidmore 2005). In this technique the assumption is that herbivory at a certain location also influences the vegetation in the neighbouring locations, because proximity of palatable plants can increase the impact of herbivores on palatable and unpalatable plants in the surrounding area (Baraza, Zamora & Hòdar 2006). Average stocking density values for each of the 32 vegetation monitoring sites were also calculated to determine how herbivore densities might have influenced the vegetation of the CNP over time.

Results

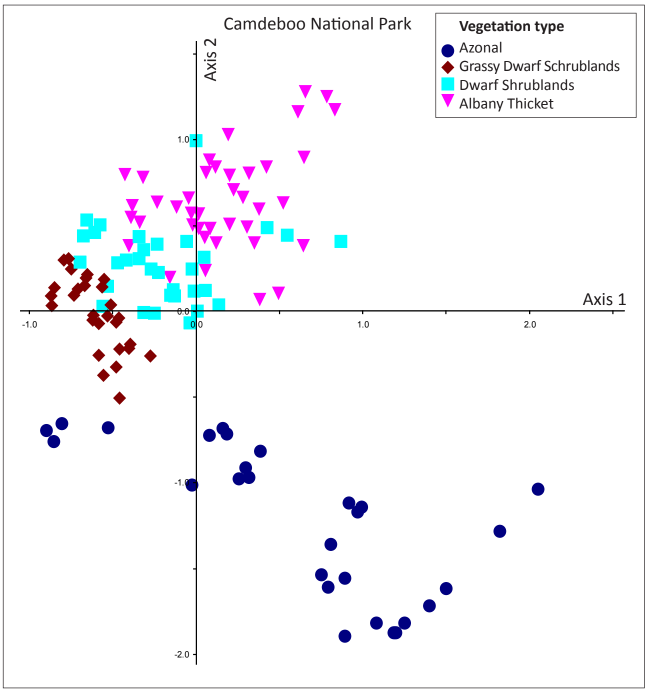
Grouping of sample sites

Ordination results of the 2010 survey data from each of the four survey directions at the 32 photo locations grouped the sites into distinct vegetation units (Figure 2). A two-dimensional solution with the final stress value of 19.1 and a final instability value of 0.00025 was recommended after 500 iterations. There is a clear separation of Azonal sites from the other vegetation units. The analysis shows some support for the more subjective grouping of photo location sites by the park manager into Grassy Dwarf Shrublands, Dwarf Shrublands, Albany Thicket and Azonal vegetation units. Azonal sites were also the most diverse and spread out in the ordination diagram. Grassy Dwarf Shrublands were separated in ordination space from Albany Thicket. Dwarf Shrublands sites were interspersed with both Grassy Dwarf Shrubland and Albany Thicket sites.

Change in growth form cover within different vegetation units

Azonal vegetation

Sites within Azonal vegetation experienced a decrease in tall shrub cover between 1998 and 2003 (Figure 3a–c). This pattern, however, is strongly influenced by what happened at site VM03 (Figure 4) and, to a lesser extent, at site VM01, which are both located in the floodplain of the Nqweba Dam. New saplings, particularly of *Acacia karroo*, emerged at both of these sites after 2004 and by 2010 had reached 2 m – 3 m in



N = 128 transects and 179 species.

FIGURE 2: A non-metric multidimensional scaling ordination of the vegetation units at Camdeboo National Park, based on species cover data of the survey carried out in 2010.

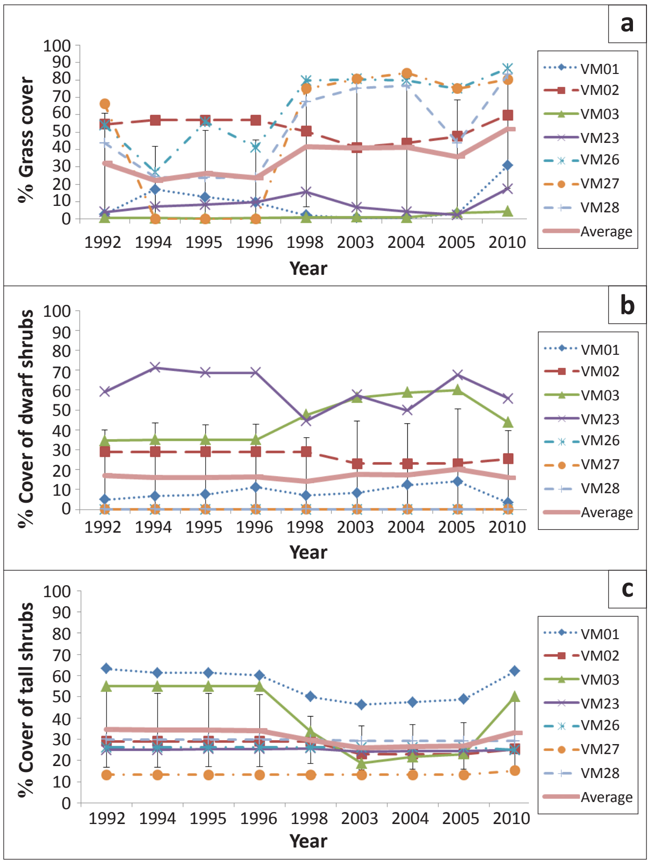
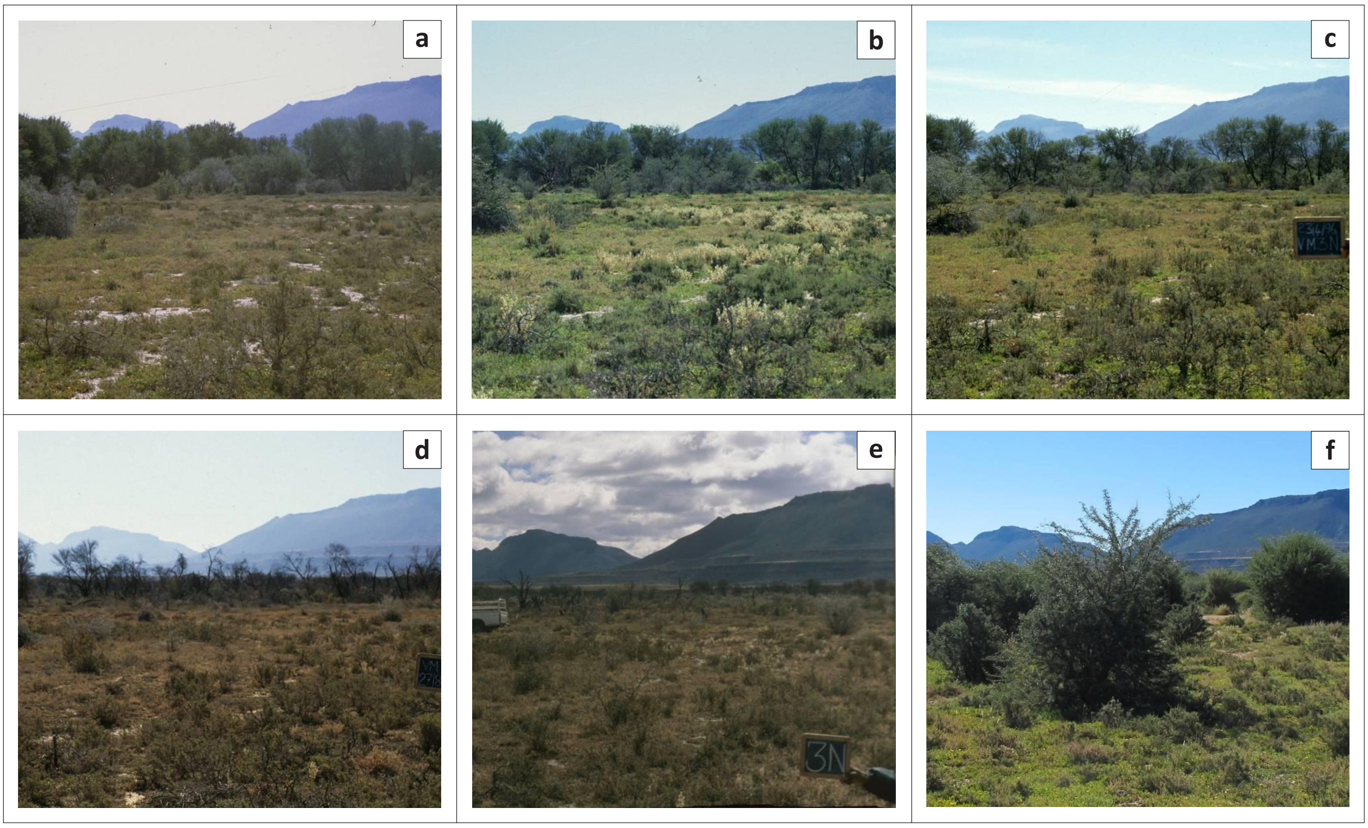


FIGURE 3: Percentage cover per site (± s.d.) of, (a) grasses, (b) dwarf shrubs and (c) tall shrubs in Azonal Vegetation as determined from an analysis of fixed-point photo monitoring sites between 1992 and 2010.



Source: Photograph by Peter Burnett

FIGURE 4: Loss of tall shrubs (primarily *Acacia karroo*) at VM03 N showing the decline between 1998 and 2003 and the subsequent increase in 2010 in the Azonal vegetation at the Camdeboo National Park. (a) 1992, (b) 1994, (c) 1996, (d) 1998, (e) 2003 and (f) 2010.

height. Tall shrub cover at the remainder of the sites within the Azonal vegetation unit remained relatively unchanged over the study period. Common tall shrub species within this vegetation unit are *A. karroo*, *Tamarix ramosissima* and *Salix babylonica*. Grass cover generally increased from 1996 to 2010, with a slight decline in 2005 (Figure 3a–c). Different sites varied both in terms of their cover of grasses as well as how this changed over time. The increase in grass cover over the study period was not mirrored by a decline in dwarf shrubs which remained relatively stable over time, except perhaps for site VM23. Much of the dwarf shrub cover comprised alien shrubs such as *Salsola tragus*, *Xanthium spinosum* and *Xanthium strumarium*.

Albany Thicket

Tall shrub cover within Albany Thicket vegetation remained unchanged over the study period (Figure 5a–c and Figure 6). Common tall shrub species at these sites include *Buddleja saligna*, *Carissa haematocarpa*, *Diospyros austro-africana*, *Euclea crispa*, *Euclea undulata*, *Grewia occidentalis*, *Grewia robusta*, *Gymnosporia heterophylla*, *Portulacaria afra*, *Pappea capensis*, *Searsia longispina* and *Searsia undulata*. The cover of dwarf shrubs varied greatly between different sites within this vegetation unit but remained relatively stable within a site over the study period. Common dwarf shrubs in this vegetation type include *Becium burchellianum*, *Cheilanthes eckloniana*, *Crassula* spp., *Euryops spatheceus*, *Felicia filifolia* and *Rhigozum obovatum*. Although grass cover fluctuated during the course of the study, Albany Thicket vegetation was the

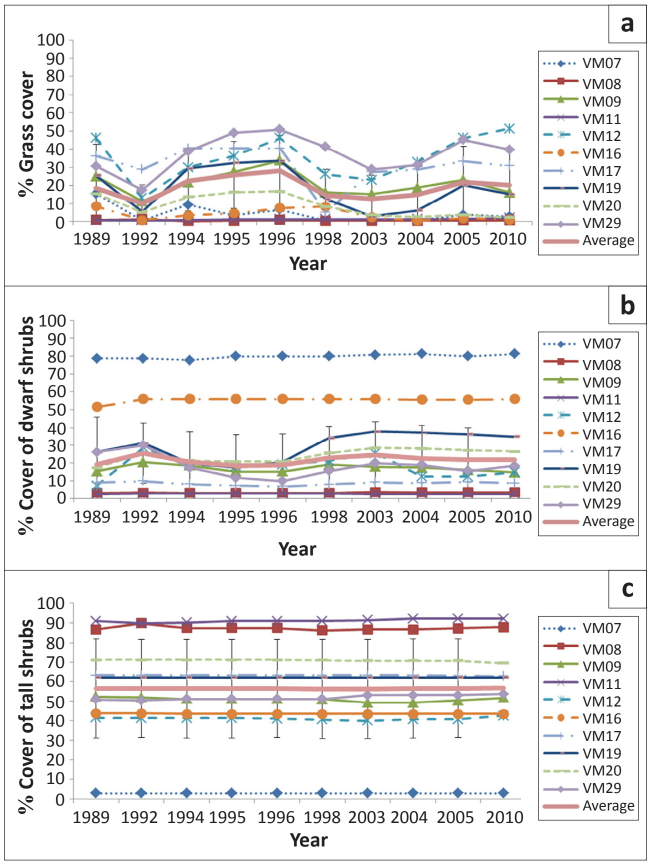
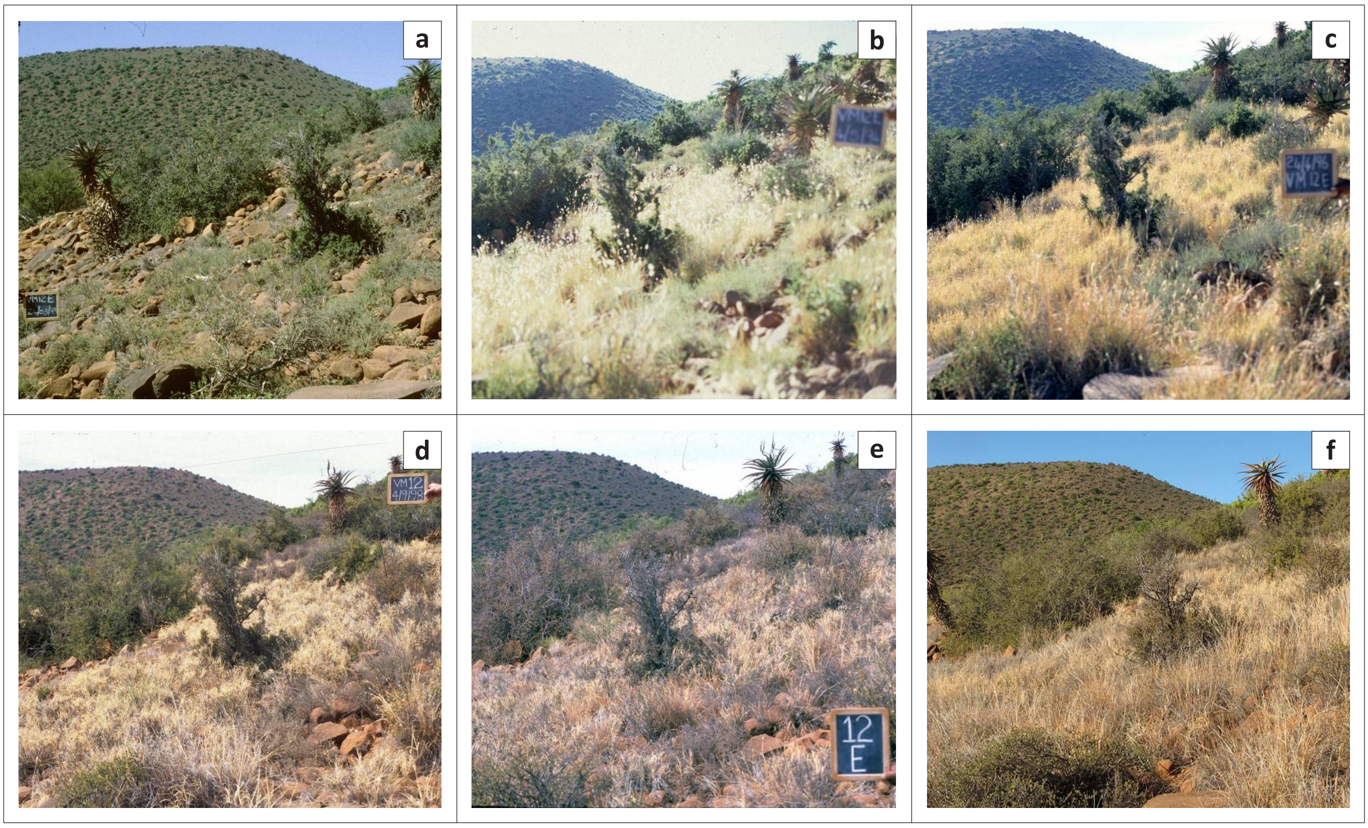


FIGURE 5: Percentage cover per site (± s.d.) of, (a) grasses, (b) dwarf shrubs and (c) tall shrubs in Albany Thicket as determined from an analysis of fixed-point photo monitoring sites between 1989 and 2010.



Source: Photograph by Peter Burnett

FIGURE 6: Albany Thicket example as shown by VM12 E depicting stability of the various growth forms between 1992 and 2010. (a) 1992, (b) 1994, (c) 1996, (d) 1998, (e) 2003 and (f) 2010.

most stable vegetation type within the CNP, with very little change recorded in the cover of dwarf and tall shrubs.

Grassy Dwarf Shrublands and Dwarf Shrublands

For sites within both the Grassy Dwarf Shrubland (Figure 7a–c and Figure 8) and Dwarf Shrubland (Figure 9a–c and Figure 10), periods of grass cover increase (e.g. between 1994 and 1997) were accompanied by a decline in the cover of dwarf shrubs observed in the photographs. Conversely, the decline in grass cover between 1998 and 2004 was associated with an increase in dwarf shrub cover. Fluctuations in dwarf shrub cover were less extreme than for grasses which changed by 60% or more at a site. The response of grass cover appeared more pronounced in Grassy Dwarf Shrubland sites than Dwarf Shrubland sites. Tall shrub cover was lower in Grassy Dwarf Shrubland at 6% compared to the Dwarf Shrubland sites at 22%, but changed very little temporally for both vegetation units over the monitoring period.

Change in growth form cover within different landforms

The three growth forms responded differently between 1988 and 2010 within the main landforms at the CNP (Figure 11a–i). Within rivers, the cover of grasses increased from an average of 30% – 50% over the study period. In contrast, the cover of grasses on the plains increased from 30% – 45% between 1994 and 1996, but declined thereafter to less than 20% in 2003, increasing again to reach average values of 35% in 2010. Whilst grass cover also fluctuated on

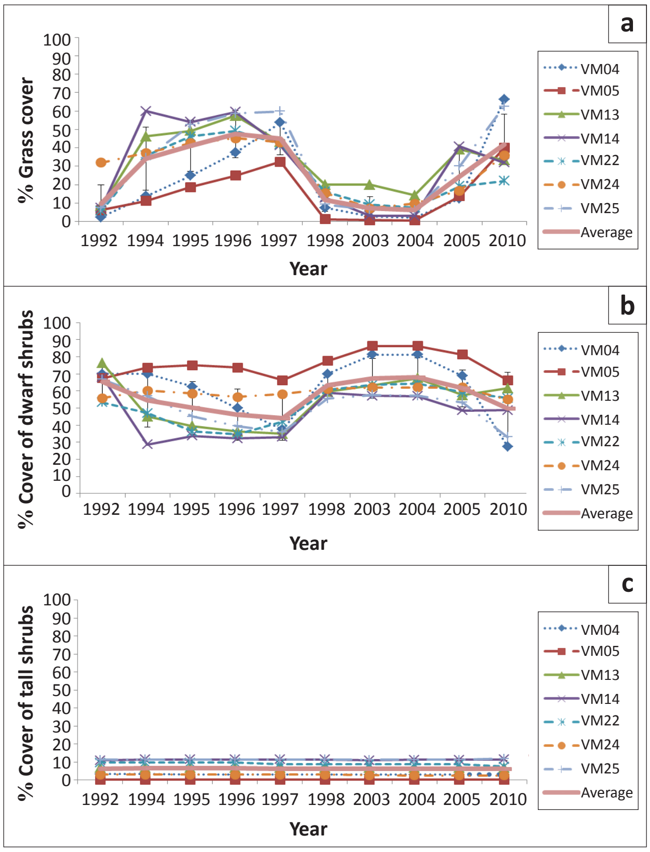
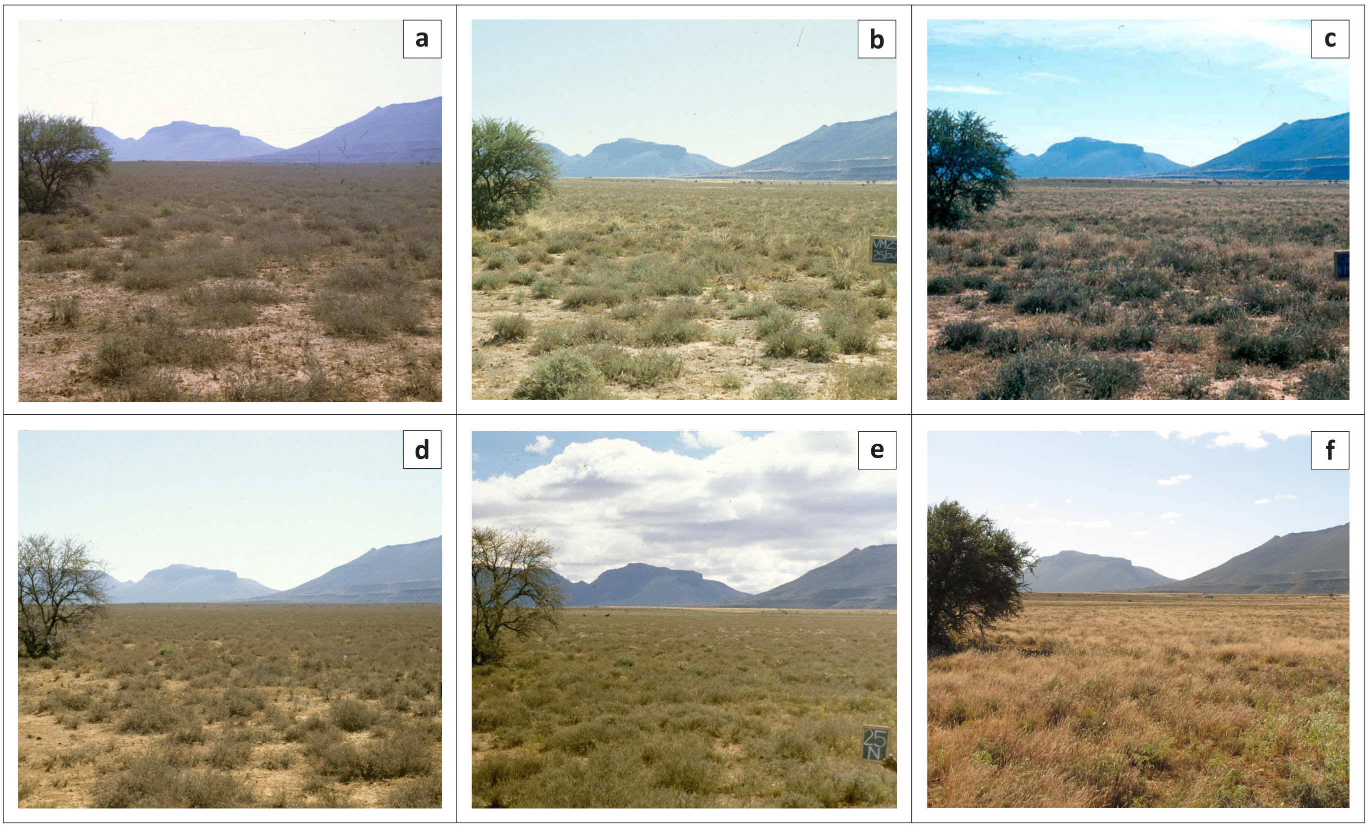


FIGURE 7: Percentage cover per site (± s.d.) of, (a) grasses, (b) dwarf shrubs and (c) tall shrubs in Grassy Dwarf Shrublands (Grassland Biome) as determined from an analysis of fixed-point photo monitoring sites between 1992 and 2010.



Source: Photograph by Peter Burnett

FIGURE 8: Grassy Dwarf Shrublands example (VM25 N) showing cyclical pattern and switch between grass and dwarf shrub dominance at the Camdeboo National Park, whilst tall shrubs have remained stable from 1992 until 2010. (a) 1992, (b) 1994, (c) 1996, (d) 1998, (e) 2003 and (f) 2010.

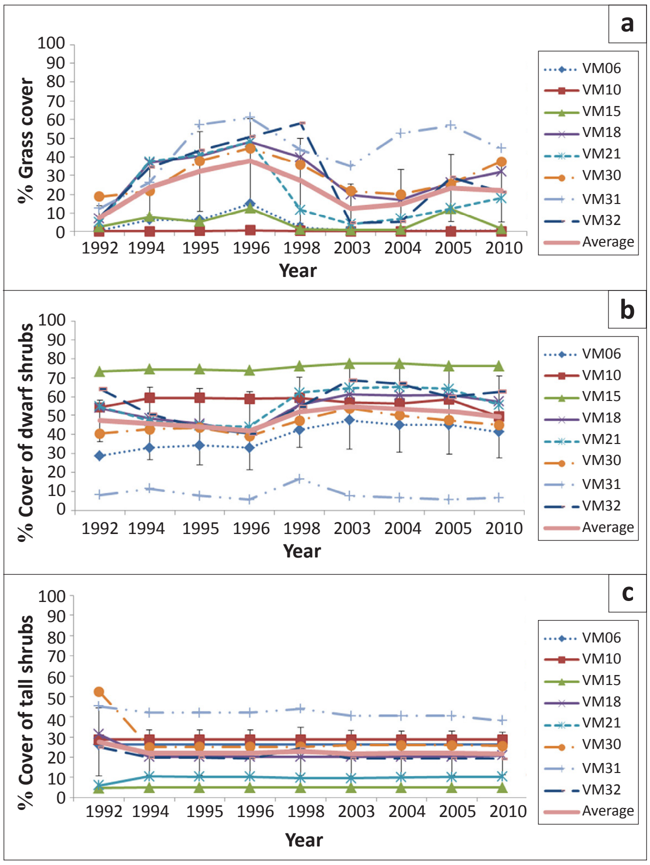


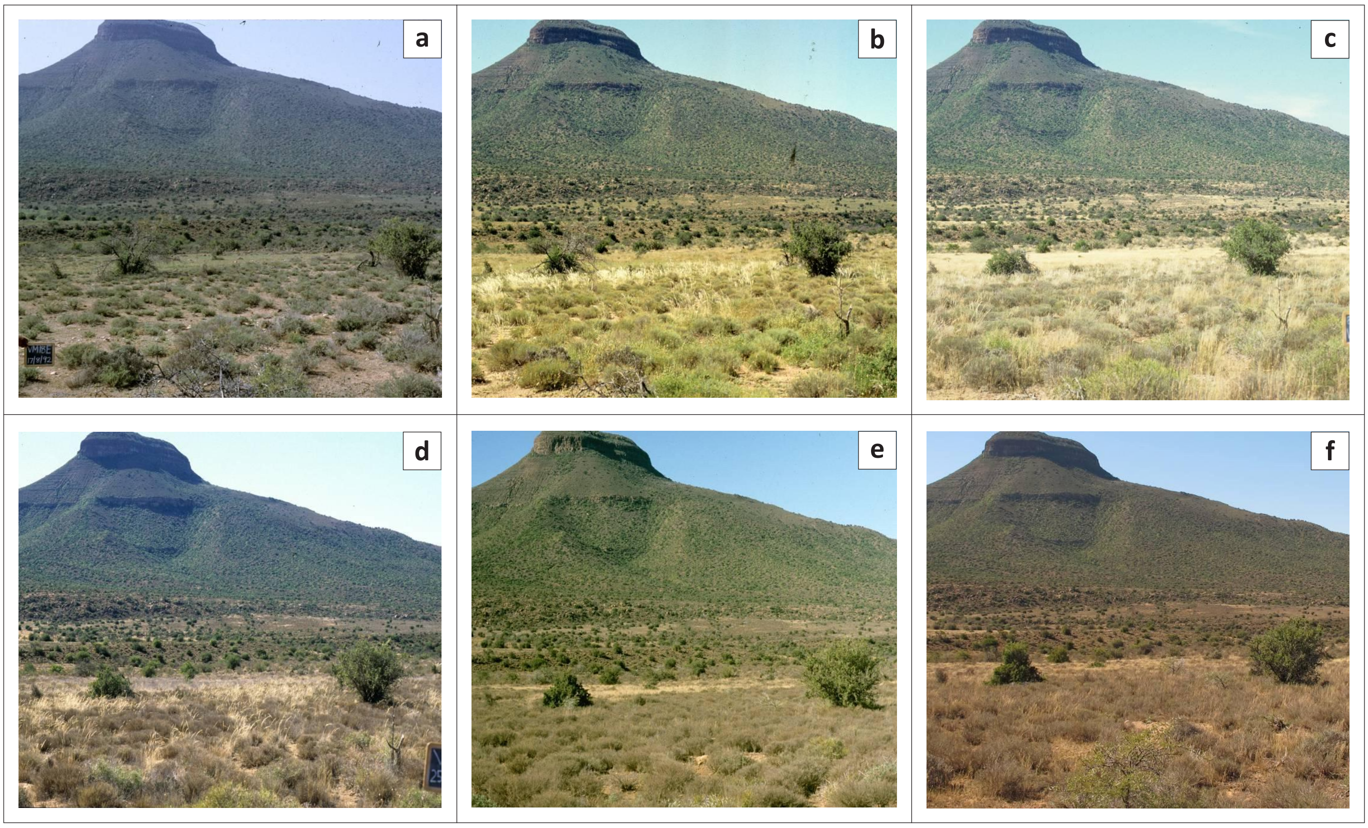
FIGURE 9: Percentage cover per site (± s.d.) of, (a) grasses, (b) dwarf shrubs and (c) tall shrubs in Dwarf Shrublands (Nama-karoo Biome) as determined from an analysis of fixed-point photo monitoring sites between 1992 and 2010.

the slopes, responses were far less extreme and remained between 10% and 25%. The cover of dwarf shrubs was relatively stable on all landforms, with slopes and rivers showing less variation over time than on the plains. Average cover values for this growth form were below 20% for rivers and slopes but around 50% on the plains. Changes in dwarf shrub cover on the plains in particular appeared to respond in an opposite direction to changes in grass cover. Tall shrub cover dominated the slopes (60%), was co-dominant within rivers (35%) and comprised a relatively minor component of the cover for plains environments (15%). Tall shrub and tree cover was relatively stable for plains and slopes over time. Within rivers, tall shrub cover declined between 1998 and 2003 but increased again over the next 7 years.

Change in historical climate

Annual rainfall

No significant change in annual rainfall was recorded over the last 18 years at the four climate stations within the CNP (Online Appendix 1; Figure 1). This pattern is consistent with the longer rainfall record for Graaff-Reinet which has not changed significantly in the last 100 years (Masubelele 2012). Annual rainfall totals varied across the landscape. They were highest for high elevation sites such as the Valley of Desolation (1243 m.a.s.l.) and Waaihoek (1276 m.a.s.l.) (not included in Figure 12, as records for these sites ceased at the end of 2005), which both had values of 358 mm. Sites slightly lower in elevation (all below 820 m.a.s.l.), such as Nqweba Dam (345 mm) and Wildebeeskom (340 mm), received lower



Source: Photograph by Peter Burnett

FIGURE 10: Dwarf shrublands example (VM18 N) showing a less pronounced cyclic patterns and switches between grasses and dwarf shrubs dominance from 1992 until 2010. (a) 1992, (b) 1994, (c) 1996, (d) 1998, (e) 2003 and (f) 2010.

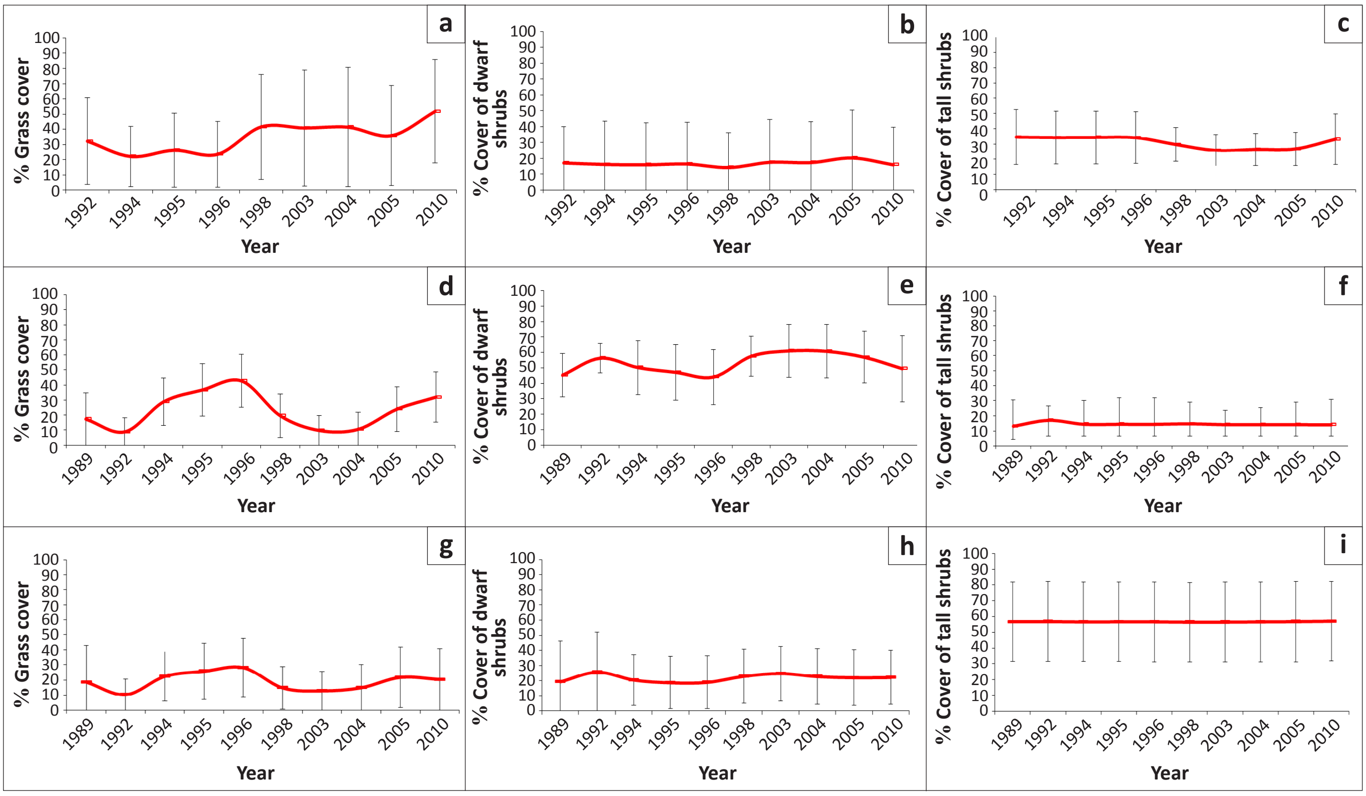


FIGURE 11: Percentage cover (± s.d.) of the main growth forms on the different landforms, rivers (a–c), plains (d–f) and slopes (g–i), as determined from an analysis of fixed-point photo monitoring sites between 1992 and 2010 for rivers and 1989 and 2010 for plains and slopes.

mean annual totals over the course of the study period. The lowest mean annual rainfall totals were recorded at Gannaleegte (294 mm) and Spekbos (293 mm), which were also the lowest in elevation.

Seasonal rainfall

Monthly rainfall data for all four weather stations were grouped and the seasonal averages compared between two time periods (1990–1999 and 2000–2009). Results showed that the average amount of rain in summer (December–February) and autumn (March–May) was significantly greater for the decade between 2000 and 2009 than for the decade which preceded it (Figure 12). The increase in both summer and autumn rain was largely the result of the significant increase in rain in February and in April, respectively. Spring and winter rainfall amounts were not significantly different between the two decades.

Standardised precipitation index

There was no significant change in the long-term SPI at all four climate stations (Figure 13a–d). The most severe drought years over the study period were 1990–1991, 1997–1998 and 2002–2003. The wettest periods were experienced in 1988, 1995, 2000 and 2006–2007. All four climate stations showed similar SPI profiles, suggesting a high degree of spatial coherence in drought and wet periods across the CNP.

Temperature

Although the average maximum temperature has increased by 0.001 °C per year since 1992 and the average minimum temperature by 0.04 °C per year, the trends were not significant (Online Appendix 1; Figure 2). The highest monthly maximum temperature was recorded in January 2003 at 34.6 °C and the highest minimum temperature recorded in 2006 at 16.6 °C. The highest average annual maximum temperature of 27.2 °C was recorded in 1999. The lowest was recorded in 1996 at 25.4 °C.

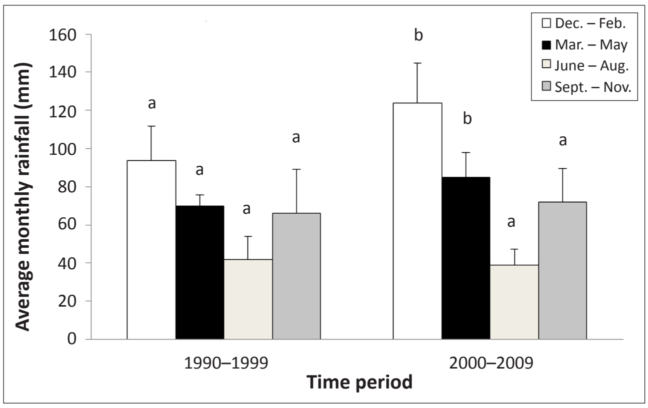
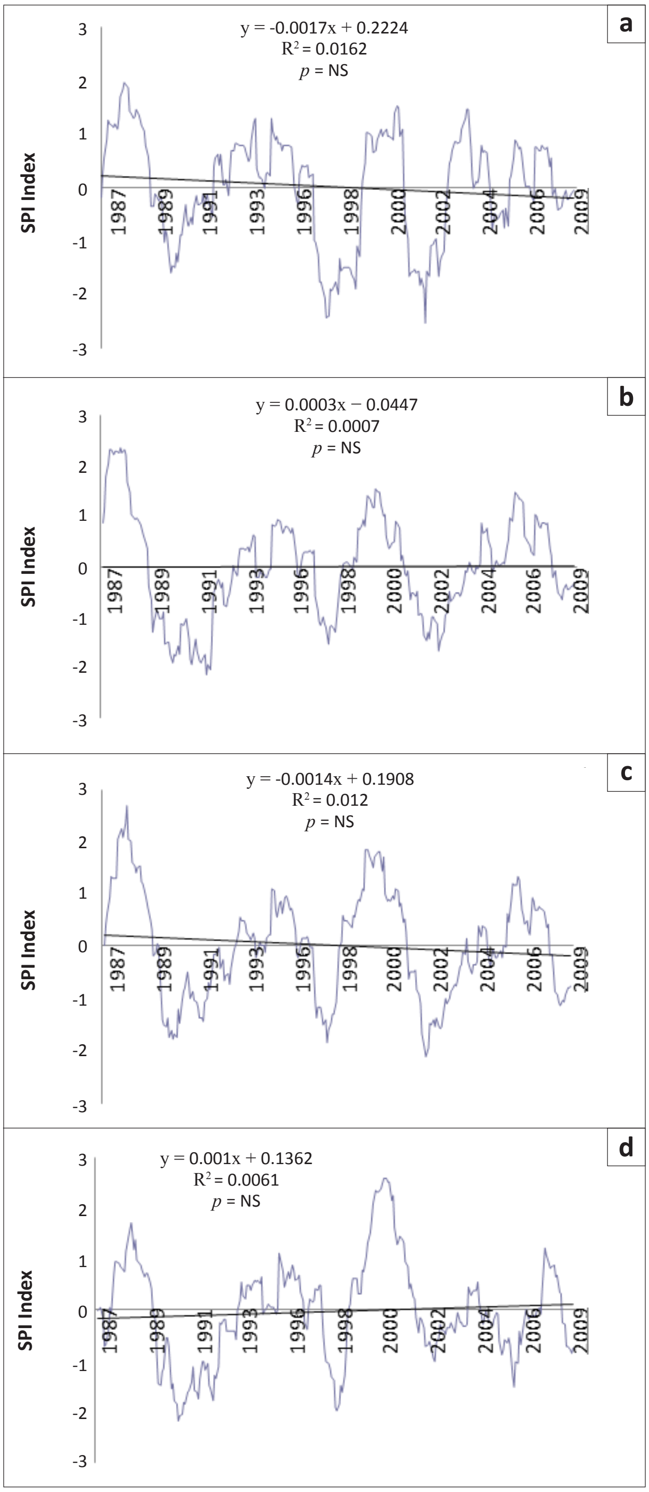


FIGURE 12: Difference in seasonal rainfall per decade at the Camdeboo National Park based on the results from four climate stations in the area. Dissimilar superscripts denote significant seasonal differences between the decades at $p < 0.05$.

Pan evaporation

There was no significant trend between 1926 and 2008 in the long-term S-pan evaporation data for Nqweba Dam. However, when analysed for the period from 1989 to 2008 only, there was a significant decline in S-pan evaporation values at Nqweba Dam (Online Appendix 1; Figure 3). The



SPI, standardised precipitation index; NS, not significant.

FIGURE 13: Standardised precipitation index values based on a 24-month period for four stations, (a) Spekbos, (b) Gannaleegte, (c) Wildebeeskom and (d) Nqweba Dam at the Camdeboo National Park.

maximum annual value for pan evaporation was recorded in 1993 at 2237 mm, whilst the minimum value was recorded in the year 2009 at 1643 mm.

Animal distribution within the Cambedoo National Park

Park scale

Over the course of the study, the highest herbivore stocking densities were recorded around the dam as well as near watering points on the plains, whilst mountainous areas had the lowest densities (Online Appendix 1; Figure 4a–u). During the period between 1990 and 1994, when rainfall was below average, stocking densities remained high and animals were widely distributed throughout the park. Animals numbers have declined since 1995 (Figure 14a–d) and they have also become less widely distributed in the landscape. The plains and the area around the dam support large bulk grazers such as *Syncerus caffer* (buffalo), *Damaliscus pygargus phillipsi* (blesbuck), *Connochaetes gnou* (black wildebeest) and *Taurotragus oryx* (eland) which are resident in these areas. *Antidorcas marsupialis* (springbok) are mixed feeders and are also present at high densities in these areas of the park. The plains and the area around the dam have a relatively high cover of grasses and animal densities have remained high compared to other areas in the park. In terms of browsers, *Tragelaphus strepsiceros* (kudu) is widespread throughout the park as well as within the Nqweba Dam area where it feeds on *A. karroo*. Tall shrubs, such as *P. afra* which are dominant within the more mountainous areas of the CNP, are also heavily utilised by kudu.

Herbivore densities associated with vegetation units

Average herbivore densities within the vegetation units showed that Azonal vegetation and the associated Grassy Dwarf Shrubland areas supported the highest densities of herbivores, whereas the Dwarf Shrublands and the Albany Thicket had the lowest (Figure 14a–d). Sites within Azonal vegetation had higher densities during the drought years of 1990–1992, 1997–1998 and 2003, whereas 1993 and 2004 had the highest densities of all. The surrounding Grassy Dwarf Shrublands had higher stocking densities immediately after the drought years. The Dwarf Shrublands and Albany Thicket communities, on the other hand, have supported relatively low densities of animals over the last 20 years.

Discussion

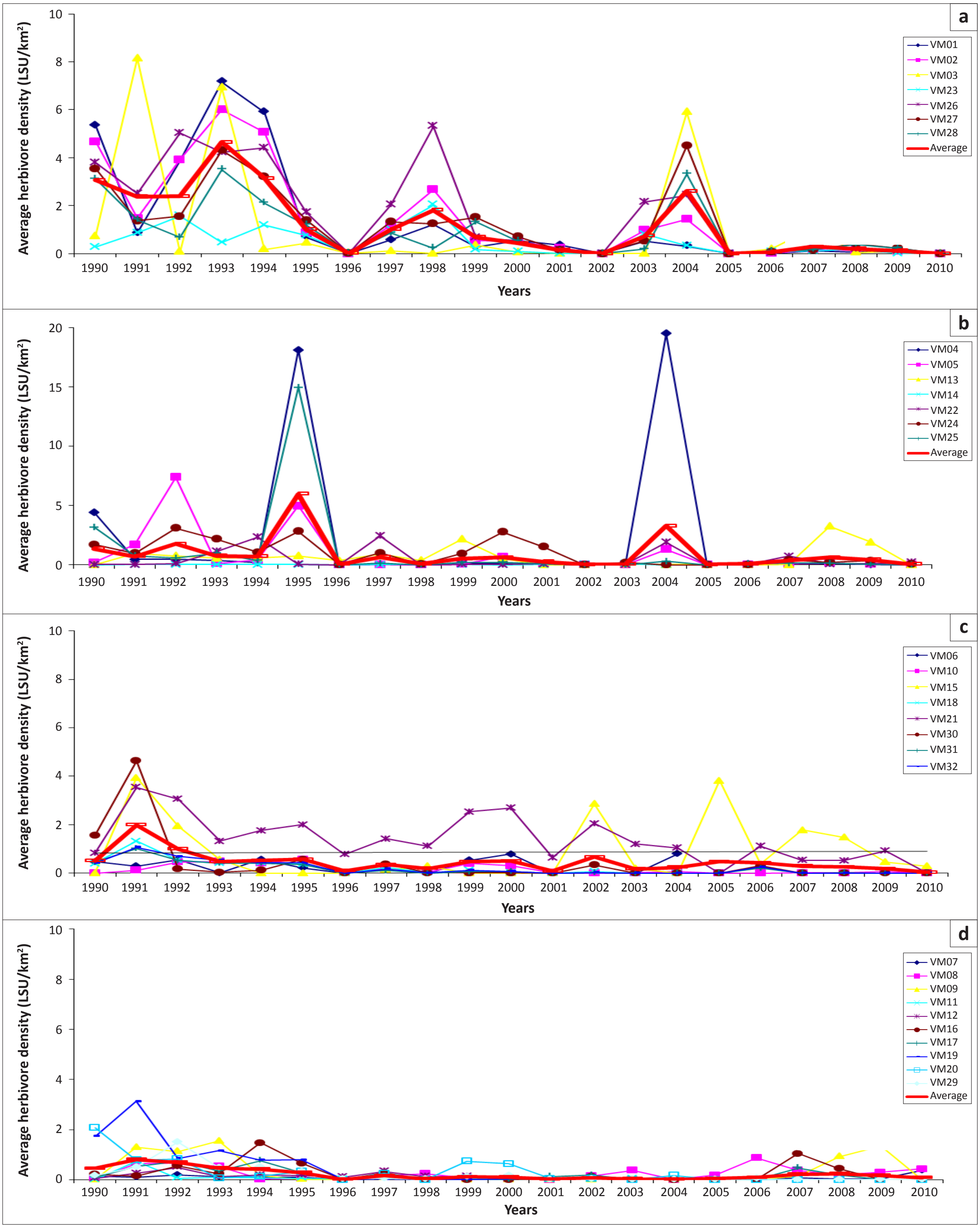
Change in vegetation cover and growth form composition since 1992

Vegetation cover and growth form composition are the most commonly used indicators of change in most terrestrial ecosystems (Godinez-Alvarez *et al*. 2009). In this study, there was considerable variation in the total cover of vegetation, as well as the cover of different growth forms between sites and even within the same vegetation unit. Although this variability makes it difficult to generalise across the CNP, some common patterns were evident in the response of different growth forms within different vegetation units and landforms.

Of all the growth forms, grasses were the most dynamic in terms of how they changed over time as compared to the changes in dwarf and tall shrubs. Whilst such changes were somewhat muted in Albany Thicket vegetation, they were most noticeable within Azonal vegetation associated with rivers and floodplains, as well as on the plains where Grassy Dwarf Shrubland and Dwarf Shrubland vegetation dominated. The response of dwarf shrubs in all vegetation units appeared different to that of grasses and generally declined when grass cover increased. Whilst the cover of dwarf shrubs might have been underestimated from the photographs because of the presence of taller grasses which might have obscured their view, the survey data in O'Connor and Roux (1995) suggests that grasses and shrubs compete for both above-ground and below-ground resources. Their survey data, as well as evidence presented in Masubelele *et al*. (in review), show that when grass cover is high, shrub cover declines.

Shiponeni *et al*. (2011) have shown experimentally how grasses and shrubs compete for resources. Their results indicate that grasses are superior competitors and can out-compete dwarf shrubs in the ecotonal environments that occur between the arid Namaqualand and Bushmanland regions in the western part of the Karoo. They present a mechanism and suggest that increased grass cover results in reduced soil water availability for the nearest shrubs. Alvarez *et al*. (2011) have also shown within the Chihuahuan desert on the US–Mexican border that when rainfall is abundant, increased competition occurs between shrubs and grasses. The cover assessments derived from a comparison of repeat photographs in this study thus appear to reflect real differences on the ground between shrub and grass cover (Hoffman & Rohde 2011a). However, more detailed experimental work is needed to determine the competitive interactions between grasses and shrubs within eastern Karoo rangelands, where fluctuations in grass and shrub cover can occur over relatively short time periods (Hoffman *et al*. 1990). Experimentally induced drought and above-average rainfall events would be especially helpful in this regard and would serve to test the state-and-transition model proposed by Milton and Hoffman (1994) for the region.

The cover of tall shrubs in all vegetation types except Azonal vegetation was remarkably stable over the course of the study. With few exceptions, the cover of tall shrubs in 2010, at almost every site within Albany Thicket, Grassy Dwarf Shrublands and Dwarf Shrublands, was the same or very similar to what it was at the beginning of the study when the first photographs were taken. This was not the case, however, for several sites within Azonal vegetation, where tall shrub cover responded relatively quickly to fluctuations in the hydrological environment. *Acacia karroo* appeared particularly dynamic on the flood plain above the Nqweba Dam. For example, the dry period between 1998 and 2003 had a negative impact on the abundance of *A. karroo*, which appeared unable to survive long periods of hydrological drought. Other studies report a similar decline in tree and shrub cover under drought conditions (Allen *et al*. 2010;



LSU, large stock equivalent.

FIGURE 14: Average herbivore stocking density per site (LSU/km²) from 1990 until 2010 recorded at the 32 vegetation monitoring sites in the Camdeboo National Park. Note the different y-axis scale for Grassy Dwarf Shrublands, with (a) representing Azonal vegetation, (b) Grassy Dwarf Shrublands, (c) Dwarf Shrublands and (d) Albany Thicket.

Fensham, Fairfax & Ward 2009). In the CNP, however, populations of *A. karroo* responded quickly again to the increase in moisture levels after the relatively good rains experienced in the region in the 2007–2008 rainy season. Hoffman and Rohde (2011b) have indicated the dynamic nature of river systems in Namaqualand which have also shown a significant increase in the abundance of *A. karroo* over time. However, their repeat photograph study, which usually only has two time steps, does not capture the dynamic nature of river systems in arid environments where shorter observation periods of 5 or 10 year time steps are preferable. Whilst riparian vegetation communities are generally acknowledged to be spatially and temporally dynamic as a result of fluvial disturbance amongst other drivers (Perry *et al*. 2012), there is a lack of long-term monitoring data to show the nature, extent and rate of this dynamism (Webb *et al*. 2011).

Changes in climate and its influence on the vegetation

Rainfall

Trends in climate parameters measured at the CNP over the last 20 years are consistent with those reported elsewhere for southern Africa (Masubelele 2012; Warburton, Schulze & Maharaj 2005). For example, there was no significant trend in annual rainfall or the incidence of drought at any of the climate stations within the CNP over the course of the study period. There were, however, significant fluctuations in annual rainfall between years, with important implications for the vegetation of the region (Milton & Hoffman 1994). The analysis of seasonal rainfall patterns suggests that the amount of rain falling in late summer and autumn increased in the second decade of the study when compared to the first, although the high degree of inter-annual variability might have had a significant influence on this pattern. This appeared not to be the case for spring and winter rainfall patterns which did not differ significantly over the course of the study. This finding is consistent with Du Toit (2010), who reported a similar increase in summer rain at a climate station at Middleburg about 100 km north of the CNP.

Inter-annual fluctuations in rainfall have important implications for the response of different growth forms in the region as evidence by the repeat photograph survey. Grasses tend to respond to short-term fluctuations in annual rainfall far more than tall shrubs and trees (Holdo, Holt & Fryxell 2009; Miranda *et al*. 2009; Scanlon *et al*. 2005; Snyder & Tartowski 2006). Summer rainfall, derived from convective thunderstorms, often contributes short-term pulses to soil moisture that can be utilised quickly by annual plants and C_4 grasses in particular (Schwinning *et al*. 2008). Evidence from the photo-monitoring programme suggests that the increase in summer rainfall over the first decade of the 21st century has influenced grass cover within the Grassy Shrubland and Azonal vegetation units at the CNP, as well as within the dominant landforms with which they are associated.

Extreme rainfall events such as droughts and floods or above-normal rainfall influence the temporal dynamics of vegetation as observed in the photo monitoring assessments. The two flood events that occurred in 2001 and 2006, for example, resulted in an increase in grasses in subsequent years. The floods were also probably responsible for the cohort of smaller *A. karroo* and *T. rammosissima* saplings which became evident soon after these events. Drought events, such as were recorded in 1998 and 2003, also influence vegetation dynamics and, in the CNP, contributed to a decline in grass cover but not that of dwarf shrubs. This was particularly evident in the Grass Dwarf Shrublands and Dwarf Shrublands, where grass–shrub interactions are mediated in part by extreme drought events (Hoffman & Cowling 1990; Snyder & Tartowski 2006).

Evidence from the photo-monitoring assessment also suggests that in arid and semi-arid environments drought years can significantly influence the structure of riparian and azonal habitats by eliminating large trees, especially when droughts occur in combination with increased temperature (Allen *et al*. 2010; Breshears *et al*. 2009). In this study, drought and higher temperatures in 1998 and 2003 might have influenced the structure of the vegetation within the Nqweba Dam floodplain through the elimination of older and therefore taller individuals of *A. karroo*.

Temperature and pan evaporation

As is the case in many parts of southern Africa over the last 20 years (Engelbrecht, McGregor & Engelbrecht 2009; Warburton *et al*. 2005), minimum temperature has increased at the CNP at a faster rate than maximum temperature. Despite this, however, pan evaporation values declined significantly from 1989. This decline has been reported elsewhere in southern Africa (Eamus & Palmer 2007; Hoffman *et al.* 2011) and appears part of a global phenomenon (Roderick, Hobbins & Farquhar 2009) which has, as yet, not been adequately explained (McVicar *et al*. 2012). In the winter rainfall region of South Africa, a significant decline in wind run appears the most plausible explanation (Hoffman *et al.* 2011) but more work is needed to resolve this issue.

Herbivory and its impact on the vegetation

An understanding of the spatial and temporal use of the landscape by the herbivores is an integral part of ecosystem management (Bailey *et al*. 1996). Herbivores are known to affect ecosystem structure through both the loss and increase of tree cover and to influence ecosystem processes such as productivity and carbon storage at local to regional scales (Tanentzap & Coomes 2012). It is therefore important to understand the temporal and spatial dynamics of herbivory at community to landscape scale at the CNP. Animal census data indicated that ungulate densities have declined over time and have also varied considerably over space within the CNP. Whilst herbivore density appears significantly influenced by the location of the Nqweba Dam, as well as the water points within the park, the occurrence of floods and droughts also affects the movement and densities of animals. Herbivore density remained relatively low on the slopes of the CNP, whilst higher animal densities were generally recorded on the plains environments nearest to the watering points. The years with the highest herbivore density included 1992, 1995, 1998 and 2004. The majority of the high animal density records were returned during drought years. The lack of available moisture in the landscape might have forced animals to concentrate around artificial water points in the park and would have influenced the ease with which animals were observed and counted.

Animal densities were highest in the Azonal vegetation followed by the Grassy Dwarf Shrublands. The location of several artificial water points in this vegetation unit, as well as the good cover of high quality grasses, could have influenced this. It is well known that both slope and distance to water points can exert a major influence on the movement and distribution of herbivores (Bailey *et al*. 1996). The density of herbivores was significantly lower on slopes, with only areas near water points having slightly higher herbivore densities. This is largely a result of the difficulty and restriction of movement by the dense vegetation on steep slopes, which also reduces the ability of rangers to observe and record animals during the census activities (Morellet *et al*. 2007). However, even within vegetation units and landforms which supported relatively high densities of animals, there is little evidence from the photo-monitoring assessment that herbivory played a significant role in influencing the cover of the dominant growth forms or species. Fluctuations in rainfall and major changes in the hydrological dynamics of the Nqweba Dam floodplain appeared far more important in influencing the cover of grasses, dwarf shrubs and tall shrubs than changes in animal densities. However, the use of a photo-monitoring approach might be an inappropriate tool to measure the impact of herbivory on the structure of the CNP ecosystems. As for other semi-arid conservation areas (Hoffman *et al.* 2009), it appears that herbivore densities currently observed at the CNP are too low to have had a major influence on the vegetation, especially when compared to those commonly recorded for livestock in surrounding areas. The selective feeding nature of wild herbivore guilds, compared to the concentrated heavy grazing and browsing associated with livestock (Laca *et al*. 2010), may explain why the impact of animals on the vegetation of the CNP appears to have been negligible (Groom & Harris 2010). However, a more detailed assessment of the spatial use of the CNP by different herbivore guilds is urgently needed.

The use of photo monitoring as a management tool

As mentioned in the 'Introduction', there is a need to initiate and support biodiversity monitoring frameworks in South Africa and abroad (Scholes *et al*. 2008; Reyers & McGeoch 2007). The photo-monitoring data from this study should contribute not only to SAEON data requests at a national scale but also to our protected areas aspirations towards achieving their monitoring frameworks (McGeoch *et al*. 2011). Park managers use photos regularly to inform their decisions and to effect policy change (Hall 2000; Hendrick & Copenheaver 2009; Lucey & Barraclough 2001; Nichols *et al*. 2009; Turner *et al*. 2003). This study has shown that a regularly updated and properly archived set of fixed-point photographs provides a relatively inexpensive and easily implemented monitoring. This monitoring technique carried out over 18 years at 32 locations in the CNP was able to document short-term changes in growth forms in different vegetation units and land forms and long-term fluctuations of several individual species as well as alien plants. These data, when collected over decades, are essential in separating directional change from short-term variability in the environment. Coupled with detailed rainfall and livestock census records, the relative importance of the underlying drivers of change can also be determined. This is the sort of information that park managers consider necessary for both their day-to-day management decisions and their long-term strategic planning activities. A sound historical assessment of the pattern of change can also help to assess possible future trajectories based on land use and climate change scenarios (Hendrick & Copenheaver 2009; Munson, Webb & Hubbard 2011; Peters *et al*. 2011; Webb *et al*. 2011).

However, the use of repeat photographs within a long-term monitoring programme is not without its problems. For example, whilst the estimation of vegetation cover from photographs can be accurate and similar in precision with point-frequency estimates (Symstad, Wienk & Thorstenson 2008), it is influenced by observer bias. Experienced observers tend to underestimate vegetation cover, whilst less-experienced observers often overestimate this value (Lucey & Barraclough 2001). It is also often difficult to identify smaller shrubs in the landscape when grass cover is high, which leads to an underestimation of this growth form in the photograph, particularly in the Grassy Dwarf Shrublands in this article. Similarly, large trees, especially when they have established close to the camera station, can also obscure the field of view as was the case for some images within the Azonal and Albany Thicket vegetation units photographed in the CNP.

This study has also emphasised that a set of repeat photographs without more detailed survey data is of limited value only. The inclusion of vegetation survey data at each camera station along the direction of the field of view adds further depth to the analysis particularly in terms of an assessment of changes in species diversity, range condition and other species-dependent metrics of ecosystem structure and function (Lucey & Barraclough 2001). Furthermore, without the vegetation surveys undertaken at each location in 2010, little insight into the looming alien plant problem (Masubelele *et al*. 2009), nor the efficacy of the alien clearing programme would have been gained. Associated metadata, such as stocking rates, rainfall and specific management interventions, also help in the interpretation of landscape-level changes and are essential components for any photo-monitoring programme. The nature of these monitoring tools, exactly what is recorded, as well as the frequency of measurement will probably differ between conservation areas. However, monitoring approaches could be similar within the programmes developed for groups of national parks such as those in the arid and semi-arid areas of South

Africa. Such a standardised programme will not only contribute to SANParks monitoring efforts, but will also heed the call for the development of national monitoring programmes (Scholes *et al.* 2008).

Conclusion

Using a repeat photo-monitoring approach this study has documented the varied response of vegetation cover within three main growth forms in different major vegetation units and landforms within the CNP since 1988. Sites within Albany Thicket and Dwarf Shrublands showed the least change in vegetation cover, whilst Azonal vegetation and Grassy Dwarf Shrublands were more dynamic in their response to rainfall and flood plain hydrology. Abiotic factors such as rainfall amount, changes in the distribution of rain between seasons and the occurrence of flood and drought events in combination with high temperatures appeared to have the greatest influence on growth form dynamics. Grasses generally responded to above-average rainfall events and because of their superior competitive ability, negatively influenced the cover of dwarf shrubs. Dwarf shrubs appeared less affected by drought conditions, whilst grass cover declined. The cover of tall shrubs and trees declined under drought conditions and increased significantly after major flood events, particularly within the flood plain associated with the Nqweba Dam. Biotic factors such as herbivory appear to have had a negligible impact on the vegetation of the CNP, at least in terms of how this could be determined from the photo-monitoring techniques used in this study. The lack of any visible impact is primarily because animal densities have remained low over the course of the study, relative to values for commercial livestock production systems in the area. Finally, the potential for using a photo-monitoring programme to document the nature, extent and rate of vegetation change over decades is clearly demonstrated. However, the value of a well maintained, properly archived and easily accessible collection of repeat photos would be considerably enhanced by the collection of additional field survey data at the same time that the photographs were taken. Well-designed experiments are also needed to determine the relative influence of different drivers identified in this study at community and landscape scales.

Acknowledgements

Competing interests

The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

Authors' contributions

M.L.M. (University of Cape Town) completed the photography in 2010, with initial assistance from M.T.H. (University of Cape Town), and also performed the analysis of climate data, whereas P.B. (Camdeboo National Park) set up the sites and photographed the locations from 1988 to 2005. P.B. also provided most of the datasets for the Camdeboo National Park. M.L.M. analysed the animal census data in both *ArcGIS* and Excel. M.T.H. and W.B. (University of Cape Town) made conceptual contributions to the project design and also commented on the draft manuscript, which was written by M.L.M. as part of his PhD thesis.

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