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Vegetation trends following fire in the Roggeveld, Mountain Renosterveld, South Africa

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Abstract

The Mountain Renosterveld vegetation of the Roggeveld is an escarpment type renosterveld showing strong karroid affinities. Fire plays an important role as a landscape scale disturbance that shapes plant communities in this vegetation type, however, post-fire succession has never before been documented for renosterveld vegetation. A study was therefore conducted in the northern Roggeveld to improve our understanding of the recovery of the vegetation following fire. The natural vegetation recovery was analysed using line transect data accumulated at five different sites over a ten year period. This paper reports on the post-fire vegetation trends with respect to changes in species composition, species richness, life form composition and life form richness. Vegetation cover began to re-establish within the first nine months following the fire, and remained at a high level from years 3 to 10. At the first survey the species richness varied from 13 to 17 species, with the highest species richness (14 to 31 species) generally encountered at each transect after three years. The highest Shannon index values were generally found within the first three years and the lowest Shannon index values were found in years 9 and 10. In all cases the Principal Co-ordinate Analysis ordinations of the species composition data indicated a clear separation in the species composition between the first two years (years 1 and 2) following the fire and the remaining years (year 3 to 10). This study also supports the 'initial floristic composition' model of Egler (1954) in that all or the majority of species encountered during the succession were already present at the beginning of the recovery phase and there was a rapid re-establishment of the initial plant community.

Keywords: Fynbos Biome; 'Initial floristic composition' model; Life forms; Long-term monitoring; Post-fire vegetation recovery

1. Introduction

The Mountain Renosterveld vegetation covering the Roggeveld mountain range is an island of Fynbos Biome vegetation surrounded by Succulent Karoo Biome vegetation (Van der Merwe et al., 2008). The Fynbos Biome coincides more or less with the area covered by the Cape Floral Kingdom which is recognised as one of the world's six floristic kingdoms (Good, 1947), on par with much larger regions worldwide (Rebelo et al., 2006). The Fynbos Biome also constitutes the largest portion of the Cape Floristic Region (CFR), a region which is internationally renowned for its exceptional species diversity and which is recognised as one of 34 global hotspots of biodiversity (http://www.biodiversityhotspot.org — accessed 22 February 2009). This biome comprises three quite different, naturally fragmented vegetation types. The three types include fynbos, renosterveld and strandveld, occur in winter- and summer-rainfall areas and are dominated by small-leaved, evergreen shrubs whose regeneration is intimately related to fire (Rebelo et al., 2006).

Renosterveld is an evergreen, fire-prone shrubland or grassland dominated by small, cupressoid-leaved, evergreen asteraceous shrubs (principally *Dicerothamnus rhinocerotis*, renosterbos, rhino bush) with an understory of grasses (Poaceae) and has a high biomass and diversity of geophytes (Cowling et al., 1997; McDowell and Moll, 1992; Moll et al., 1984; Rebelo et al., 2006). The escarpment renosterveld types, such as on the Roggeveld Mountains, show strong karroid affinities. A major feature of renosterveld, at least of the coastal units, is the extensive transformation that has taken place over the last 100 years (Rebelo et al., 2006).

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Dicerothamnus rhinocerotis, after which the renosterveld is named, is an indigenous perennial species which has encroaching properties and is not grazed (Shearing, 1997). Early explorers to the Roggeveld indicated the abundance of grasses in renosterveld and noted that as a result of the high grazing pressure renosterbos was increasing in abundance and the grasses were becoming scarcer (transcriptions and translation of R.J. Gordon's travels, Cullinan, 2003). Marloth (1908) suggested that the frequent burning of the vegetation by early settlers to increase the palatable vegetation for their livestock was actually increasing the dominance of *D. rhinocerotis*.

Fire is a landscape scale disturbance that creates gaps in plant communities which provide space for plant establishment (Carson and Pickett, 1990). Disturbance by fire can contribute to the maintenance of diversity in two manners: firstly, fire contributes to the maintenance of species richness by avoiding competitive exclusion and secondly, fire can increase spatial heterogeneity (Lavorel et al., 1994).

The Mediterranean-type vegetation is one of the world's major fire-prone biomes (Capitanio and Carcaillet, 2008). In areas where this type of vegetation occurs, fire is a crucial process controlling the vegetation dynamics and structure (Capitanio and Carcaillet, 2008), and the post-fire regeneration processes are highly dependent on the pre-fire vegetation (Hanes, 1971; Lloret and Vilá, 2003; Pausas, 1999; Trabaud and Lepart, 1980). Various studies have found that in these ecosystems species composition and structure rapidly recover after fire (Hanes, 1971; Lloret and Vilá, 2003). In fynbos, the effect of fire on species composition, vegetation structure and successional patterns depends on the frequency, intensity and the season of the fire and it was also found that there is considerable variation in response between sites (Cowling et al., 1997; Kruger and Bigalke, 1984). To date post-fire vegetation recovery has never been documented for any of the renosterbos vegetation types (Rebelo et al., 2006).

Guo (2001) found that using plant groups provided a useful framework for describing post-fire chaparral succession because these groups affected ecosystem processes in predictable ways and could also reflect the underlying environmental changes after fire. Raunkiaer's life form system (Raunkiaer 1934) classifies plants into groups in terms of dormant bud position. This life form classification encapsulates sets of correlated traits relating to persistence and architecture that are relevant to disturbance response (McIntyre et al., 1995, 1999).

On 26 January 1999 more than 10 000 ha burnt in the Roggeveld in a lightning induced fire. This event created an opportunity to investigate the post-fire recovery of the vegetation in the Mountain Renosterveld. The aim of the current paper is to report on the post-fire vegetation trends in the Mountain Renosterveld vegetation of the northern Roggeveld, with reference to the changes in species composition, species richness, life form composition and life form richness over a time-span of 10 years (1999–2008). An understanding of the successional processes that take place in the Roggeveld can be used to guide farmers, agricultural and conservation managers on how best to manage the vegetation following fire.

1.1. Study area

The study was conducted in the Mountain Renosterveld vegetation of the Roggeveld on three adjacent farms (Botuin, Klawervlei and Droëkloof) (Table 1). According to Mucina et al. (2005) and Rebelo et al. (2006), the study area falls within the Roggeveld Shale Renosterveld vegetation type. The finer scale classification and mapping (Van der Merwe et al., 2008) showed that the study area was part of the *Dicerothamnus rhinocerotis* Mountain Renosterveld plant association (association 2). This plant association is dominated by *D. rhinocerotis* with *Merxmuellera stricta* and *Chrysocoma ciliata* further characterising the vegetation unit. Following good winter rains, the annual and geophyte components make up a large part of the vegetation.

Although the rains within this region fall mainly in winter, a few summer thunderstorms contribute to the total annual precipitation of 132 mm to 467 mm per year (Weather Bureau, 1998). Winter snowfalls occur with a mean of 6 snow days recorded per year over a 24-year period for Sutherland (Weather Bureau, 1998). The mean daily maximum temperature for January (the warmest month), as measured at Sutherland, is 27.1 °C, while the mean daily minimum temperature for July (the coldest month) is −2.4 °C.

Rocks of the Ecca Group cover most of the Roggeveld Mountains (Rubidge and Hancox, 1999) and shallow stony lithosols are characteristic (Francis et al., 2007). Three of the five post-fire monitoring sites were located on Land Type Da 69 with red B horizons, while the other two sites were located on Land Type Fa 650 on Glenrosa and/or Mispah forms where lime is rare or absent in the entire landscape (Council for Geoscience, 1989) (Table 1).

2. Materials and methods

To acquire objective quantitative data on the vegetation changes that occurred following the fire in 1999, a point or plotless method was used. Due to the steep slopes and rock-strewn areas, the descending point method (Roux, 1963; Novellie and Strydom, 1987) was deemed the most appropriate method to track post-fire vegetation trends at the five selected sites. A canopy strike was recorded when the descending point touched any plant material or fell within the canopy spread of an individual plant.

The transects were permanently marked with iron poles ('droppers') which indicated the beginning and end points of a 50 m rope marked at 1 m intervals. Four lines, 1 m apart and parallel to one another were surveyed in order to limit the chance of surveying transitional areas between different vegetation types or habitats. The transects were monitored yearly in the last week of September or the first week of October. Ten years (from 1999 to 2008) of data were collected.

The number of strikes on a species were calculated as a percentage of the total number of point observations made and were not expressed as a percentage of all the strikes (Du Toit, 1998a). Using this method the sum of the individual plant species percentages obtained rarely totals one hundred (Du Toit,

Table 1
Prominent features of the five post-fire monitoring sites in the Roggeveld, indicating GPS starting point co-ordinates, altitude, aspect, land type and dominant perennial plant species ten years after a fire.

	Site 1	Site 2	Site 3	Site 4	Site 5
GPS co-ordinates: Starting point	31°58′35.6″S 20°00′27.3″E	31°59′15.2″S 20°01′11.5″E	31°58′39.6″S 20°01′26.2″E	31°55′49.7″S 20°01′34.7″E	31°55′19.8″S 20°01′43.9″E
Altitude	1440 m	1371 m	1296 m	1334 m	1385 m
Aspect	East	North	West	South	South
Land type	Da 69 [a]	Da 69	Da 69	Fa 650 [a]	Fa 650
Dominant perennial plant species after 10 years following a fire	*Dicerothamnus rhinocerotis, Merxmuellera stricta, Muraltia vulnerans*	*Merxmuellera stricta, Chrysocoma ciliata, Dicerothamnus rhinocerotis*	*Merxmuellera stricta, Chrysocoma ciliata*	*Dicerothamnus rhinocerotis, Merxmuellera stricta*	*Leysera gnaphalodes, Lotononis hirsuta*

[a] Land type Da 69 is characterised by red B horizons, while Land type Fa 650 on Glenrosa and/or Mispah forms has lime rare or absent in the entire landscape.

1998b). In this study, the number of strikes per species was expressed as a percentage of the 200 points surveyed and these totals added to determine the total percentage vegetation cover.

The species were also classified into the dominant life forms as defined by Raunkiaer (1934) and modified by Mueller–Dombois and Ellenberg (1974).

Temporal changes in the post-fire vegetation were investigated in terms of (a) total vegetation cover, (b) total species richness, (c) the Shannon index of diversity, (d) vegetation cover per life form, (e) species richness per life form, and (f) changes in species composition across a 10 year period.

Shannon's index of diversity (H′), often referred to as the Shannon–Wiener index, was calculated for each sampled plot using the PC-ORD computer program (PC-ORD Version 4 for Windows, MjM Software design) which calculates this diversity measure as follows:

$$H' = \text{Shannon diversity}$$

$$H' = -\sum_{i=1}^{S} p_i \log p_i$$

Where p_i = importance probability of species i.

The Shannon index is one of the numerous diversity indices that exists (Magurran, 1988; Shmida, 1984; Stirling and Wilsey, 2001). It has the advantage that it combines both components of diversity, i.e. species richness and species evenness, into a single measure. In spite of various criticisms, the Shannon index has sparked renewed interest in handling problems associated with the conservation of natural heritage or the changes in global ecology (Mouillot and Leprêtre, 1999).

The species compositional data for each of the five post-fire monitoring transects over the ten year period were ordinated using Principal Co-ordinate Analysis (PCoA) in the SYN-TAX computer program (Podani, 2001). A Principal Co-ordinate Analysis generally performs well with species data because it allows the use of a wide array of distance measures and therefore is a marked improvement over the Principal Component Analysis (McCune and Grace, 2002).

3. Results and discussion

The vegetation cover increased within the first nine months following the fire (Fig. 1). Vegetation cover at sites 1 and 5 increased steadily from 1999 to 2001 (Fig. 1a, e), while at sites 2 and 3 it decreased from 1999 to 2000 and then increased again from 2000 to 2001 (Fig. 1b, c). The post-fire transect 4 showed no change in vegetation cover between 1999 and 2000 but there was an increase in 2001 (Fig. 1d). The high vegetation cover recorded in the 2001 season could be attributed to the region receiving good rains in that year. Between 2001 and 2008 the vegetation cover in all the post-fire monitoring transects remained higher than the vegetation cover found in the first two years following the fire. In most instances there was a decrease in vegetation cover in 2003, 2004 and 2005. These three years were characterised by low rainfall and these drought conditions resulted in a low therophyte vegetation cover (Fig. 1). The vegetation on Land Type Da (sites 1, 2 and 3) had a far higher cover of perennial species (59.5%–71%) than Land Type Fa (sites 4 and 5) (35.5%–47%).

Within nine months after the fire, the total number of species surveyed in the 200-point line transects ranged from 13 to 17 species per transect (Fig. 2). At all sites on Land Type Da the highest species richness was reached within 3 years after the fire, whereafter the species richness declined or remained more or less constant. A similar increase in the second and third post-fire years and subsequent decrease in species richness was reported in the Californian chaparral (Guo, 2001). In the case of the sites on Land Type Fa, species richness initially declined after the high value in 2001 but increased again to reach a maximum in 2006. Therophyte species contributed more to the species numbers on Land Type Fa (Fig. 2d, e) than on Land Type Da (Fig. 2a–c). In all cases, chamaephyte species made a large contribution to the total species numbers.

Various studies in the Mediterranean-type ecosystems have indicated a quick community recovery after fire and therefore it is concluded that species richness is at its highest soon after fire (Capitanio and Carcaillet, 2008). Species diversity has been found to peak within the first year (Keeley et al., 1981; Schwilk et al., 1997) or second year (Potts et al., 2003). Guo (2001) reported the highest species richness in the second post-fire year on the north-facing slopes and in the third year on the south-facing slopes. In all instances species richness was reported to decline in the following years. It is evident from studying the species composition soon after the fire that all, or the majority of species present during the succession are in place from the beginning of the recovery phase. It appears that species richness in fynbos vegetation is higher soon after fire and the succession proceeds by successive elimination of species (Bond and Van

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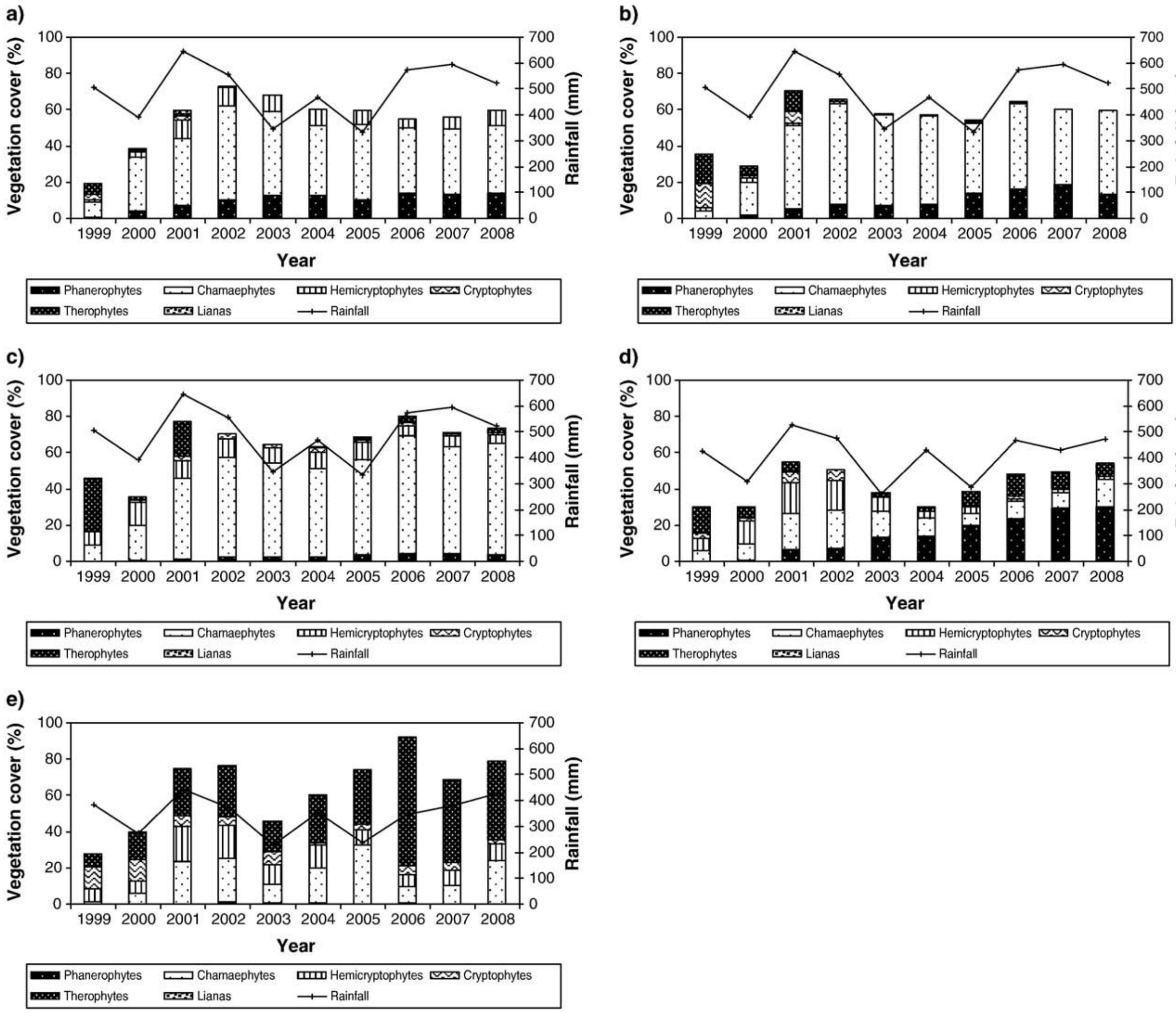

Fig. 1. Vegetation cover changes per life form (columns – left hand axis) determined from a 200-point survey and annual rainfall (line – right hand axis) for five post-fire monitoring transects: a) site 1, b) site 2, c) site 3, d) site 4; and e) site 5.

Wilgen, 1996). Since data collected in this study supports the fact that nearly all of the species were already present in the early recovery phase, with new species being added continually, and that the initial plant community established rapidly, the 'initial floristic composition' model of Egler (1954) seems to apply to this ecosystem. However, further research is needed to resolve which, if any, model of vegetation dynamics most accurately reflects post-fire dynamics in Mediterranean ecosystems (Capitanio and Carcaillet, 2008).

The Shannon index values for the five monitoring sites ranged from 1.11 (site 2) to 3.03 (site 5) (Table 2) across the ten year period. The highest two values for sites 1 to 4 were found within the first three years following the fire and the lowest Shannon values for these sites were found in years 9 and 10. In the case of site 5, the highest two values were found in years 3 (2001) and 10 (2008). The lowest Shannon value for site 5 was 2.56, which is higher than the highest values encountered in sites 1 to 4 (Table 2). This initial high Shannon value following the fire is as a result of the presence of a high number of geophytes (cryptophyte species) and annuals (therophyte species), which react quickly after fire. In a study conducted in the natural unburnt Mountain Renosterveld vegetation, the Shannon index values were found to range from 2.23 to 3.65 (Van der Merwe, 2009).

Upon comparing the relative contributions of Raunkiaer's (1934) classic life form categories, two different patterns emerged across the 10 years of the survey. The three post-fire monitoring transects located on Land Type Da (sites 1, 2 and 3) produced different life form spectra from the two post-fire monitoring sites located on Land Type Fa (Sites 4 and 5) (Figs. 3 and 4). In general, the contribution of phanerophyte and chamaephyte species was higher on Land Type Da (Fig. 3a–c) than on Land Type Fa (Fig. 3d, e), whereas the contribution of therophyte species was higher on Land Type Fa than on Land Type Da (Fig. 3a–e).

The relative percentage contribution per life form to the vegetation cover produced different results (Fig. 4) from the percentage contribution at a species level (Fig. 3). Phanerophytes contributed to a larger proportion of the vegetation cover than their species numbers suggested at sites 1, 2 and 4

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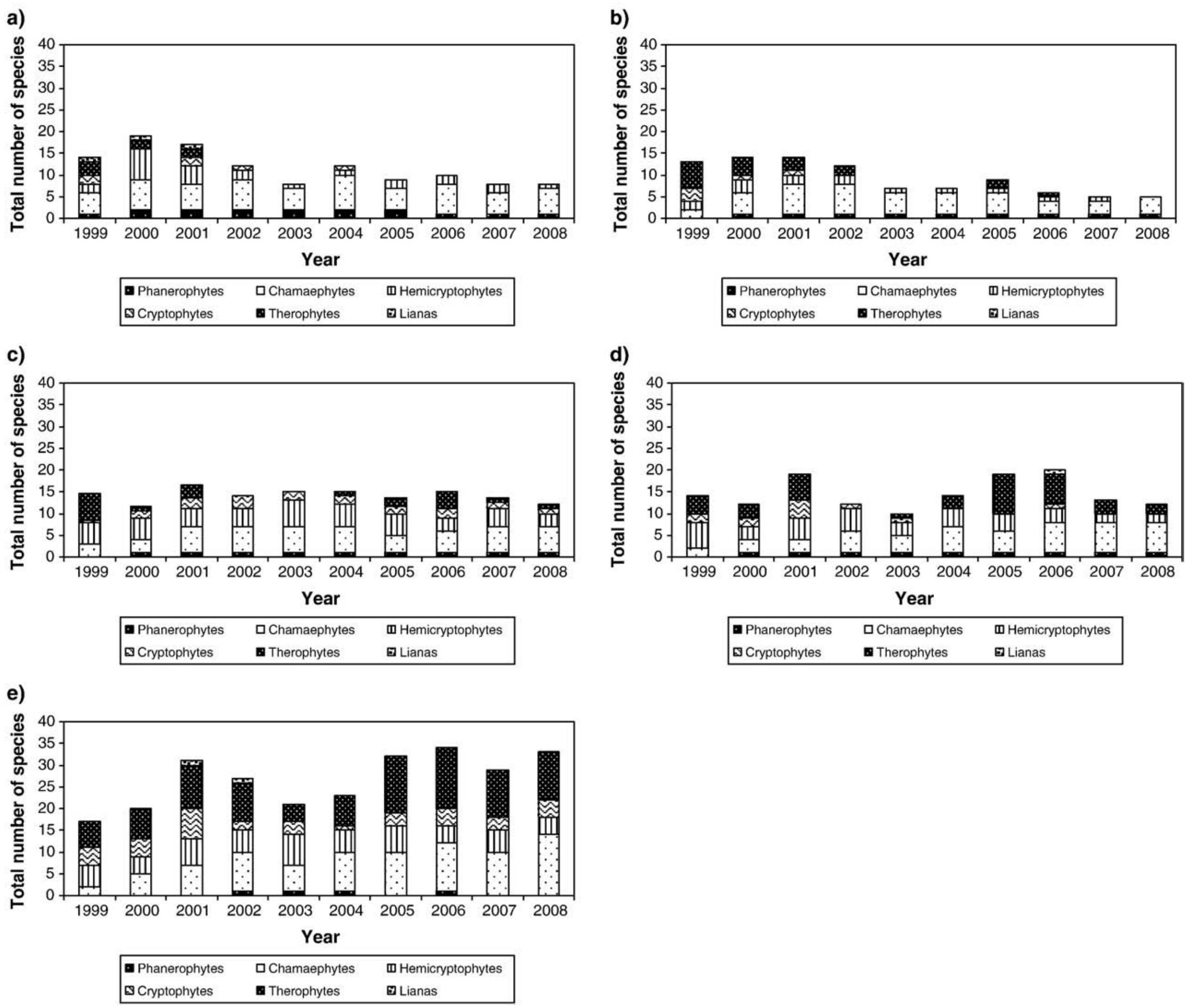

Fig. 2. Total number of species per life form determined from a 200-point survey for the five post-fire monitoring transects: a) site 1, b) site 2, c) site 3, d) site 4; and e) site 5.

(Fig. 4a, b, d). This was primarily as a result of the dominance by *D. rhinocerotis*. Site 3 was a *Merxmuellera stricta* grass-dominated site with the grass limiting *D. rhinocerotis* establishment, hence the lower phanerophyte cover contribution (Fig. 4c). Chamaephyte cover dominated in the three Land Type Da post-fire monitoring transects (Fig. 4a–c), whereas the contribution of therophytes to the overall vegetation cover of these transects was limited to a small percentage in the first four years following the fire (Fig. 4a–c). In contrast, the therophyte cover contribution on Land Type Fa (Fig. 4d, e) remained relatively high throughout the first 10 years following the fire.

The prominent difference between site 4 and site 5 on Land Type Fa was the high cover contribution of phanerophytes in site 4 and their near absence in site 5 (Fig. 4d, e). This difference was due to the farmer removing all the *D. rhinocerotis* plants in site 5 in 2000 in order to limit their establishment and later dominance of the area. This intervention by the farmer limited *D. rhinocerotis* to a few individuals and therefore the percentage contribution of therophytes to the vegetation cover was higher than in site 4 (Fig. 4d, e). Also, the species richness in site 5 was more than twice as high where the *D. rhinocerotis* individuals were removed (Fig. 2). When considering only the perennial species, sites 1 to 4 had between five and ten perennial species in 2008, whereas 22 perennial species were encountered in site 5. Yet, at a vegetation cover level sites 1 to 4 had a perennial vegetation cover of between 47% and 71% while site 5 only had a perennial

Table 2
Shannon index values for five post-fire monitoring transects in the Roggeveld (site 1–5) from 1999 to 2008.

Year	Site 1	Site 2	Site 3	Site 4	Site 5
1999	2.26	2.09	2.15	2.04	2.56
2000	1.77	2.01	1.78	1.87	2.69
2001	2.08	1.97	2.06	2.20	2.98
2002	1.97	1.57	1.78	1.97	2.91
2003	1.45	1.15	1.45	1.75	2.61
2004	1.73	1.22	1.64	1.91	2.66
2005	1.60	1.34	1.47	1.98	2.93
2006	1.55	1.17	1.37	2.02	2.74
2007	1.57	1.11	1.30	1.41	2.94
2008	1.52	1.14	1.48	1.58	3.03

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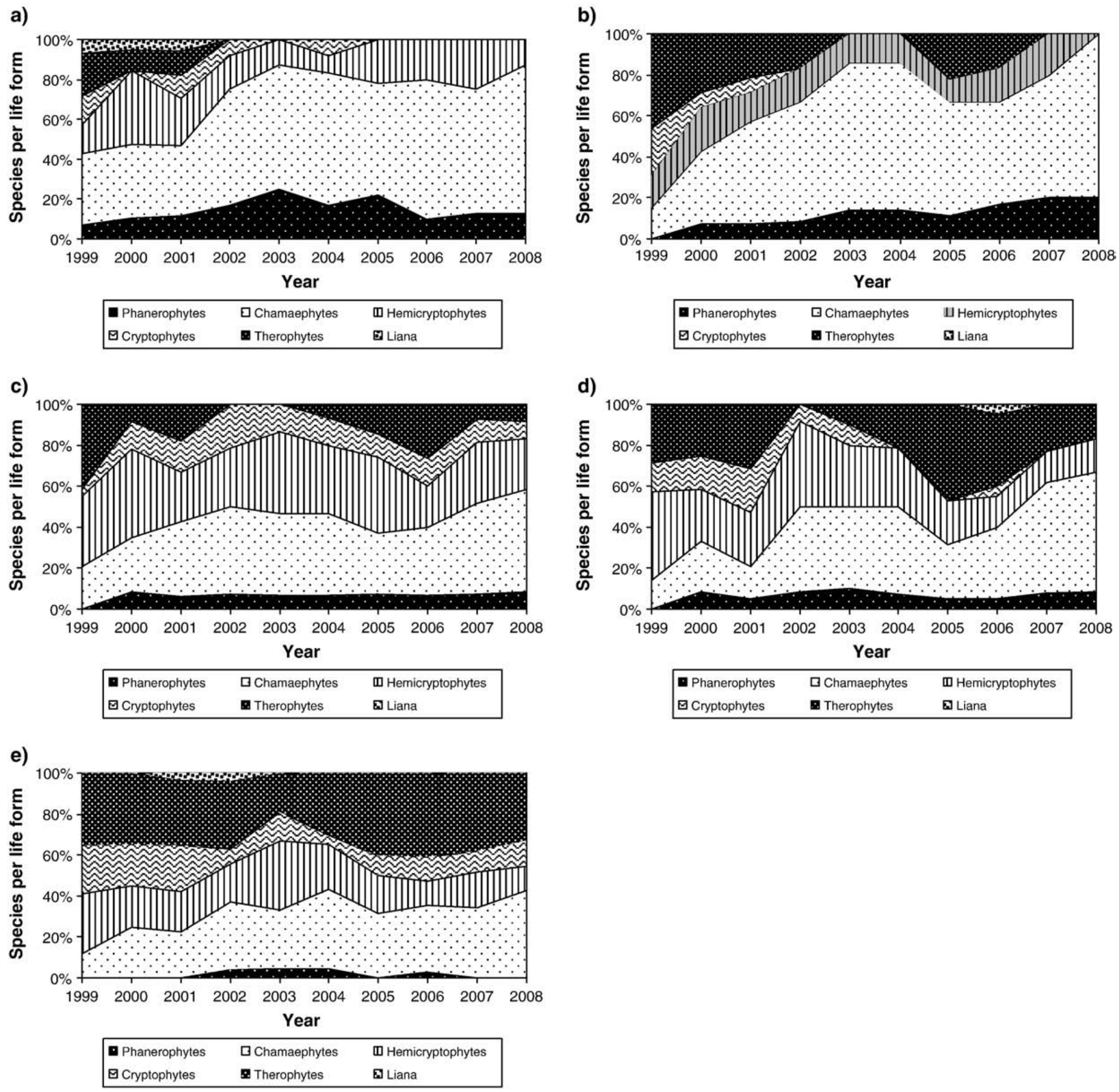

Fig. 3. Number of species per life form expressed as a percentage of the total number of species for post-fire monitoring transects: a) site 1, b) site 2, c) site 3, d) site 4; and e) site 5.

vegetation cover of 35.5%. In 2008, the vegetation cover at site 5 was 79% of which 45% was contributed to perennial species. In contrast, in 2008 at site 4 the total vegetation cover was 54.5%, but 47% was contributed by perennial species. Whether this annual dominated vegetation cover resulting from the removal of *D. rhinocerotis* is more desirable than the perennial *D. rhinocerotis* vegetation cover remains to be seen.

The Principal Co-ordinate Analysis of the species compositional data for the ten years following the fire produced varying results at each post-fire monitoring transect (Fig. 5). There was, however, in all cases a clear spread along the two axes separating the ten years. Years 1 and 2 were found to be on the right hand side of the ordination diagram while subsequent years were found towards the left of the ordination space. The three Da land type transects (sites 1, 2 and 3) produced similar ordination diagrams in that years 1 and 2 were quite well separated from the other years along the *x*-axis (Fig. 5a–c). Results for years 4 to 10 produced various sequences however, and in all cases some convergence seemed to occur towards the left hand side of the ordination space (Fig. 5a–c).

The two Land Type Fa transects (sites 4 and 5) were similar in that years 1 and 2 occurred close together on the extreme right hand side of the ordination diagram (Fig. 5d, e). The order of the subsequent years (years 3 to 10) were chronologically spread out towards the left hand side of the ordination for site 4, but were rather haphazardly arranged for site 5 (Fig. 5d, e). This haphazard arrangement in the ordination space of site 5 could be as a result of the removal of *D. rhinocerotis* seedlings in 2000.

With regards to the vegetation cover, the successional sequence following the fire, began with an initial dominance of therophytes and geophytes. These life forms were progressively replaced by chamaephytes and phanerophytes. Hemicryptophytes

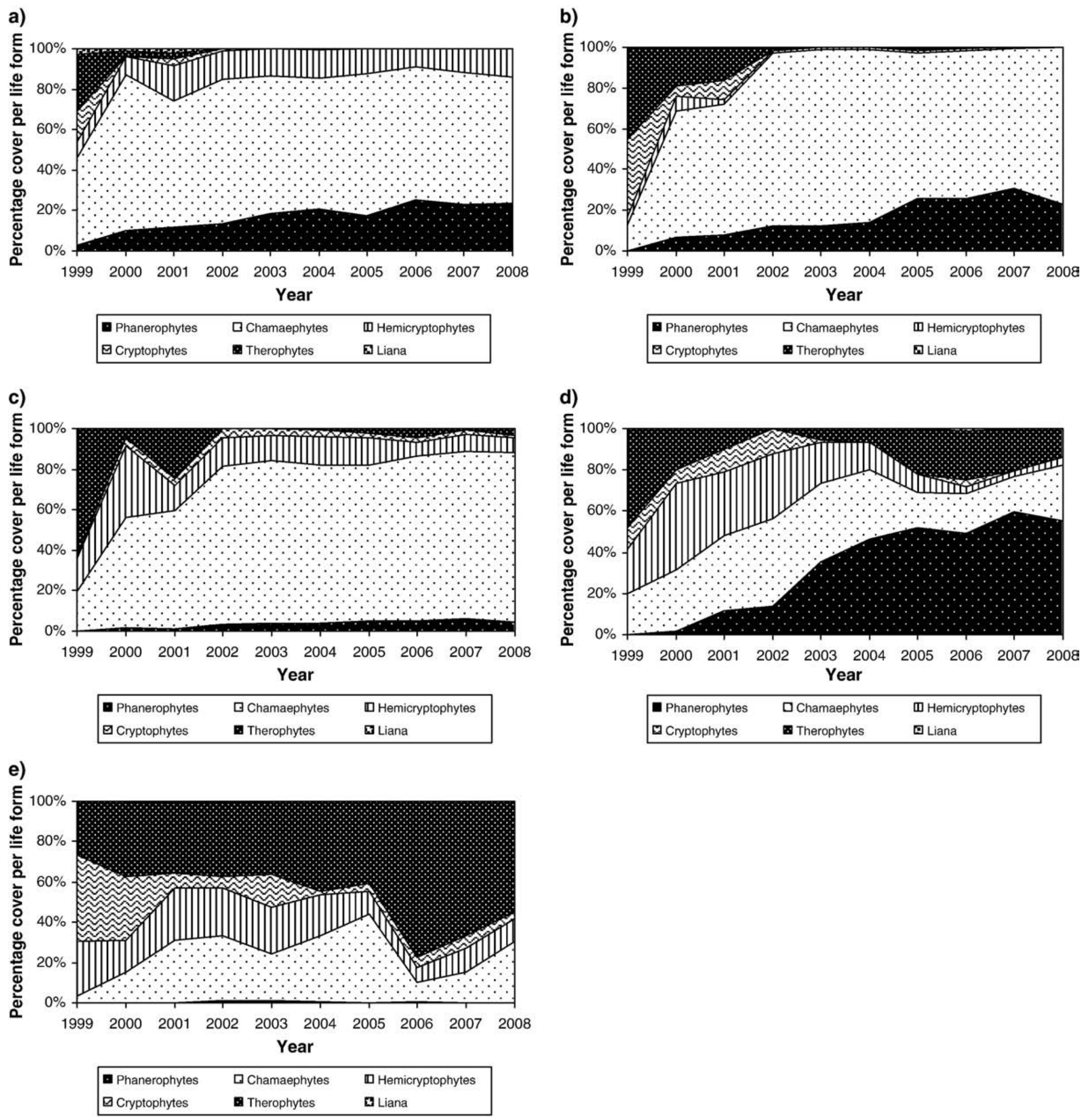

Fig. 4. Percentage vegetation cover per life form expressed as a percentage of the total vegetation cover for post-fire monitoring transects: a) site 1, b) site 2, c) site 3, d) site 4; and e) site 5.

were variable and seemed, in most instances, to increase at first and then decline. The prominence of geophytes after fire has also been reported for fynbos, but fynbos usually does not have a large therophyte component.

The successional sequence is expected to be easily affected by grazing pressure and the time at which the vegetation is grazed. Grazing, for example, is expected to have a much greater influence on vegetation recovery if the vegetation is more heavily grazed during the growing season than in the dry season. Additionally, a subsequent fire within a short space of time of the first would severely impact on the phanerophytes and chamaephytes, however, geophytes (cryptophytes) and therophytes would not be as seriously impacted upon.

Furthermore the study suggests that in the Roggeveld the vegetation recovery following fire is rapid. This recovery process could be further enhanced by a reduced grazing pressure in order to improve the establishment chances of palatable species thereby guiding the recovery process to a healthier vegetation condition.

4. Conclusions

Vegetation began to re-establish within the first few months following a fire in the Mountain Renosterveld vegetation of the Roggeveld. At all the post-fire monitoring sites, the vegetation cover remained higher from years 3 to 10 than that found immediately following the fire (years 1 and 2). Additionally, a single high rainfall year and three consecutive drought years had a large influence on the vegetation cover, increasing especially the therophyte cover under the good rainfall conditions and decreasing their cover under poor rainfall conditions.

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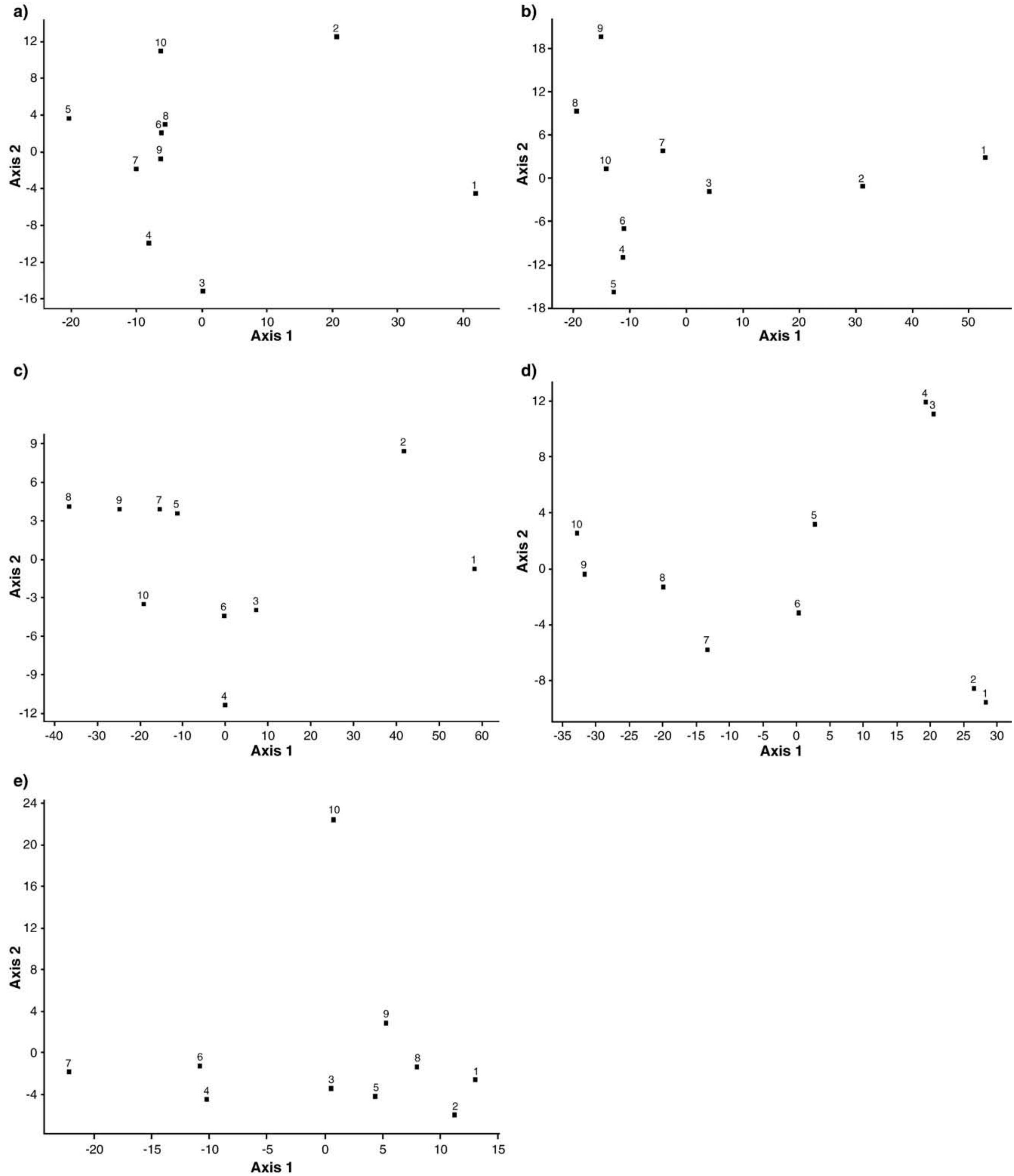

Fig. 5. Principal Co-ordinate Analysis of species composition data for ten years (1–10) following a fire in the Roggeveld at post-fire monitoring transects: a) site 1, b) site 2, c) site 3, d) site 4; and e) site 5.

The total number of species per transect varied from 13 to 17 species within the first nine months following the fire. Species richness in most instances was highest (14 – 31 species) three years after the fire with chamaephyte species contributing the most in all the transects. However, on the two Land Type Fa sites, therophyte species often contributed more to the total species richness of the transect.

Shannon index values generally ranged from 1.11 to 2.26 with the exception of one study transect where the lowest Shannon value was 2.56 and the highest value 3.03. This transect also differed from the others in that the lowest Shannon value was found in the first year following the fire and the highest value was found in the tenth year following the fire. In all the other transects the pattern was reversed and the lowest Shannon values were found in years 9 and 10 and the highest Shannon values were in years 1 to 3.

Temporal changes in life form composition were found at species and vegetation cover levels and depended on the land type. Generally, at species level, the phanerophyte and chamaephyte species contribution was higher on Land Type Da than on Land Type Fa, while the therophyte species percentage contributions were higher on Land Type Fa than Land Type Da. Between the five post-fire monitoring transects, the phanerophyte vegetation cover contribution was highest on two transects on Land Type Da and one transect on Land Type Fa due to the dominance of *D. rhinocerotis*. Chamaephyte vegetation cover was highest on Land Type Da while the therophyte or phanerophyte vegetation cover was highest on Land Type Fa.

An ordination of species data for each survey plot indicated the large difference in species composition between the first two years and subsequent years following the fire. The current data support Egler's (1954) 'initial floristic composition' model which states that all or the majority of species present during the succession are in place at the beginning of the recovery phase and that re-establishment of the initial plant community is a rapid phenomenon (Capitanio and Carcaillet, 2008).

This study was the first to record vegetation recovery following fire in the renosterveld vegetation type. The improved understanding will guide Roggeveld farmers, agricultural and conservation managers in their decision making on how to manage vegetation establishment following fire.

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