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Landscape fragmentation in South Coast Renosterveld, South Africa, in relation to rainfall and topography

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Abstract The South Coast Renosterveld has been fragmented extensively by agriculture. The extent of this fragmentation in terms of overall habitat loss, fragment sizes and fragment numbers has not been described previously, thereby limiting the development of conservation strategies for this vegetation type. Patterns of renosterveld loss in three sectors along a west–east gradient were described using LANDSAT imagery and a Geographical Information System-based program (FRAGSTATS) for spatial pattern analysis. These patterns were then correlated with rainfall and topography measures, which are indicators of agricultural potential. Over 80% of the South Coast Renosterveld has been cultivated. Fragmentation levels increased significantly from east to west, with 33% of natural vegetation remaining in the east and only 4% in the west. Topographical variables were the strongest predictors of patterns of renosterveld loss, with fragments being largely confined to slopes too steep for ploughing; they therefore face little risk of future cultivation. These results have implications for conservation planning options for the South Coast Renosterveld. There is the potential for large reserves in the east, as well as corridor reserves along major river valleys, but for only small, isolated reserves in the west.

Key words: agriculture, conservation planning, environmental predictors, habitat loss, landscape fragmentation, renosterveld.

INTRODUCTION

Highly fragmented landscapes pose particularly difficult problems for conservation planning. This is because remnants of natural habitat tend to have a high conservation value and are also highly vulnerable to a wide array of threats (Saunders *et al.* 1991; Fahrig & Merriam 1994). Thus, many remnants qualify as priorities for conservation action, despite their lack of appeal to conservation authorities and lobby groups (Pressey 1994; Balmford 1996). The high conservation value of fragments is associated with high irreplaceability: as a result of large-scale habitat loss, each fragment potentially can make a high contribution to a reservation goal; alternatively, the loss of a fragment may greatly restrict options for attaining a representative reserve system (Pressey *et al.* 1994, 1995). Their location in an agricultural matrix makes fragments highly vulnerable to a wide array of processes that threaten the long-term maintenance of biodiversity (Terborgh & Winter 1980; Gilpin & Soulé 1986).

Fragmentation is invariably associated with land systems where conservation competes poorly with other forms of land use such as agriculture and urbanisation. This is certainly true of renosterveld, a fire-prone, small-leaved, grassy shrubland of South Africa's Cape Floristic Region (Low & Rebelo 1996). Renosterveld, renowned for its spectacularly rich geophyte flora (Cowling 1990; Johnson 1992), is largely associated with shale-derived and moderately fertile lowland soils, making this vegetation type highly suitable for cereal cultivation (Hoffman 1997). The West Coast Renosterveld, which covers an undulating coastal plain north of Cape Town (Fig. 1), has been extensively transformed by cereal and pasture crops: only 3% remained in 1988 as isolated fragments, largely on lands too steep for agriculture (McDowell 1988; Heydenrych & Littlewort 1995). The South Coast Renosterveld, which is the focus of this paper, is mostly confined to the semi-arid to subhumid (350–600 mm year^{-1}) coastal forelands of the southern Cape of South Africa (Fig. 1). This vegetation type is apparently less fragmented than the West Coast Renosterveld (Cowling *et al.* 1986; Rebelo 1995), although no quantitative data exist.

For centuries, the South Coast Renosterveld was grazed by livestock initially belonging to Khoi-Khoi pastoralists and later to Dutch settlers (Rebelo 1995). Mechanisation after World War I facilitated large-scale, intensive agriculture, and an estimated 160 000 ha of

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natural vegetation was cleared for cereals and pastures between 1918 and 1990 (Cowling *et al.* 1986; Hoffman 1997). However, estimates of the amount of loss of natural vegetation are crude (Moll & Bossi 1984; Low & Rebelo 1996) and no account of the number and sizes of renosterveld fragments exists. Despite its critical conservation status, only 0.8% of the South Coast Renosterveld is formally conserved (Rebelo 1992). An overview of patterns of renosterveld loss, together with a knowledge of smaller-scale patterns and processes (Kemper 1997) can provide useful information for developing strategies for renosterveld conservation.

The establishment of a predictive understanding of transformation of natural vegetation will allow estimates of future threats to the remaining vegetation (Pressey *et al.* 1996). Reliable winter rainfall is a prerequisite for cereal cultivation in the warm temperate Western Cape. Rainfall patterns across the distribution of the South Coast Renosterveld change from west to east, with winter rainfall in the west and a bimodal spring–autumn regime in the east (Deacon *et al.* 1992). Accordingly, we predict less fragmentation in the eastern sector where winter rainfall is less reliable. In addition, slope strongly influences agricultural practices. In guidelines set by the Agricultural Resources Act, land can be worked on slopes of <1.8°; on slopes between 1.8 and 8.1°, land can be worked but measures to prevent erosion, such as the construction of contours, must be taken; land with slopes of >8.1° cannot be worked. Slope also changes from west to east, with gently rolling, almost flat country in the west being gradually replaced by steeper country in the east. Therefore, we predict a strong relationship between steep topography and patterns of renosterveld loss.

In this paper, we examine the South Coast Renosterveld landscape fragmentation patterns in terms of overall habitat loss, fragmentation sizes and fragmentation numbers. Our objectives were: (i) to provide a descriptive, broad, regional overview of fragmentation patterns in the South Coast Renosterveld, (ii) to describe how these patterns change from west to east; and (iii) to model the extent of habitat loss in terms of rainfall regime and topographical features. Finally, we discuss the implications of our results in terms of future options for conserving this vegetation type.

METHODS

Landscape fragmentation patterns

1992–94 LANDSAT Thematic Mapper satellite imagery was used to develop a landcover map at a 1 : 250 000 scale as part of a national project, initiated

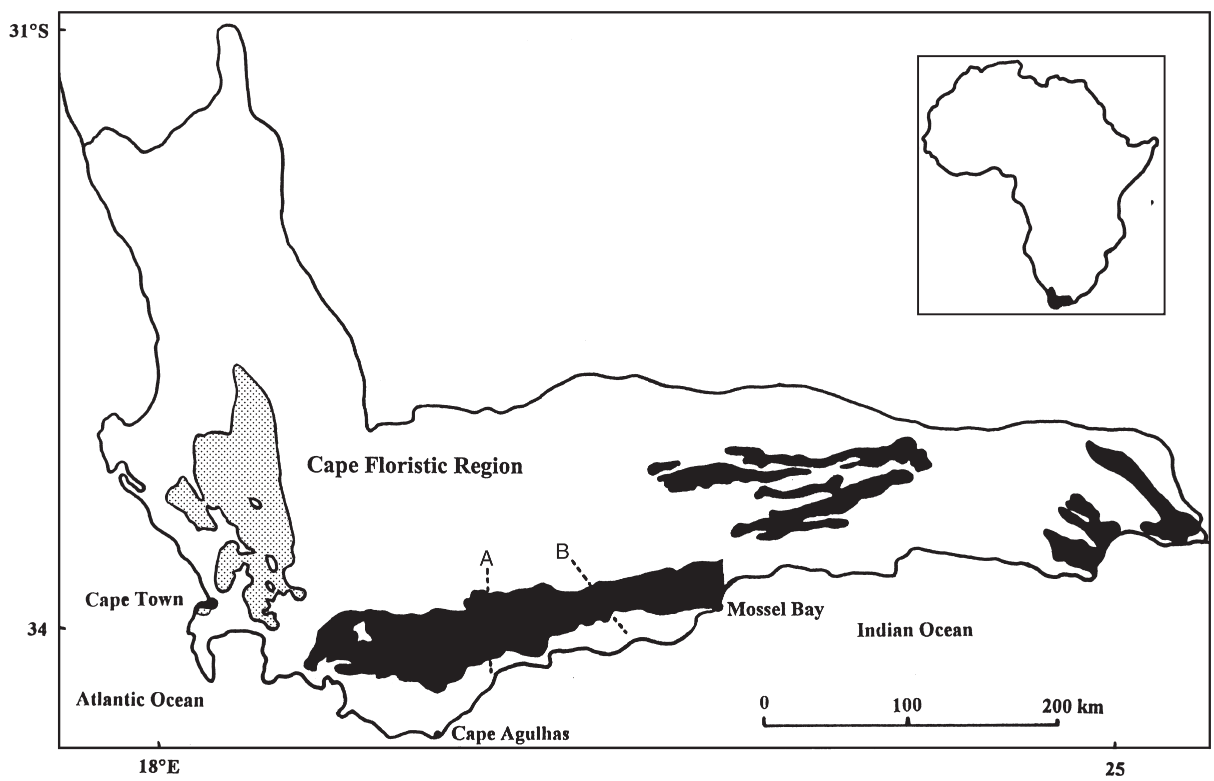

Fig. 1. Map showing the study area within the Cape Floristic Region, South Africa. Dotted lines indicate (A) division between western and central sector and (B) division between central and eastern sector. Adapted from Rebelo (1995), with permission.

by the Council for Scientific and Industrial Research (CSIR), South Africa, and the Institute of Soil, Climate and Water (Agricultural Research Council), South Africa. Landcover data were classified based on known and identifiable landcover types (Thompson 1996). The extent of the study area was limited to those areas underlain by Bokkeveld Group shale and Cretaceous sediments, both of which give rise to soils of relatively good agricultural potential, and further bounded by the foothills of the Riviersonderend and Langeberg mountain chains in the north and the town of Mossel Bay to the east (Fig. 1). This area includes the largest contiguous block of the South Coast Renosterveld in the Cape Floristic Region (Low & Rebelo 1996).

We categorised landcover into three classes: renosterveld; cultivated land, including perennial crops (e.g. orchards, vineyards) and annual crops (cereals, pastures); and other, including waterbodies, fragments of non-renosterveld vegetation, residential and industrial sites and quarries. Annual crops make up the bulk of cultivated land in the study area. We included only fragments of >6 ha (all classes). The landcover map was manipulated on a workstation using ARC/INFO version 7.0.4 (Environmental Systems Research

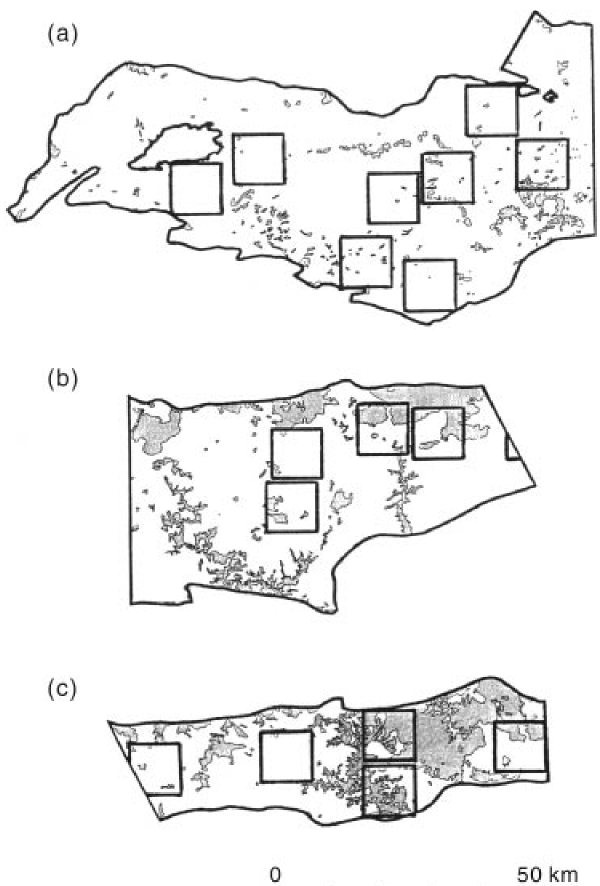

Fig. 2. Extent of study area showing renosterveld fragments (grey) and position of 17 sampling cells: (a) western sector; (b) central sector; (c) eastern sector.

Institute, Redlands, CA, USA). We divided the study area subjectively into three sectors (west, central, east) to allow the quantification of landscape pattern change from west to east (Fig. 1). The boundaries were drawn to ensure minimal splitting of fragments into different sectors.

We analysed the three subsets and the full landcover dataset with the vector version of FRAGSTATS (McGarigal & Marks 1994). We tested for significant differences in mean values of renosterveld and cultivated land area for each sector (west, central, east) using Kruskal–Wallis one-way analysis of variance by ranks. This non-parametric analysis was chosen because data were non-normally distributed. In addition, chi-squared analysis was used to test the null hypothesis that renosterveld fragment size classes were distributed in the same frequency in the different sectors. Classes were as follows: <10 ha, 10–50 ha, 51–200 ha and >200 ha. These size classes were also used in a parallel study on the effects of fragmentation on plant diversity patterns (Kemper 1997; Kemper *et al.* 1999).

Predictors of landscape fragmentation patterns

We obtained annual and monthly rainfall data for 17 weather stations located in the study area (Computing Centre for Water Research 1996). The weather stations were located on the landcover map and a cell (10×10 km) was centred on each station (Fig. 2). We assumed climate data to remain uniform within the 100-km^2 cell. In six cases, cells fell partially outside the study area; these were shifted to be completely included. The landcover map was used to calculate the percentage of renosterveld within each cell. This design was limited by the non-random distribution of weather stations.

We used a digital elevation model (Chief Directorate: Surveys and Land Information 1996) to measure slope within each 100-km^2 cell. Resolution was 400×400 m, with steep areas interpolated to 200×200 m. This coverage was overlaid on the landcover map. Slope was sampled from 50 randomly located points within each 100-km^2 cell. We chose the following explanatory variables for modelling patterns of fragmentation of renosterveld in the study area.

1. Total annual rainfall (mm).
2. Rainfall seasonality: rainfall between May and September (winter) / total annual rainfall × 100 (%).
3. Coefficient of variation of the rainfall in the three wettest months: standard deviation / mean rainfall of the three wettest months over *n* years (%).
4. Mean slope angle (°).
5. Coefficient of variation of slope angle: standard deviation / mean slope angle (%).

All variables were tested for normality. Per cent renosterveld and rainfall seasonality were arcsin transformed. Spearman rank correlation analysis was used to test for colinearity among explanatory variables. Bivariate models of the relationship between percentage renosterveld and explanatory variables were developed using least squares regression. Multiple regression was used to model renosterveld cover in terms of the full set of explanatory variables.

RESULTS

Landscape fragmentation patterns

The study area covered 816 796 ha (Fig. 2); of this, 117 967 ha (14.4%) was natural vegetation (renosterveld), 672 194 ha (82.3%) was cultivated and 26 954 ha (3.3%) was classified as 'other'. Thus the area is overwhelmingly dominated by agriculture, followed by renosterveld; landcover attributed to residential/industrial use was minimal. Renosterveld was highly fragmented with 394 fragments scattered throughout the landscape.

Both renosterveld and cultivated land showed changes in landscape patterns from west to east (Table 1). Renosterveld was most fragmented in the west with a large number of small fragments embedded in a sea of cultivated land. Renosterveld made up only 4.4% of the western sector. By contrast, 33.4% of the eastern sector comprised renosterveld, with a mean fragment size nearly 20 times greater than in the west, and more than twice the mean fragment size in the central sector. The extent of cultivated land decreased from nearly 89.7% in the west to 62.8% in the east. Mean size of cultivated fragments decreased from west to east by nearly 97%, but median fragment size remained comparatively even both for renosterveld and for cultivated land. This reflects the skewed (non-normal) distribution of fragment sizes. Most renosterveld and cultivated fragments were comparably small, and the presence of a few very large fragments resulted in large mean fragment size values. The coefficient of variation of renosterveld and cultivated fragment size increased from west to east. Kruskal–Wallis analysis of variance for both landcover classes showed that renosterveld fragment size differed significantly between sectors (H = 41.68, $P < 0.01$). Mean fragment size of cultivated land did not differ significantly between sectors (H = 1.74, $P = 0.419$).

The results of the chi-squared analysis (Fig. 3) show that the frequency of fragment size classes varied significantly along the gradient. Small fragments (<10 ha) were over-represented in the west; large fragments (>200 ha) were over-represented in the east.

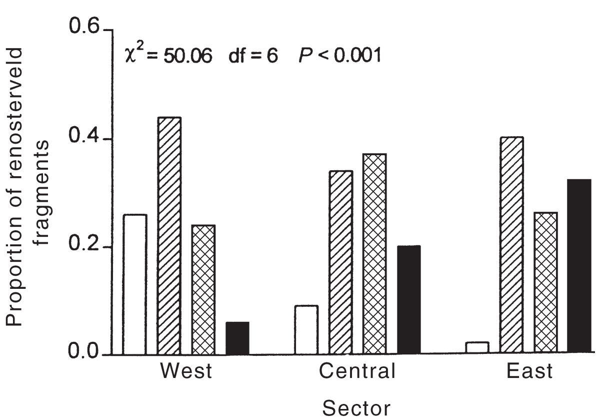

Fig. 3. Proportion of South Coast Renosterveld fragments in each of four size classes for three study area sectors. Chi-squared analysis, shown, was carried out on frequency (untransformed) data. Fragment size classes (ha): □ <10, ▨ 10–50, ⊠ 51–200, ■ >200.

Predictors of landscape fragmentation patterns

Spearman rank correlation analysis revealed a weak but significant negative relationship between rainfall

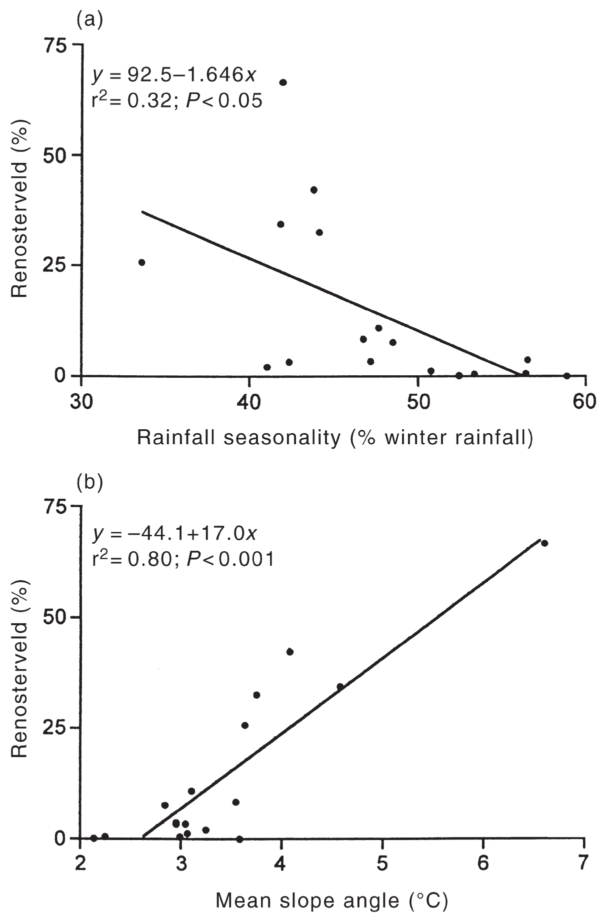

Fig. 4. Linear regressions of renosterveld extent per square and (a) rainfall seasonality and (b) mean slope angle. Percentage data were arcsin transformed. Data were tested for normality.

Table 1. Summary of landcover class composition in each of three study area sectors and for the total study area. Landcover classes: renosterveld (natural) and cultivated land (cultivated)

	Sector						Total	
	West		Central		East			
	Natural	Cultivated	Natural	Cultivated	Natural	Cultivated	Natural	Cultivated
Total area (ha)	17 420.7	354 674.1	46 196.3	210 866.4	54 349.5	106 652.9	117 966.5	672 193.4
Number of fragments	271.0	6.0	81.0	13.0	42.0	59.0	394.0	78.0
Percentage of landscape (%)	4.4	89.7	17.9	81.6	33.4	62.8	14.4	82.3
Mean fragment size (ha)	64.9	59 112.4	570.3	16 220.5	1294.0	1807.7	300.2	8844.7
Median fragment size (ha)	24.6	41.1	69.9	76.6	86.9	106.2	30.7	88.2
CV of fragment size (%)	249.1	223.4	339.3	340.7	441.7	578.8	702.7	735.4

CV, coefficient of variation.

Table 2. Spearman rank correlations between explanatory variables and response variables

Total rainfall	Seasonality	CV three wettest months	Mean slope angle	CV slope angle
Seasonality	$r_s = -0.17$			
CV 3 wettest months	$r_s = -0.31$	$r_s = -0.65$**		
Mean slope angle	$r_s = 1.67$	$r_s = -0.60$*	$r_s = 0.28$	
CV slope angle	$r_s = 0.14$	$r_s = -0.45$	$r_s = 0.21$	$r_s = 0.25$

CV, coefficient of variation. *$P < 0.05$, **$P < 0.01$. All other values: not significant.

seasonality and rainfall variation (CV) of the three wettest months ($r_s = -0.65$, $P < 0.01$), and between rainfall seasonality and mean slope angle ($r_s = -0.60$, $P < 0.05$) (Table 2). These relationships suggest that areas with low rainfall seasonality also have rainy seasons with less predictable rainfall, and that areas with low rainfall seasonality have the most broken topography. No other significant colinearities were found.

Linear regressions produced the best fit. We recorded non-significant relationships between percentage renosterveld and total rainfall ($r^2 = 0.01$, $P = 0.82$), CV of the three wettest months ($r^2 = 0.04$, $P = 0.45$) and CV of slope angle ($r^2 = 0.21$, $P = 0.06$). However, there were strong, positive relationships between percentage renosterveld and explanatory variables rainfall seasonality and mean slope angle (Fig. 4).

The multiple regression equation using those two explanatory variables was:

$$\text{REN} = -16.312 - 0.520\ \text{SEA} - 16.598\ \text{MES},$$
$$R^2\ (\text{adj}) = 0.82,\ n = 17,\ F\text{-ratio} = 38.283,\ P < 0.001,$$

where REN = %renosterveld (arcsin transformed), SEA = rainfall seasonality (arcsin transformed) and MES = mean slope angle.

The equation for the final model of stepwise multiple regression using all five rainfall and slope variables was:

$$\text{REN} = -84.082 + 17.288\ \text{MES} + 70.531\ \text{CVS},$$
$$R^2\ (\text{adj}) = 0.90,\ n = 17,\ F\text{-ratio} = 71.375,\ P < 0.001,$$

where CVS = variation in slope angle.

DISCUSSION

Landscape fragmentation patterns

Two main patterns emerged from this study. First, over 80% of the South Coast Renosterveld has been replaced by cultivation. This value is particularly significant because cultivated land forms sharp boundaries with fragments of natural vegetation (Wiens 1995). Cultivated land is ploughed, planted, sprayed with pesticides and herbicides and burned annually, and therefore offers virtually no opportunity for the colonization and establishment of biota from renosterveld fragments (Kemper 1997). Moreover, vast areas of agricultural landscape form barriers between fragments of natural vegetation, reducing successful dispersal and increasing the risk of species extinction (Noss & Csuti 1994).

Second, the study showed a significant decrease in fragmentation levels of the South Coast Renosterveld from west to east. Decreases in number of renosterveld fragments were accompanied by increases in total fragment area, mean fragment size and fragment size variability. These results agree well with the trends described by Godron & Forman (1983) and Krummel *et al.* (1987), which predicted that in an increasingly managed landscape, the overall number of fragments would increase and fragments would become smaller. The extent of habitat loss of the South Coast Renosterveld in the western sector is comparable to that of the West Coast Renosterveld (McDowell 1988). Both areas have similar levels of agricultural potential, expressed as reliable winter rainfall, and are found on flat to gently rolling topography. Together, they represent the most fragmented and transformed vegetation types in the species-rich Cape Floristic Region (McDowell 1988; Hoffman 1997).

Predictors of landscape fragmentation patterns

Although rainfall seasonality and mean slope angle clearly influence the extent of renosterveld, the results of the stepwise multiple regression model suggest that the extent of renosterveld is best explained by a combination of mean slope angle and slope angle variation. These variables were not collinear. Therefore, although rainfall seasonality undoubtedly influences suitability for sustainable wheat cultivation and, therefore, indirectly renosterveld extent, topographical variables are the best correlates of the extent of remaining natural vegetation. This agrees with the notion that landscape patterns produced by fragmentation are not random (Sharpe *et al.* 1987; Usher 1987; Pressey *et al.* 1996). The clearing of remnants in the future is unlikely because of the topographical constraints on ploughing, although the possibility of future changes in technology and/or crops cannot be overlooked. However, owing to higher grass cover as a consequence of a higher proportion of summer rain (Cowling 1984), renosterveld in the east is widely used as a natural pasture (Cowling *et al.* 1986; Low & Rebelo 1996). This form of land use has probably also contributed to the retention of renosterveld habitat in these areas.

Conservation planning implications

In the western sector of the study area, options for establishing a representative reserve system are very limited, as all remnants would be required to achieve a conservation goal of 5% reservation. Thus, strictly, each and every remnant is irreplaceable (Pressey *et al.* 1994). However, even if it were possible to conserve each remnant, either formally in strict reserves or as a result of some form of contractual agreement with landowners (Lombard *et al.* 1997), the smaller fragments are likely to continue to lose species as a result of a variety of processes (Terborgh & Winter 1980; Gilpin & Soulé 1986). Small fragments still appear relatively intact in terms of maintaining plant species diversity and biological attribute representation (Kemper 1997), and must therefore not be disregarded, but fragmentation of these areas has been recent and the long-term persistence of these and smaller patches is questionable in the absence of intensive management.

Owing to the greater extent of renosterveld in the central and eastern sectors and the larger areas of fragments, options for establishing representative reserve systems are more promising (Rebelo & Siegfried 1992) and opportunities exist for the establishment of protected areas that will be large enough to conserve a large component of biodiversity patterns and processes (including larger herbivore processes). Thus, theoretically it is possible to establish a system that conserves at least 10% of renosterveld in these areas, a conservation goal recommended by the IUCN (World Conservation Union) (McNeely 1993). As a first step, remnants should be surveyed using cost-effective techniques (Margules & Austin 1991) in order to stratify remnant vegetation into meaningful categories and identify localities of rare and endemic species. Next, these data should be analysed using a minimum set approach, whereby interactive iterative algorithms are employed to identify a representative system efficiently and effectively (Bedward *et al.* 1992; Pressey *et al.* 1993). These techniques have recently been successfully employed to identify an efficient and representative reserve system for the species-rich and highly fragmented Agulhas Plain region, immediately to the south of the western sector of our study area (Lombard *et al.* 1997).

Implementation of this reserve system will probably be highly problematic, despite the fact that the South Coast Renosterveld is regarded as a major conservation priority in South Africa (Rebelo 1997). Conservation authorities and lobby groups generally do not support the establishment of reserves in fragmented landscapes that involve privately owned land (Pressey 1994; Pressey *et al.* 1996). Furthermore, particular attention should be given to threats, especially the potential for clearing flatter land on the larger remnants in the east. Priority areas for inclusion in the system should be identified on the basis of irreplaceability (presence of unique attributes; contribution to achieving a reservation goal) and on actual and potential threats (Pressey *et al.* 1996).

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