ADDENDUM I

Priority areas for conserving South African vegetation: a coarse-filter approach

Priority areas for conserving South African vegetation: a coarse-filter approach

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Abstract

South Africa has an important responsibility to global biodiversity conservation, but a largely inadequate conservation area network for addressing this responsibility. This study employs a coarse-filter approach based on 68 potential vegetation units to identify areas that are largely transformed, degraded or impacted on by road-effects. The assessment highlights broad vegetation types that face high biodiversity losses currently or in the near future due to human impacts. Most vegetation types contain large tracts of natural vegetation, with little degradation, transformation or impacts from road networks. Regions in the grasslands, fynbos and forest biomes are worst affected. Very few of the vegetation types are adequately protected according to the IUCN's 10% protected area conservation target, with the fynbos and savanna biomes containing a few vegetation types that do achieve this arbitrary goal. This investigation identifies areas where limited conservation resources should be concentrated by identifying vegetation types with high levels of anthropogenic land use threats and associated current and potential biodiversity loss.

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Introduction

South Africa contains a wealth of biodiversity within its borders, unequalled by other temperate regions, earning a place in the top 25 most biodiverse nations (WCMC, 1992; Conservation International, 1998). In addition South Africa harbours the fifth highest number of plant species in the world, with the Cape Floristic Region being recognised as one of the six floral kingdoms of the world. This region contains 8200 plant species of which 5682 are endemic and has lost approximately 30.3% of its primary vegetation (Fairbanks *et al.*, 2000; Myers *et al.*, 2000).

Although its responsibility towards global biodiversity conservation is large, South Africa with only 4.8% (DEAT, 1996) (Figure 1a) of its land surface under formal protection falls far short of the IUCN's nominal recommendation of 10% protected area coverage. This coverage also lags behind the 10% average attained by the rest of sub-Saharan Africa, with Botswana reaching 18.5%, Mozambique 12.7% and Namibia 12.4% (WRI, 1994; McNeely 1994; Siegfried et al., 1998). A moderately expanding human population (Central Statistical Survey, 1998) and associated land transformation in South Africa (mainly urbanisation, cultivation and afforestation (Hoffmann, 1997)) leaves 79% of the country covered with natural woody and grassland vegetation communities (Figure 1b) (Fairbanks *et al.*, 2000). Waterbodies and wetlands cover less than one percent of the land surface area, with human land uses making up the remaining 20% (Fairbanks *et al.* 2000). Fairbanks *et al.* (2000) demonstrate that along with the approximately 30% transformation in the fynbos biome, the savanna and grassland biomes are about 10% and 26% transformed and degraded by human land uses respectively (Figure 1c) (see also Thompson *et al.*, In Review). In addition to this there are a total of 1176 species presently recognised as threatened (WRI, 1994; van Jaarsveld, 2000). Thus with these valuable and often endemic biodiversity resources facing ever-increasing threats from human-induced land transformation, and mostly inadequate conservation efforts to stem these threats, South Africa has an obvious responsibility to do more towards the conservation of biodiversity (van Jaarsveld, 2000).

Most of South Africa's existing protected areas were proclaimed in an *ad hoc* fashion, usually because they contained areas with high scenic or tourism potential, contained endemic diseases and did not conflict with other forms of land use (Pringle, 1982; Freitag *et al.*, 1996; Pressey *et al.*, 1993). Because this form of land allocation to conservation is highly inefficient and fails to effectively conserve biodiversity, several techniques have been developed for the systematic selection of land with a high conservation value, i.e. with high levels of biodiversity and large anthropogenic threats facing that biodiversity (for reviews see Williams, 1998; Margules & Pressey, 2000). However, these techniques require data on the distribution of biodiversity and threats facing biodiversity in order to identify areas important to conservation. Because the biodiversity of a region can never be fully observed and inventoried, species distribution data are often used as a surrogate or substitute measure of biodiversity. This form of data however, has a large number of shortcomings associated with it.

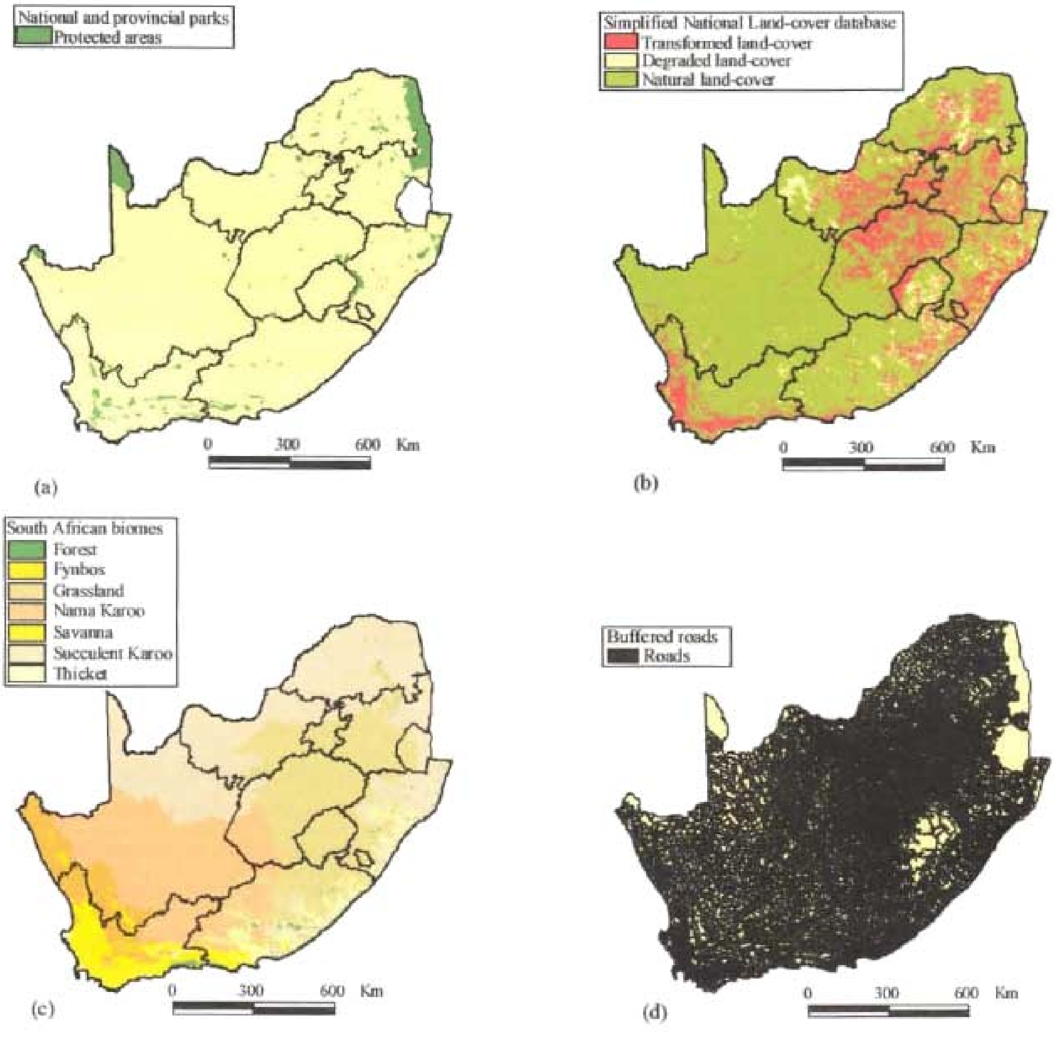

Figure 1: Maps of: (a) South African national and provincial protected areas (DEAT, 1996); (b) transformed, degraded and natural land-cover; (c) biomes (Low & Rebelo, 1996); and (d) road network buffered according to Stoms (2000).

These include inadequate taxonomical knowledge of the groups employed, biased sampling efforts and lack of spatial congruency between areas of conservation importance to different taxa (van Jaarsveld *et al*, 1998; Maddock & du Plessis, 1999, Fairbanks & Benn, 2000; Reyers *et al.*, 2000).

Broad-scale biodiversity surrogates

In recent years, the focus for conservation has shifted, with recommendations towards a more holistic approach of protecting biodiversity in the aggregate, the so-called 'coarse-filter' approach (Noss, 1987; Noss, 1990). This approach focuses on protecting higher levels of the biodiversity hierarchy (e.g. landclasses and landtypes) rather than species, assuming that these broad-scale biodiversity surrogates represent the finer scale aspects of biodiversity (Williams & Humphries, 1996; Pressey, 1994; Pressey & Logan, 1994; Wessels *et al.*, 1999; Fairbanks & Benn, 2000). However, as Pressey (1994) points out, the assumed relationship between environmental classes and species distribution and abundance is unclear and seldom investigated. In addition, certain species, especially rare species confined to small patches of habitat which are not recognised as distinct environmental classes, may "fall through the coarse filter" when using broad-scale environmental classes (Noss, 1983; Bedward, 1992; Panzer & Schwartz, 1998). Despite the shortcomings associated with a species-based approach to conservation planning, these higher order biodiversity surrogates may well fail to identify the composition, configuration and quantity of elements necessary for biodiversity retention, making species data a necessary component of the conservation planning process (Lambeck, 1997). The shortcomings of species distribution data and the limitations of environmental surrogate measures in the selection of priority conservation areas suggest that perhaps a combination of the two approaches in conservation planning may be advisable (Maddock & du Plessis, 1999).

At a national scale South Africa has a few databases of broader surrogates for biodiversity, including Acocks' Veld Types (Acocks, 1988) and the more recent Vegetation of South Africa, Lesotho and Swaziland (Low & Rebelo, 1996; McDonald, 1997). Acocks (1988) defined biological resources from a purely agricultural potential perspective, while Low and Rebelo (1996) looked at the definition of these resources from a management and potential use angle. These vegetation units were defined as having, "... similar vegetation structure, sharing important plant species, and having similar ecological processes." Thus, these are units that would have potentially occurred today, were it not for all the major human-made transformations e.g. agriculture and urbanisation. Therefore the Low and Rebelo (1996) vegetation map contains significant potential for acting as a broad scale surrogate of South African biodiversity and for identifying land important to biodiversity conservation.

Methods

Current land-cover data

Before the Low and Rebelo (1996) map can be used one has to differentiate between the potential vegetation cover of regions (as defined by Low & Rebelo, 1996) and that which is in reality found in the region. In other words one needs an indication of current natural vegetation pattern, degree of transformation, and amount of protection afforded each vegetation type before one can decide if it constitutes a conservation priority (Rebelo, 1997). As Low and Rebelo (1996) point out "there is little point in setting aside more of a vegetation type with vast expanses in pristine condition, while ignoring the last patches of a type which is not yet conserved." Low and Rebelo (1996) provide some estimates of protection and transformation data, however as they admit, "these are woefully incomplete". Thus, some indication of current land-cover (the suite of natural and human-made features that cover the earth's immediate surface) at a national scale is required for effective land-use planning, sustainable resource management, environmental research and in this instance conservation planning (Rebelo, 1997; Fairbanks *et al.*, 2000).

To this end the advent of the National Land-cover (NLC) database is of extreme relevance. This national database was derived using manual photo-interpretation techniques from a series of 1:250,000 scale geo-rectified hardcopy satellite imagery maps, based on seasonally standardised, single date Landsat Thematic Mapper (TM) satellite imagery captured principally during the period 1994-95 (Fairbanks & Thompson, 1996). It provides the first single standardised database of current land-cover information for the whole of South Africa, Lesotho and Swaziland (Fairbanks *et al.*, 2000). For the purpose of the present study the 31 land-cover classes were reclassified into three categories: natural, degraded and transformed land-cover (Table 1). Natural land-cover included all untransformed vegetation, e.g. forest, woodland, thicket and grassland. The degraded land-cover category was dominated by degraded classes of land-cover. These areas have a very low vegetation cover in comparison with the surrounding natural vegetation cover and were typically associated with rural population centres and subsistence level farming, where fuel-wood removal, over-grazing and subsequent soil erosion were excessive (Thompson 1996). The transformed category consisted of areas where the structure and species composition were completely or almost completely altered which includes all areas under crop cultivation, forestry plantations, urbanised areas, and mines/quarries.

The databases of potential vegetation cover and current land-cover were overlaid in a geographic information system (GIS) to determine the extent of natural, degraded and transformed area within each of the 68 vegetation types identified in Low and Rebelo (1996). These values could then be used to highlight areas of high current and future vulnerability to biodiversity loss through land use impacts. Levels of transformation were compared against the transformation thresholds predicted by a geometric model developed by Franklin and Forman (1987). This work suggested that the most critical time for land planning and conservation is when between 10-40% of the landscape has been transformed or impacted upon. Specifically, most of the rapid ecological changes (e.g., loss of interior species) can be expected when this level increases from 20-40%. Regions showing greater than 40% loss of natural habitat have already undergone significant ecological disruptions.

Table 1: Land-cover classes reclassified into broad categories

Transformation category	% area	Land-cover class
Natural land-cover	73.4%	Wetlands, grassland, shrubland, bushland, thicket, woodland, forest
Degraded land-cover	10.1%	Degraded land, erosion scars, waterbodies
Transformed land-cover	16.5%	Cultivated lands, urban/built-up areas, mines and quarries, forestry plantations

An additional GIS layer of protected area coverage for the country (DEAT, 1996) was also employed to determine the extent of conservation areas existing within the vegetation types.

Patterns of roads

In addition to these land use threats, one of the most widespread forms of alteration of natural habitats and landscapes over the last century has been the construction and maintenance of roads (Trombulak & Frissell, 2000). Road networks affect landscapes and biodiversity in seven general ways: (1) increased mortality from road construction; (2) increased mortality from vehicle collisions; (3) animal behaviour modification; (4) alteration of the physical environment; (5) alteration of the chemical environment; 6) spread of exotic species, and (7) increased alteration and use of habitats by humans (from Trombulak & Frissell, 2000). These networks cover 0.9% of Britain and 1.0% of the USA (Forman & Alexander, 1998), however the road-effect zone, the area over which significant ecological effects extend outward from the road, is usually much wider than the road and roadside. This road effect zone can thus provide an additional estimate of areas with a high vulnerability to biodiversity loss through changing land uses and increased human impacts.

Some evidence on the size of the road-effect zone is available from studies in Europe and North America. Reijnen *et al.* (1995) estimated that road-effect zones cover between 12-20% of The Netherlands, while Forman (2000) illustrated that 19% of the USA is affected ecologically by roads and associated traffic. The road-effect zone for South Africa was determined using a similar method to that used by Stoms (2000) in which the spatial extent of road effects can be used as an ecological indicator that directly represents impacts on biodiversity. For this, the road-effect zone was used as a measure of the area potentially affected by roads. The affected distances were estimated from the reviews mentioned above, as well as from local studies (Milton & MacDonald, 1988). Therefore national routes and freeways were assumed to affect biodiversity for a greater distance from the roadway (1 km on each side) than farm roads (100 m, Table 2).

Road segments from the South African Surveyor General 1993 1:500,000 scale map series files (SA Surveyor General, 1993) were buffered using a standard GIS operation to the distance related to its class (Figure 1d). Although the roads in protected areas do have an impact on biodiversity within these areas, they were excluded from this analysis as by and large protected areas overwhelmingly contribute to biodiversity conservation. A road-effect zone was calculated for the remaining untransformed areas within each vegetation type by summing the total area within the road effect zone surrounding roads in each vegetation type and converting to a percentage of the total remaining untransformed area in that vegetation type. However, the road-effect zone used here does not consider the spatial pattern of roads. So, although roads clearly have a significant impact on many species, meaningful indicators of road-effects on landscapes await the attention of landscape ecologists and other scientists (Forman, 1998).

Table 2: Buffer widths assigned to road classes for calculating road effect zone (after Stoms 2000).

South African Surveyor General Description	Buffer width (m)
National route	1000
Freeway	1000
Arterial	500
Main	250
Secondary (connecting and magisterial roads)	100
Other (rural road)	50
Vehicular trail (4 wheel drive route)	25

Most of these factors also vary over daily, weekly, and annual cycles, which may interfere with critical behavioural periods such as breeding or migration. As such, the road-effect zone can represent only a first order approximation attempt to capture more of the multi-dimensional nature of road network effects.

Results and Discussion

Vulnerability assessment of vegetation types

The majority of vegetation types of South Africa are not largely degraded or transformed (Table 3). Of the 68 vegetation types 61 contain more than 50% natural vegetation cover with a median value of 81.1% natural vegetation cover across all vegetation types. The vegetation types show low levels of degradation with a median value of 2.8%, with all but one (Afro Mountain Grassland) being less than 20% degraded (Table 3). Only five of the vegetation types are more than 50% transformed by anthropogenic land uses, with a median of 10% being transformed within vegetation types.

Figure 2 provides a diagrammatic representation of the current levels of transformation, degradation and protection across all vegetation types. Similar to the findings of the coarse-scale species-based approach used by Rebelo (1997), the grasslands and fynbos have experienced the most transformation (see Fairbanks *et al.*, 2000), with the coastal indigenous forests having been subjected to extensive transformation for its size (Figures 2a, b). Although degradation levels are generally low, a few regions in the grasslands biome as well as a few in the savanna biome show the highest levels of degradation ranging from 10 to 36% of the vegetation extent (Figure 2c).

The average amount of vegetation type currently under protection is 9.6% (median value of 1.5%) with only 18 vegetation types conforming to the IUCN's nominal recommendation of 10% protected area coverage (Table 3). However, this well cited protected area recommendation of 10% is widely criticised as too little to guarantee the persistence of biodiversity within the region. Soulé & Sanjayan (1998) illustrate that up to 50% of land area may be required to successfully represent all biodiversity elements. Therefore, perhaps even these 18 supposedly well-protected vegetation types are inadequately protected (Figure 2d).

The road-effect zone impacts on an average of 5.5% (with a median value of 6) of the remaining natural land-cover in all vegetation types (Table 3). Five vegetation types (Mesic Succulent Thicket, Moist Clay Highveld Grassland, Dune Thicket, Eastern Thorn Bushveld, Rocky Highveld Grassland) containing between 10 and 14.2% road-effect zones (Table 3). The rest of the vegetation types lie under this 10% level, with the Mopane Shrubveld containing no road-effect due to the fact that it all falls entirely within the boundaries of the Kruger National Park (Table 3).

In Table 4 the areas within each vegetation type that are transformed, degraded or exposed to road-effects are summed to provide an indication of vegetation that has been disturbed or affected by these human land uses.

Table 3: Percentage natural, degraded, transformed and protected area of each of the vegetation types, as well as the percentage of each vegetation type exposed to road-effect zones.

Code	Vegetation type	% natural	% degraded	% transformed	% protected	% road-effect
1	Coastal Forest	89.3	1.2	9.3 (43)	1.3 (9.5)	6.5
2	Afromontane Forest	67.9	2.9	29.2 (44)	**16.1** (17.6)	6.4
3	Sand Forest	72.3	15.6	5.8 (45)	**46.7** (44.6)	1.7
4	Dune Thicket	62.2	8.5	27.6 (25)	**10.6** (14.5)	11.2
5	Valley Thicket	72.1	13.0	14.8 (51)	1.5 (2.1)	6.1
6	Xeric Succulent Thicket	95.0	2.0	3.0 (51)	4.6 (8.0)	6.4
7	Mesic Succulent Thicket	78.5	7.0	14.5 (51)	4.0 (5.3)	14.2
8	Spekboom Succulent Thicket	93.1	4.2	2.6 (unknown)	1.2 (1.8)	4.9
9	Mopane Shrubveld	100.0	0.0	0.0 (0)	**100** (100)	0.0
10	Mopane Bushveld	92.4	0.9	6.6 (8)	**34.0** (38.3)	3.0
11	Soutpansberg Arid Mountain Bushveld	83.8	10.2	6.0 (65)	**10.1** (12.6)	4.3
12	Waterberg Moist Mountain Bushveld	90.2	0.8	9.0 (28)	6.2 (8.6)	3.2
13	Lebombo Arid Mountain Bushveld	90.2	0.1	9.1 (unknown)	**37.1** (38.0)	1.0
14	Clay Thorn Bushveld	58.7	7.1	34.1 (60)	1.0 (0.9)	5.1
15	Subarid Thorn Bushveld	78.7	12.6	8.7 (unknown)	0.0 (0.2)	8.2
16	Eastern Thorn Bushveld	69.7	13.8	16.5 (unknown)	0.2 (0.5)	11.1
17	Sweet Bushveld	78.3	12.0	9.5 (27)	1.8 (2.3)	4.5
18	Mixed Bushveld	69.3	14.1	16.6 (60)	3.6 (3.1)	5.3
19	Mixed Lowveld Bushveld	70.4	9.9	19.8 (30)	**22.5** (28.3)	3.1
20	Sweet Lowveld Bushveld	85.1	1.4	13.5 (30)	**62.2** (67.3)	1.1
21	Sour Lowveld Bushveld	54.4	9.6	36.0 (76)	7.0 (9.7)	4.7
22	Subhumid Lowveld Bushveld	84.1	12.3	3.6 (36)	**20.9** (21.5)	1.1
23	Coastal Bushveld-Grassland	43.5	15.9	39.8 (unknown)	**13.5** (14.0)	5.9
24	Coast-Hinterland Bushveld	56.7	8.2	35.0 (87)	2.1 (3.6)	4.4
25	Natal Central Bushveld	72.2	9.9	18.0 (80)	1.3 (1.6)	7.2
26	Natal Lowveld Bushveld	72.5	11.9	15.6 (35)	**14.1** (17.8)	5.3
27	Thorny Kalahari Dune Bushveld	83.5	0.0	0.0 (unknown)	**99.6** (99.8)	0.0
28	Shrubby Kalahari Dune Bushveld	96.0	3.1	0.0 (55)	**19.4** (19.5)	2.2
29	Karroid Kalahari Bushveld	98.8	1.2	0.0 (55)	0.1 (0.1)	3.3

30	Kalahari Plains Thorn Bushveld	73.6	18.9	7.1 (55)	0.5 (0.5)	3.9
31	Kalahari Mountain Bushveld	99.5	0.2	0.3 (25)	0.0 (0.0)	4.6
32	Kimberley Thorn Bushveld	76.1	4.4	19.5 (55)	1.8 (3.1)	6.8
33	Kalahari Plateau Bushveld	92.7	3.0	4.2 (55)	0.0 (0.0)	5.5
34	Rocky Highveld Grassland	66.3	0.1	33.6 (65)	0.8 (1.4)	10.2
35	Moist Clay Highveld Grassland	68.2	0.4	31.4 (79)	0.0 (0.0)	11.3
36	Dry Clay Highveld Grassland	34.9	0.1	65.1 (67)	0.0 (0.0)	9.0
37	Dry Sandy Highveld Grassland	63.5	0.8	35.8 (65)	0.3 (0.3)	9.1
38	Moist Sandy Highveld Grassland	67.6	0.7	31.6 (55)	0.0 (0.7)	9.4
39	Moist Cool Highveld Grassland	60.4	1.6	38.0 (72)	0.7 (0.3)	9.6
40	Moist Cold Highveld Grassland	46.8	11.3	41.8 (70)	0.8 (0.6)	6.7
41	Wet Cold Highveld Grassland	88.0	2.4	9.7 (60)	9.4 (6.7)	4.1
42	Moist Upland Grassland	61.4	17.0	21.6 (60)	2.3 (2.5)	5.5
43	North-eastern Mountain Grassland	67.6	7.1	25.3 (45)	3.3 (7.4)	4.8
44	South-eastern Mountain Grassland	94.5	4.0	1.5 (32)	0.6 (0.3)	5.7
45	Afro Mountain Grassland	51.9	36.7	11.4 (32)	0.0 (0.0)	0.8
46	Alti Mountain Grassland	87.5	8.8	3.6 (32)	**11.7** (12.5)	1.2
47	Short Mistbelt Grassland	38.5	4.6	56.9 (89)	0.9 (2.4)	7.6
48	Coastal Grassland	81.7	5.1	12.9 (unknown)	0.1 (1.1)	7.0
49	Bushmanland Nama Karoo	99.7	0.2	0.1 (unknown)	0.0 (0.0)	3.4
50	Upper Nama Karoo	99.0	0.9	0.1 (unknown)	0.0 (0.0)	5.8
51	Orange River Nama Karoo	98.1	0.1	1.6 (unknown)	0.1 (1.5)	4.6
52	Eastern Mixed Nama Karoo	94.9	1.8	3.3 (unknown)	1.6 (1.1)	7.4
53	Great Nama Karoo	99.1	0.8	0.2 (unknown)	0.7 (0.2)	5.4
54	Central Lower Nama Karoo	90.2	9.0	0.8 (unknown)	0.1 (0.0)	6.0
55	Strandveld Succulent Karoo	86.3	2.0	9.5 (24)	0.4 (0.4)	4.0
56	Upland Succulent Karoo	97.1	0.7	1.7 (unknown)	4.2 (4.4)	4.4
57	Lowland Succulent Karoo	94.2	2.6	3.2 (unknown)	0.9 (1.3)	3.9
58	Little Succulent Karoo	89.0	2.6	8.4 (unknown)	3.2 (2.3)	7.7
59	North-western Mountain Renosterveld	94.0	0.0	6.0 (unknown)	0.0 (0.0)	3.0
60	Escarpment Mountain Renosterveld	98.9	0.3	0.8 (unknown)	0.0 (0.1)	2.4
61	Central Mountain Renosterveld	80.4	1.8	17.8 (11)	5.1 (3.6)	5.4
62	West Coast Renosterveld	9.0	1.1	89.8 (97)	0.7 (1.8)	8.1
63	South & South-west Coast Renosterveld	39.4	1.9	58.7 (32)	1.5 (1.4)	8.8
64	Mountain Fynbos	88.5	0.7	10.8 (11)	**26.4** (26.1)	2.9
65	Grassy Fynbos	88.7	0.8	10.3 (3)	**15.5** (16.1)	6.0

66	Laterite Fynbos	64.8	1.1	34.1 (50)	0.0 (0.5)	8.6
67	Limestone Fynbos	87.2	7.6	5.2 (40)	**13.6** (13.8)	4.0
68	Sand Plain Fynbos	34.4	8.5	57.1 (50)	1.2 (1.1)	7.1

(Values in brackets indicate estimates from Low and Rebelo (1996))

(Vegetation types with more than 10% protected area coverage are indicated in bold)

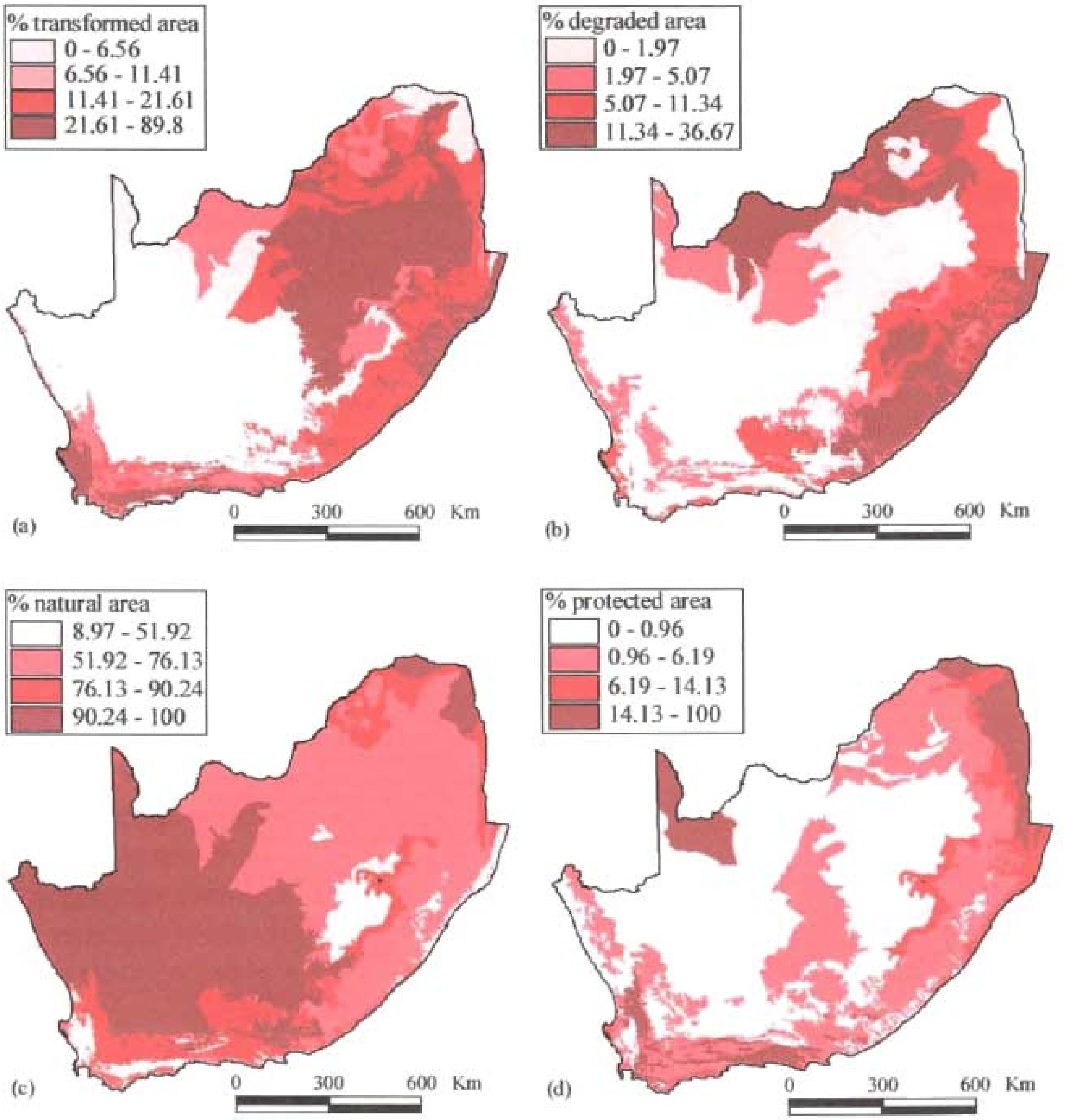

Figure 2: Diagrammatic representation of levels of percentage (a) transformed, (b) degraded, (c) natural and (d) protected vegetation cover within each of Low and Rebelo's (1996) vegetation types.

Table 4 provides a list of vegetation types ordered according to their area affected as an indication of their vulnerability to biodiversity loss. Types with large areas affected face a high risk of biodiversity loss due to a combination of extensively degraded and transformed areas with a large road network. The West Coast Renosterveld, Sand Plain Fynbos, Dry Clay Highveld Grassland, South and South-west Renosterveld, Short Mistbelt Grassland, Coastal Bushveld-Grassland, Moist Cold Highveld Grassland, Sour Lowveld Bushveld, Afro Mountain Grassland, Coast-Hinterland Bushveld, Moist Cool Highveld Grassland, Clay Thorn Bushveld, Dune Thicket, Moist Upland Grassland, Dry Sandy Highveld Grassland, Rocky Highveld Grassland and Laterite Fynbos are all areas of concern due to the fact that over 40% of their extent is impacted on by land use threats. This level of land use impact corresponds with the threshold determined by Franklin and Forman (1987), indicating extreme ecological disruption within these vegetation types.

All of these vegetation types are also poorly protected (Table 3) with the Coastal Bushveld-Grassland and Dune Thicket being the only types to reach the IUCN's recommended 10% protected area coverage. However, as stated previously this level of protection is inadequate, especially in the case of these two vegetation types where it would not be sufficient to stem the biodiversity loss associated with such high levels of land use change. Of the 68 vegetation types 38 (56%) fall within the 10-40% category of land use impact determined by Franklin and Forman (1987) and are thus at a critical time for land use planning and conservation.

Table 5 provides a list of the land-cover types within each of the top 10 priority conservation vegetation types drawn from Table 4. The Afro Mountain Grassland and Moist Cold Highveld Grassland contain large areas of degraded vegetation. These same vegetation types along with the West Coast Renosterveld, Sand Plain Fynbos, Dry Clay Highveld Grassland, South and South-west Coast Renosterveld, Short Mistbelt Grassland, Coastal Bushveld-Grassland, Sour Lowveld Bushveld and Coast-Hinterland Bushveld contain extensive areas of commercial, semi-commercial and subsistence dryland cultivation (Table 5). The Short Mistbelt Grassland, Coastal Bushveld-Grassland, Sour Lowveld Bushveld and Coast-Hinterland Bushveld contain large areas of exotic forestry plantations and, with the exception of the Sour Lowveld Bushveld, commercial sugarcane cultivation (Table 5).

Of all these priority vegetation types only the Coastal Bushveld-Grassland has more than 10% protected area coverage at 13.5%, but high levels of degradation as well as high levels of transformation still make it an area of concern along its entire latitudinal distribution. The rest of these top 10 priority vegetation types all fall below five percent protected area coverage (Table 3). This land use analysis is an example of a potential management tool for vulnerable areas, and is not limited to these top 10 vegetation types. Other vegetation types, although not as affected as these 10, are nonetheless also impacted on by land use changes and should therefore also be considered and monitored in a conservation plan. Table 5 is an example of what can be done and similar analyses can be performed on all vegetation types in order to investigate the land use impacts and management parameters within each area.

Table 4: Percentage area of vegetation type exposed to the combined land-cover threats of degradation, transformation and road effects

Code	Vegetation type	Affected area (%)
62	West Coast Renosterveld	92.3
68	Sand Plain Fynbos	69.5
36	Dry Clay Highveld Grassland	67.8
63	South & South-west Coast Renosterveld	65.4
47	Short Mistbelt Grassland	64.8
23	Coastal Bushveld-Grassland	60.3
40	Moist Cold Highveld Grassland	56.7
21	Sour Lowveld Bushveld	49.1
45	Afro Mountain Grassland	48.6
24	Coast-Hinterland Bushveld	47.0
39	Moist Cool Highveld Grassland	45.8
14	Clay Thorn Bushveld	45.1
4	Dune Thicket	43.9
42	Moist Upland Grassland	42.5
37	Dry Sandy Highveld Grassland	42.3
34	Rocky Highveld Grassland	42.2
66	Laterite Fynbos	40.8
35	Moist Clay Highveld Grassland	39.6
38	Moist Sandy Highveld Grassland	39.3
16	Eastern Thorn Bushveld	38.2
2	Afromontane Forest	37.9
43	North-eastern Mountain Grassland	36.2
18	Mixed Bushveld	34.8
7	Mesic Succulent Thicket	34.0
25	Natal Central Bushveld	33.3
5	Valley Thicket	32.9
19	Mixed Lowveld Bushveld	32.0
26	Natal Lowveld Bushveld	31.6
32	Kimberley Thorn Bushveld	29.4

30	Kalahari Plains Thorn Bushveld	29.0
15	Subarid Thorn Bushveld	28.0
61	Central Mountain Renosterveld	25.9
17	Sweet Bushveld	25.2
48	Coastal Grassland	23.8
3	Sand Forest	22.8
11	Soutpansberg Arid Mountain Bushveld	20.0
58	Little Succulent Karoo	18.7
65	Grassy Fynbos	17.9
67	Limestone Fynbos	17.2
22	Subhumid Lowveld Bushveld	16.9
1	Coastal Forest	16.8
41	Wet Cold Highveld Grassland	16.2
20	Sweet Lowveld Bushveld	16.0
54	Central Lower Nama Karoo	15.2
55	Strandveld Succulent Karoo	15.1
64	Mountain Fynbos	14.8
46	Alti Mountain Grassland	13.5
12	Waterberg Moist Mountain Bushveld	12.9
33	Kalahari Plateau Bushveld	12.4
52	Eastern Mixed Nama Karoo	12.3
8	Spekboom Succulent Thicket	11.8
6	Xeric Succulent Thicket	11.3
44	South-eastern Mountain Grassland	11.1
13	Lebombo Arid Mountain Bushveld	10.3
10	Mopane Bushveld	10.3
57	Lowland Succulent Karoo	9.5
59	North-western Mountain Renosterveld	9.1
56	Upland Succulent Karoo	6.8
50	Upper Nama Karoo	6.7
53	Great Nama Karoo	6.3
51	Orange River Nama Karoo	6.3
28	Shrubby Kalahari Dune Bushveld	5.2
31	Kalahari Mountain Bushveld	5.1
29	Karroid Kalahari Bushveld	4.5
49	Bushmanland Nama Karoo	3.6

60	Escarpment Mountain Renosterveld	3.5
27	Thorny Kalahari Dune Bushveld	0.0
9	Mopane Shrubveld	0.0

Table 5: Description and percentage area coverage of land-cover threats facing conservation priority vegetation types

Description	West Coast Renosterveld	Sand Plain Fynbos	Dry Clay Highveld Grassland	South & South-west Coast Renosterveld	Short Mistbelt Grassland	Coastal Bushveld-Grassland	Moist Cold Highveld Grassland	Sour Lowveld Bushveld	Afro Mountain Grassland	Coast-Hinterland Bushveld
Natural land-cover	*9.01*	*34.64*	*34.89*	*39.87*	*39.32*	*43.56*	*46.85*	*54.44*	*51.92*	*56.87*
Waterbodies	0.24	0.14	0.05	0.83	0.24	4.69	0.21	0.11	0.01	0.12
Dongas and sheet erosion scars	0.00	0.05	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00
Degraded: forest and woodland	0.00	0.00	0.00	0.00	0.00	0.87	0.00	5.88	0.00	0.42
Degraded: thicket and bushland (etc)	0.11	0.63	0.00	0.00	0.61	7.50	0.02	3.12	**36.65**	4.77
Degraded: unimproved grassland	0.00	0.00	0.00	0.00	3.73	2.82	**11.02**	0.49	0.00	2.93
Degraded: shrubland and low fynbos	0.76	7.66	0.00	1.05	0.00	0.00	0.00	0.00	0.00	0.00
Cultivated: permanent - commercial irrigated	**11.70**	5.20	0.00	1.77	0.03	0.00	0.00	1.55	0.00	0.01
Cultivated: permanent - commercial dryland	0.32	0.05	0.00	0.00	0.00	0.39	0.01	1.78	0.00	0.00
Cultivated: permanent - commercial sugarcane	0.00	0.00	0.00	0.00	**10.79**	**15.39**	0.00	0.34	0.00	**8.91**
Cultivated: temporary - commercial irrigated	0.15	2.78	0.02	2.17	1.67	0.02	0.05	2.55	0.00	0.23
Cultivated: temporary - commercial dryland	**74.78**	**39.53**	**64.65**	**53.07**	4.74	0.00	**19.58**	1.30	0.00	0.49
Cultivated: temporary - semi-commercial / subsistence dryland	0.00	0.00	0.00	0.00	7.02	**10.18**	**21.27**	**11.80**	**11.40**	**13.75**
Forest plantations	0.60	4.88	0.00	0.31	**30.86**	**9.31**	0.06	**15.29**	0.00	**9.11**
Urban / built-up land: residential	1.59	7.11	0.36	0.78	0.83	3.10	0.79	1.30	0.01	1.98
Urban / built-up land: residential (small holdings: woodland)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Urban / built-up land: residential (small holdings: bushland)	0.00	0.00	0.00	0.00	0.14	0.90	0.00	0.00	0.00	0.04
Urban / built-up land: residential (small holdings: shrubland)	0.45	1.03	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00
Urban / built-up land: residential (small holdings: grassland)	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.15
Urban / built-up land: commercial	0.06	0.20	0.00	0.00	0.02	0.13	0.00	0.02	0.00	0.06
Urban / built-up land: industrial / transport	0.03	0.56	0.02	0.07	0.00	0.33	0.01	0.01	0.00	0.15
Mines & quarries	0.07	0.00	0.01	0.00	0.00	0.06	0.00	0.03	0.01	0.02

Bold values indicate main land uses in the vegetation type

The vegetation types listed at the bottom of Table 4 are less impacted on by land uses, and are generally better protected (Table 3), with the Mopane Shrubveld and Thorny Kalahari Dune Bushveld including 100 and 99.6% protected area, respectively. These areas also contain extensive tracts of natural vegetation ranging from 83.5% for the Thorny Kalahari Dune Bushveld to 100% for the Mopane Shrubveld (Table 3). This however does not preclude them from further analysis and the tools developed in this study have a potential role to play in the monitoring and future management of these currently less impacted areas.

Comparison of vulnerability status

Low and Rebelo (1996) also provided an estimate of threat status of the vegetation types. This included a measure of land transformed by agriculture and other uses, based on "scant information for some of the Acocks Veld Types and should be cautiously interpreted as a rough index of habitat loss" (Low & Rebelo, 1996). They also include an estimate of the proportion of each vegetation type falling within conserved areas, based on an approximation of conservation area boundaries which still require confirmation (Low & Rebelo, 1996). Following a similar methodology to Thompson *et al.* (in review), we evaluate these estimates from Low and Rebelo (1996) as well as the calculations of protected and transformed land obtained from this study using the National Land-cover database and the DEAT (1996) protected area database (Table 3). Top conservation priority vegetation types identified based on Low and Rebelo's (1996) estimates of transformed area in Table 3 highlight the West Coast Renosterveld, Short Mistbelt Grassland, Coast-Hinterland Bushveld, Natal Central Bushveld and the Moist Clay Highveld Grassland as areas of conservation concern due to large areas transformed. The Mopane Shrubveld, Grassy Fynbos, Mopane Bushveld, Central Mountain Renosterveld and Mountain Fynbos are estimated to be areas of low priority for conservation as they are little transformed according to Low and Rebelo's (1996) estimates (Table 3). Once again the areas of high threat are estimated by Low and Rebelo (1996) to be poorly protected with less than 4% of their surface area protected and those that are low priorities are seen to be generally well protected.

As found in Thompson *et al.* (in review), there is some degree of similarity in the rank orders of vegetation types according to threat status found in this study (i.e., affected area) and in Low and Rebelo's (1996) (i.e., areas estimated to be transformed) ($r_s = 0.55$; $p < 0.001$). However, as Table 3 illustrates, there are differences between these estimates of transformation and protection from Low and Rebelo (1996) and values generated in this study. The Low and Rebelo (1996) estimates for land transformation and protection being consistently and significantly higher (paired t-test for levels of transformation, $t = 9.00$, degrees of freedom = 49, $p < 0.0001$; paired t-test for levels of protection, $t = 3.8$, degrees of freedom = 67, $p < 0.01$). This could however be explained by the fact that the estimates of transformation in Low and Rebelo (1996) included grazed areas, while the NLC transformation category does not (Thompson *et al.* in review). The grazed areas (especially overgrazed area) are included in the degraded category of the NLC database and as such are included in the present study in the measure of affected areas (Table 4).

Conclusion

South Africa, with its large biodiversity conservation responsibility, faces the additional problems of limited resources for conservation as well as pressing land reform initiatives. The land tenure system is a problem for conservation throughout Africa and is now becoming an increasingly demanding problem in South Africa. The almost total transfer of land in most regions of South Africa, from government to private ownership, is possibly unique in the annals of European colonisation. The state by the mid 1930's had lost control over resources which in countries such as Australia or the USA were retained by the authorities because of their unsuitability for agriculture (Christopher, 1982). In effect the absence of state interest in land through a leasehold system has lead to a strong demand for land and an attempt to make a living in areas highly unsuitable for the purposes of farming. Demand for land has further driven land prices to levels far in excess of its value as an agricultural commodity.

Therefore the limited resources of available government land and funding need to be efficiently applied in order to ensure effective conservation as well as development opportunities. This investigation provides an important first approximation towards identifying areas where these limited resources should be concentrated by identifying vegetation types with high levels of current and potential anthropogenic land use and inadequate conservation efforts in order to constrain future spreading of transformation. As Rebelo (1997) points out, few vegetation units are spatially uniform in terms of species composition and ecosystem processes, thus further study within these priority areas is required to identify representative conservation sites within these types. Although Low and Rebelo (1996) provided rough estimates of areas considered to be facing high threats, the value of timely land-cover information on the decision making ability for planning is evident from the present study. The advent of the National Land-cover database has provided a much-needed standardised dataset of current land-cover to significantly improve South African land use and conservation planning.

Further issues relevant to the identification of priority conservation areas are the scale of conservation priority setting, and the effects of global climate change on southern African vegetation. Rebelo (1997) points out that generally vegetation types shared with other neighbouring nations are more adequately conserved than vegetation endemic to South Africa. Thus a classification of vegetation types across political boundaries, as well as international co-operation are urgent requirements for future priority setting. In addition to this, future conservation strategies will have to consider the effects of climate change on biodiversity (Rutherford *et al.*, 2000). Not much is known on what these climate changes or their biological impacts will be, but recent work has highlighted a general eastward shift in South African species distributions as areas in South Africa dry out and warm up (Rutherford *et al.*, 2000; van Jaarsveld & Chown, 2000; van Jaarsveld *et al.*, 2000). It has also been shown that premier flagship conservation areas in South Africa are not likely to meet their conservation goals due to an inability to track climate induced species (especially vulnerable species) range shifts (van Jaarsveld *et al*., 2000). This is of obvious importance in any conservation-planning scenario.

In many respects "lines conquer", and the South African landscape is a testament to their power. Compasses and plumblines, more than a force of arms, subdue landscapes, and henceforth demarcate control and change. If current development policies (i.e., Spatial Development Initiatives, unstructured land reform) continue without proper equity towards conserving the most threatened vegetation communities, in a few decades not only will the remaining "natural" areas be gone, but the people will be even poorer for it.

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ADDENDUM II

Incorporating land-cover information into regional biodiversity assessments in South Africa.

Incorporating land-cover information into regional biodiversity assessments in South Africa.

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Abstract

Anthropogenic natural habitat transformation presents the single most important threat to global biodiversity. Land-cover data, based on Landsat TM imagery, were used to derive land-use information for the Gauteng, Mpumalanga and Northern provinces of South Africa. The assessment integrated land-use data with species presence data (15' x 15' grid cell resolution) for butterflies, mammals, birds and endemic vascular plants. The objectives of the present study were: (i) to identify areas at a regional scale where there is a possible conflict between biodiversity conservation interests and current land-uses; (ii) to investigate the influence of incorporating a land-use constraint (LUC) into a conservation area selection algorithm, while taking cognizance of the existing reserve system; and (iii) to investigate the circumstances of species recorded within these conflict areas. Many grid cells identified as species richness hotspots, rarity hotspots or as part of the complementarity network selected by the unconstrained algorithm were in reality largely transformed or modified. These areas should thus be avoided when striving to identify a viable conservation network. Although the LUC algorithm selected more grid cells to represent all species, it succeeded in increasing the percentage natural vegetation within the selected conservation network and highlighted areas where potential conflicts should be thoroughly investigated at a local scale.

Introduction

Land-cover refers to the suite of natural and man-made features that cover the earth's immediate surface (Thompson, 1996). Natural land-cover represents the green interface between the lithosphere and the atmosphere that has a profound influence on the climate and biogeochemical systems and forms the basic fabric of biodiversity (Graetz, Fisher & Wilson, 1992). Land-cover changes, caused by increases in crop cultivation and urban development, present the single most important threat to global biodiversity (Soulé, 1991; Dale *et al.*, 1994). Habitat destruction, as a direct consequence of human activity, accounts for the fact that current species extinction rates exceed historical global extinction rates by between 1000 and 10000 times (Wilson, 1988; UNEP, 1995). Macdonald (1989) estimated that up to 25% of South Africa's natural land-cover has been converted to other forms of land-use such as agriculture, which accounts for more than half of that transformation.

As signatories to the Convention of Biodiversity, South Africa is obligated to: "Review the impact of agriculture and commercial forestry practices on biodiversity (natural habitats) and seek changes where necessary" (DEAT, 1996). Satellite remote sensing has provided us with an effective tool for gathering this essential land-cover information (Dale *et al.*, 1994; Scott *et al.*, 1993). Land-cover data, generated by the Agricultural Research Council (ARC - Institute for Soil, Climate and Water) and the CSIR (Council for Scientific and Industrial Research), recently became available for South Africa. Although land-cover and land-use are not necessarily synonymous (Thompson, 1996) broad land-use categories (e.g. cultivation, urban or natural vegetation) can be derived from satellite derived land-cover data.

Existing protected areas were primarily proclaimed on an *ad hoc* basis and are mostly ineffective at representing regional biota's (Pressey, 1994; Lombard, 1995a,b). In response, systematic reserve selection procedures were developed to identify priority conservation areas that complement one another in terms of their contributions towards protecting regional biodiversity, while ensuring that minimal land allocation is required (Margules, *et al.*, 1988; Nicholls & Margules, 1993; Pressey *et al.*, 1993; Margules, Cresswell & Nicholls, 1994; Csuti *et al.*, 1997; Lombard, 1995a; Freitag, Nicholls & van Jaarsveld; 1996, Wessels, Freitag & van Jaarsveld, 1999). Within South Africa several national and regional biodiversity assessments based on historical species presence data of specific taxa within 15' x 15' grid cells have been conducted, including fish (Skelton *et al.*, 1995); frogs (Drinkrow & Cherry, 1995); tortoises (Branch, Benn & Lombard, 1995); snakes (Lombard, Nicholls & August, 1995); mammals (Gelderblom *et al.*, 1995; Mugo *et al.*, 1995; Gelderblom & Bronner, 1995; Freitag *et al.*, 1996); birds (Lombard, 1995a); plants (Rebelo & Siegfried, 1992); and multiple taxa including birds, mammals, insects and plants (van Jaarsveld *et al.*, 1998a). It is however possible that an area (e.g. grid cell) selected for its contribution to species representation, according to historical data, may in reality be largely transformed by extant land-uses. For this reason a number of previous studies have used aerial photographs (Awimbo, Norton & Overmars, 1996; Lombard *et al.*, 1997), NOAA (Bull, Thackway &

Cresswell, 1993) and Landsat TM satellite images (Bedward, Pressey & Keith, 1992; Scott *et al.*, 1993; Pressey *et al.*, 1996) to map transformed areas and exclude these during conservation area selection.

Although specific species may persist within the altered landscape mosaic of a highly transformed grid cell (Soulé, 1991; Jules & Dietsch, 1997; Vandermeer & Perfecto, 1997), the long-term survival of all native species is ultimately determined by a complex interaction between (i) the susceptibility of individual species to extirpation, i.e. life-history, gap-crossing ability, area requirements (Dale *et al.*, 1994; White *et al.*, 1997), (ii) local scale landscape pattern, i.e. availability, diversity, fragmentation, spatial configuration, patch size of natural habitat (Lovejoy *et al.*, 1983; Freemark, 1995; Allan *et al.*, 1997; van Jaarsveld, Ferguson & Bredenkamp, 1998b; Brokaw, 1998) , (iii) the nature and environmental impact of interspersed alternative land-uses, i.e. land-use diversity, intensity, and the impact of e.g. agricultural or forestry practices on hydrological processes and soil properties (Hobbs, 1993; McFarlane, George & Farrington, 1993; Nulsen, 1993; Saunders *et al.*, 1993; Freemark, 1995; Smith, 1996; Jules & Dietsch, 1997) and (iv) degradation within natural areas, e.g. overgrazing of rangelands (Grant *et al.*, 1982; Barnes, 1990; O'Connor, 1991; Scholtz & Chown, 1993; Srivastava, Smith & Forno, 1996a, Joubert, 1998; Seymour, 1998; Todd & Hoffman, In Press). Although highly transformed areas may currently harbor certain species, these may not sustain natural ecological processes and complete samples of other non-target taxa (Baudry, 1993; Di Benedetto *et al.*, 1993; Hobbs, 1993; Freemark, 1995), thus largely precluding these areas from feasible regional conservation networks.

The objectives of the present study were: (i) to identify areas at a regional scale where there is a possible conflict between biodiversity conservation interests and current land-uses; (ii) to investigate the influence of avoiding such potential conflict areas by incorporating a land-use constraint (LUC) into a conservation area selection algorithm, while simultaneously taking cognizance of the existing reserve system; and (iii) to investigate the circumstances of species recorded within these conflict areas.

Methods

Study area

The study area comprised the Gauteng, Mpumalanga and Northern provinces of South Africa (Figure 1) and represents 17.3% (219180 km^2) of the land area of one of the most biologically rich countries in the world (WCMC, 1992). The study area includes three of South Africa's seven biomes, namely grasslands, savanna and forests (Low & Rebelo, 1996).

Species distribution data

Information on historically recorded species presence within 15' x 15' grid cells (~ 26km x 26km; hereafter referred to as grid cells) was collated for butterflies (Lepidoptera: superfamilies Hesperiodea, Papilionoidea), mammals, birds and endemic vascular plants (van Jaarsveld *et al.*, 1998a). According to

Harrison (1992) the bird data reflect no survey bias. Although the butterfly dataset contains the fewest number of records (Table 1), it represents the best available insect dataset for the study area (Muller, 1999). The mammal database incorporates all terrestrial orders and contains no fundamental sampling bias within the study area (Freitag & van Jaarsveld, 1995; Freitag *et al.*, 1998). Only endemic plant species (i.e. species that have not been recorded outside the study area in South Africa) were included in this analyses, since the representation of all plant species set outrageous conservation demands, i.e. 50% of total area (unpublished). Plant data were available for all grid cells in the study area, but only 87% of them contained records of endemic species (Table 1). These data represent the most comprehensive regional biodiversity data currently available for South Africa (van Jaarsveld *et al.*, 1998c).

Land-cover data

Land-cover data were mapped (using manual photo-interpretation) from 1:250000 scale geo-rectified space-maps, based on seasonally standardized LANDSAT Thematic Mapper satellite imagery captured primarily during 1994-95 (Thompson, 1996). For the purpose of the present study, the 31 land-cover classes were reclassified into three categories, namely natural vegetation, modified vegetation and transformed (Table 2). Natural vegetation included all untransformed vegetation, e.g. forest, thicket and grassland. The modified vegetation category was dominated by various "degraded" classes and also included waterbodies (mostly dams) (Thompson, 1996). The degraded classes included all areas with very low vegetation cover in comparison with the surrounding natural vegetation cover and were typically associated with subsistence level farming and rural population centres, where wood-resource removal, overgrazing and subsequent soil erosion were excessive (Thompson, 1996). Transformation was defined as changes to the natural ecosystems in which the structure and species composition were completely or almost completely altered (Poore, 1978). The transformed category therefore encompassed all the cultivated and urban/built-up classes, forestry plantations (mainly commercial *Pinus* and *Eucalyptus* species), as well as mines and quarries (Macdonald, 1989).

GIS analysis

The land-cover data for the study area were overlaid with a 15' x 15' grid. Only grid cells that overlapped at least 20% with the study area were included in the analyses (n = 336; Figure 1). The extent of the protected areas (provincial and national parks) and various land-cover classes within each grid cell were calculated using ArcInfo (Albers equal area projection).

Conservation Area Selection

Richness and rarity hotspots were identified within the study area. Richness hotspots were defined as the top five percent (n = 17) species-rich grid cells, whereas rarity hotspots were all grid cells containing database rare species (< 1% of grid cells; $n \leq 3$) (van Jaarsveld *et al.*, 1998a).

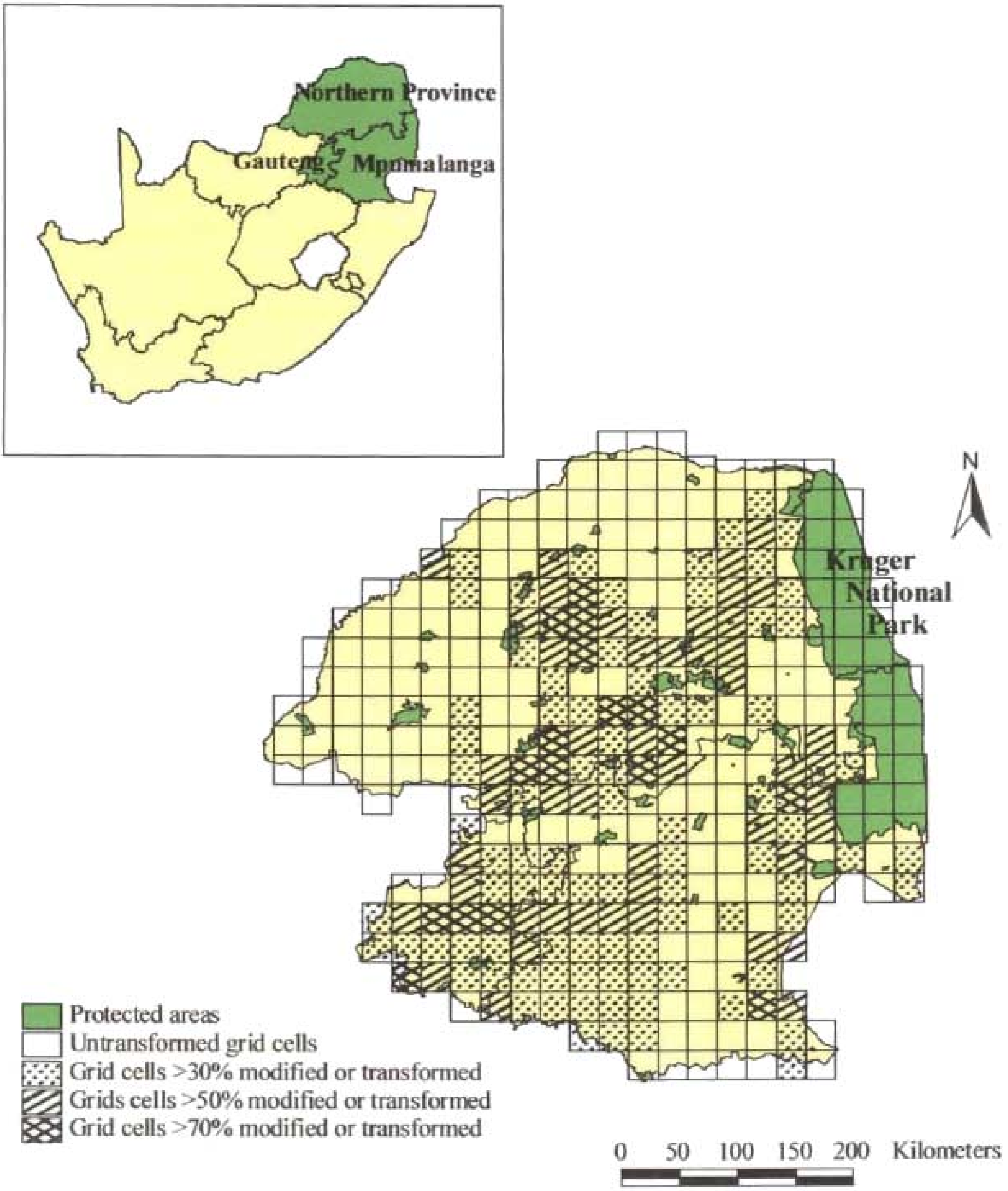

Figure 1: Three provinces of South Africa (see inset), with protected areas (Provincial and National parks), overlaid with a 15' x 15' grid and showing cells that are more than 30, 50 and 70% modified or transformed.

Table 1: Information on species presence data.

Taxa	**Number of records**	**Time span**	**Number of species**	**Number of grid cells with records**	**Rare species, in less than 1% of grid cells**
Birds	79082	1980-95	581	336 (100%)	25 (4.3%)
Butterflies	3 725	1900-80	369	142 (42%)	92 (24%)
Endemic plants	4451	1900-96	366	295 (87%)	112 (30.6%)
Mammals	5929	majority after 1980	191	268 (79%)	32 (16.8%)
Total	**93187**		**1507**	**336 (100%)**	**261 (17.3%)**

Table 2. Land-cover classes reclassified into categories and the percentage of the study area covered by each category.

Land-cover category	**% area**	**Land-cover classes**
natural vegetation	70.7%	forest and woodland; forest; thicket, bushland; shrubland and low fynbos; herbland; grassland; wetlands.
modified vegetation	6.6%	all degraded classes (6.2%); waterbodies (0.3%).
transformed	22.7%	all cultivated classes (15.7%); all urban/built-up classes (2.8%); mines and quarries (0.4%); forest plantations (3.8%).

This defined rarity could be the consequence of a restricted range or inadequate sampling effects (Gaston, 1991). Complementary sets representing all species at least once, were identified using a rarity-based algorithm that included an adjacency constraint (Nicholls & Margules, 1993). To take the contribution of existing national and provincial parks into account (Figure 1), all species occurring in one or more grid cells that overlap more than 90% with protected areas, were treated as already represented and were excluded from the selection procedures.

To identify a conservation area network that reduces conflict with other land-uses, the algorithm was modified to include constraints that successively exclude from selection grid cells that are more than 10, 20, 30...90% transformed or modified (Lombard *et al.*, 1997). In essence, the land-use constrained (LUC) algorithm was initially limited to select only grid cells that were less than 10% modified or transformed until no new species could be added to the system. After that it proceeded in a step-wise fashion to select grid cells that are more than 10, 20, 30 ...90% modified or transformed, until all species were represented. The LUC algorithm was therefore based on a trade-off between the primary objective of avoiding transformed land and a secondary objective of minimising the number of grid cells required to represent all species, i.e. maximising efficiency (Pressey *et al.*, 1993; Nantel *et al.*, 1998).

Results

Table 2 provides the percentages of the study area covered by the three land-cover categories. Approximately 23% of the study area was transformed, whereas 6.6 % was modified, with degradation accounting for the majority (6.2%) of the latter (Table 2). Figure 1 to Figure 3 illustrate the distribution of grid cells that have been modified or transformed to various degrees.

Of the 17 identified richness hotspots, nine (53%), six (35%) and two (12%) were respectively more than 30, 50 and 70% modified or transformed. 17% (261/1507, Table 1) of the species were recorded in less than one percent of the grid cells. These rare species occurred in 149 rarity hotspots of which 60 (40%), 29 (19%) and six (4%) were more than 30, 50 and 70% modified or transformed.

Seventeen of the grid cells overlapping with the Kruger National Park (2 million ha) fall more than 90% within this protected area (Figures 1–3). These 17 grid cells included at least one record for 772 species, thus leaving 735 species (hereafter referred to as remaining species) to be represented elsewhere.

Figure 4a illustrates the cumulative number of remaining species represented within each grid cell selected by the unconstrained and LUC algorithms. To represent all remaining species (n = 735), the unconstrained algorithm selected 77 grid cells (24% of 319), of which 36 (47%), 20 (26%) and four (5%) were respectively more than 30, 50 and 70% modified or transformed (Figure 2). Species were rapidly added during the first quarter of the unconstrained algorithm's curve, after which progress was slower (Figure 4a). The curve of the LUC algorithm periodically accelerated and slowed down to form distinct steps as the algorithm successively selected from sets of grid cells which were increasingly modified or transformed, at 10% increments (Figure 4a).

Figure 4b illustrates the percentage modification and transformation within each individual grid cell selected by the two algorithms. The unconstrained algorithm showed considerable variation throughout the entire curve, with no apparent trend (Figure 4b). The LUC algorithm's curve (Figure 4b) displayed some variation within each of the steps and clearly illustrates its attempt to near-minimise the extent of modified or transformed areas within the grid cells selected.

Figure 5 illustrates the land-use scenarios within the grid cells selected by the unconstrained and LUC algorithms. The complete reserve network selected by the LUC algorithm contained 7.8% more natural habitat than the set selected by the unconstrained algorithm (Figures 5a & 5b). The LUC algorithm required a total of 119 grid cells to represent all remaining species (Figure 3); 54% more than the unconstrained algorithm (n = 77). The LUC algorithm managed to represent 88% of all species within 81 grid cells which were less than 30% modified or transformed (Figures 4a & 4b), with an average of 13% modified or transformed area per grid cell. The LUC algorithm proceeded to represent 95.4% of the species in 102 grid cells which were less than 50% modified or transformed (average of 19% modified or transformed area per grid cell) (Figures 3 & 5c). An additional 17 grid cells, which were more than 50% modified or transformed (average of 60% modified or transformed area per grid cell) were required to represent the deficit of 34 (4.6%) species (Figures 3 & 5d).

Discussion

Land-use scenarios and potential conflict areas

Since the turn of the century the area of cultivated land in SA has steadily increased from approximately three percent in 1911 to eight percent in 1981 (Scotney *et al.*, 1988). The three provinces (Mpumalanga, Gauteng and Northern province) include extensive areas of arable land and as a result 15.7% of the study area has been transformed by cultivation. Forestry plantations (3.8%) and urban/built-up areas (2.8%) account for the remaining land transformation (Table 2). However, the study area has not been excessively modified or transformed, since 70% is still covered by natural vegetation. Land-uses within areas covered by natural vegetation include wildlife reserves, game ranching and cattle grazing (rangeland), all of which are considered to be amenable to biodiversity conservation (Pressey, 1992). When compared with other biodiversity assessments, where only 34% (Hokitika, New Zealand; Awimbo *et al.*, 1996), 8% (Bega Valley, New South Wales; Keith, 1995) or as little as 7% natural vegetation remains (Western Australian wheatbelt; Saunders, Hobbs & Arnold, 1993), the biodiversity in the present study area does not appear to be in the dire situation prevailing elsewhere.

A number of grid cells identified as species richness hotspots, rarity hotspots or part of the complementary set selected by the unconstrained algorithm (Figure 2), were in reality largely transformed or modified (e.g. around the towns of Sabie, Tzaneen, Graskop, Warmbad; Table 3).

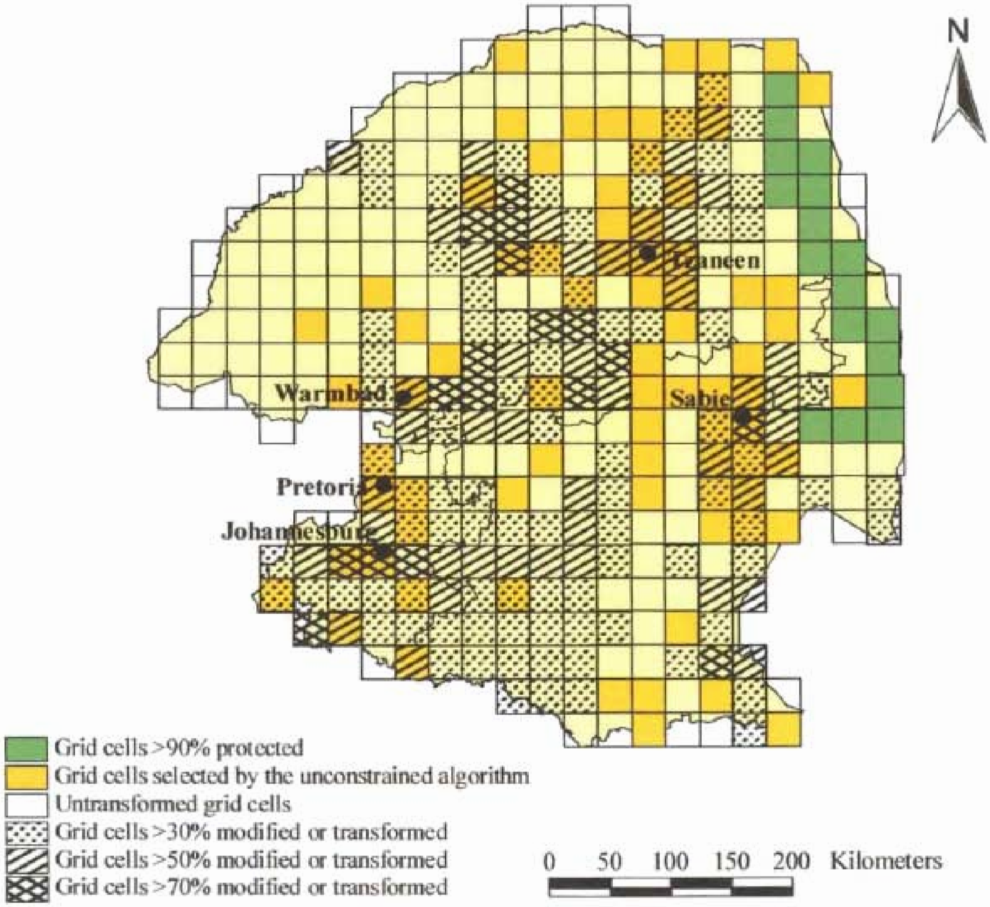

Figure 2: Map of study area with grid cells selected by unconstrained complementarity algorithm, while taking cells into account that are more than 90% protected. Overlap with grid cells that are more than 30, 50 and 70% modified or transformed is also included.

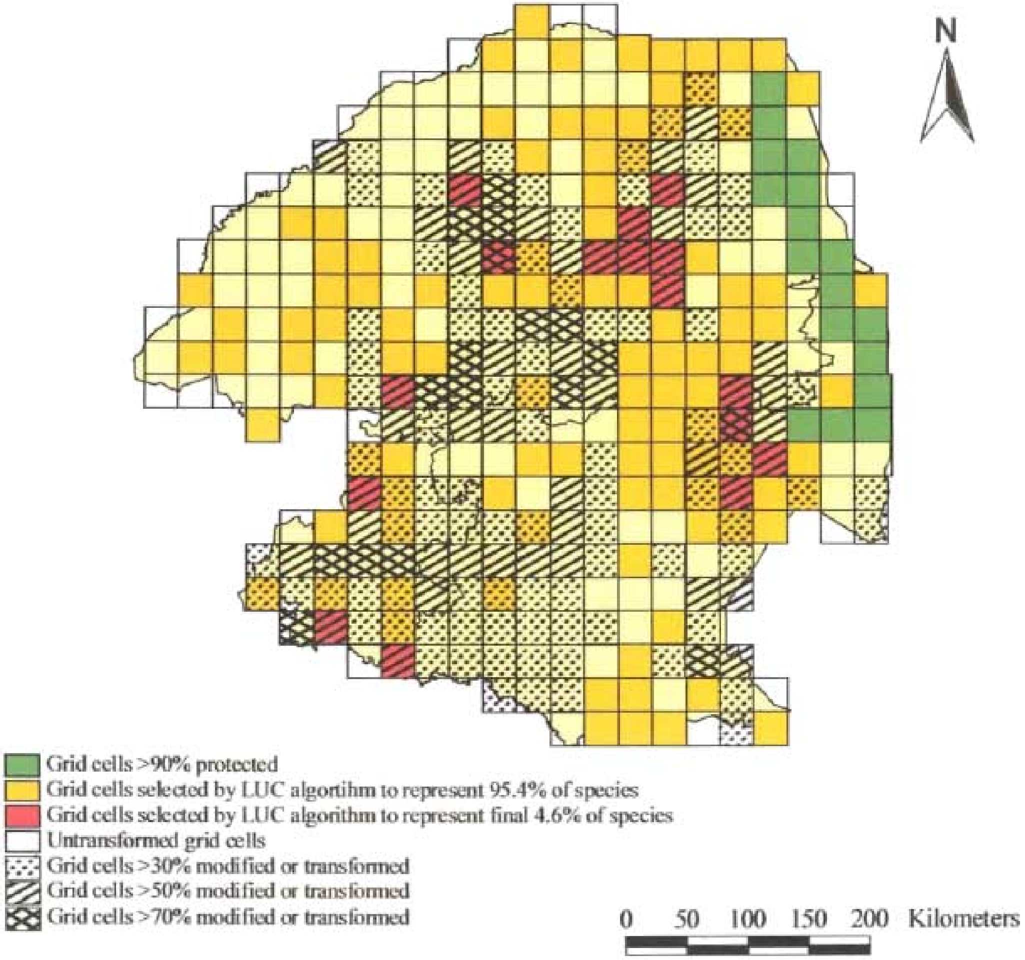

Figure 3: Map of study area with grid cells selected by land-use constrained algorithm (LUC), while taking cells into account that are more than 90% protected. The initial 102 cells selected are distinguished from the additional 17 cells that were more than 50% modified or transformed.

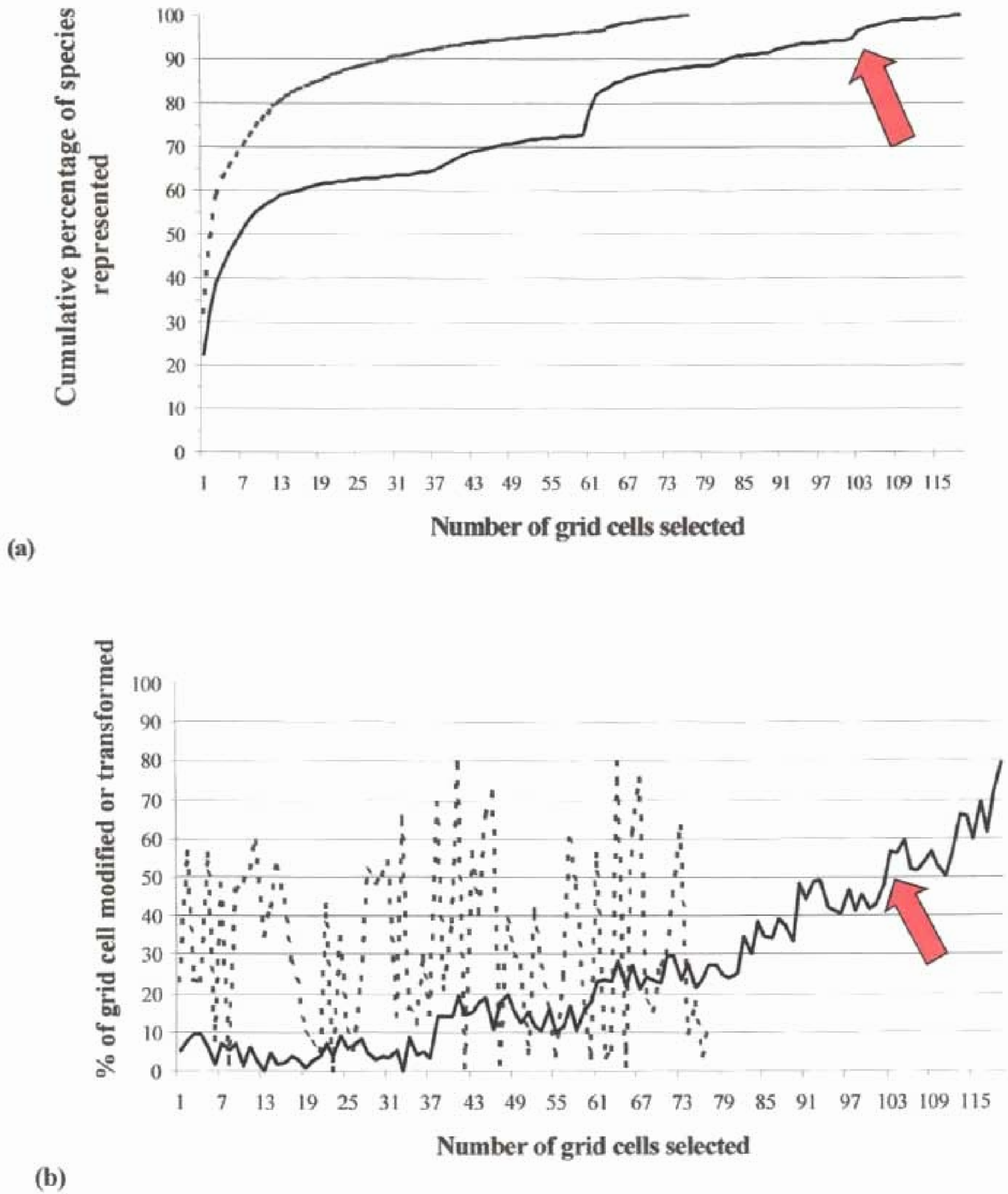

Figure 4: Results of the unconstrained (dashed lines) and LUC (solid lines) selection algorithms: (a) Number of species represented within grid cells selected. (b) Percentage area modified or transformed within selected grid cell. Arrows indicate where the LUC algorithm starts selecting grid cells that are more than 50% transformed in order to represent the remaining 4.6% of the species.

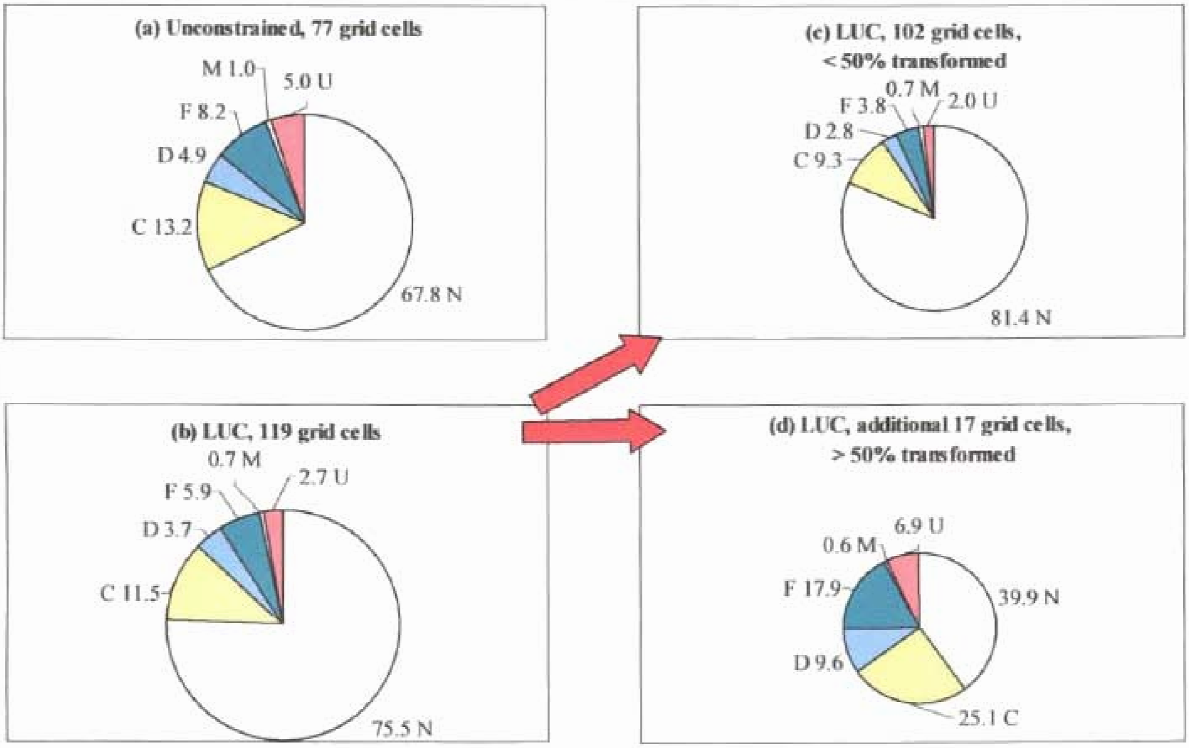

Figure 5: Percentage area of specified (a-d) selected sets of grid cells covered by natural vegetation (N), cultivation (C), urban / built-up (U), forestry plantations (F), degradation (D) or other modified land-cover classes (M). (a) Unconstrained algorithm, 77 grid cells representing all species; (b) Land-use constrained (LUC) algorithm, 119 grid cells representing all species; (c) LUC algorithm, 102 grid cells which are less than 50% modified or transformed, representing 95.4% of remaining species; (d) LUC algorithm, 17 additional grid cells which are more than 50% modified or transformed representing 4.6% of remaining species.

Table 3: Land-use within a subset of highly transformed grid cells identified as richness hotspots, rarity hotspots or belonging to a complementary set selected by both the unconstrained and the LUC algorithms (Figure 2).

Grid cell	Cultivated	Forestry	Urban	Degraded and other modified	Natural vegetation
Sabie	2%	76%	1.5%	0.5%	20%
Tzaneen	25.5%	33%	2%	1.5%	38%
Graskop	1.5%	57%	0.5	1%	40%
Warmbad	43%	0.5%	3.5%	5%	48%
Pretoria	12.5%	1%	42.5%	0.5%	43.5%
Johannesburg	0.02%	1%	67%	11.08%	20%

The most conspicuous of these potential conflict areas are grid cells that coincide with the Johannesburg and Pretoria metropolitan areas (Table 3) (Figure 2). Although these species data ascribe a high conservation value to the above-mentioned transformed areas, these areas may not support natural ecological processes or a complete assemblage of all native species (Baudry, 1993; Di Benedetto *et al.*, 1993; Hobbs, 1993; Freemark, 1995). Therefore, these transformed areas should be avoided when striving to identify an attainable and viable conservation network.

Comparison of the unconstrained and LUC algorithms

The seventeen grid cells that were regarded as sufficiently protected (more than 90% overlapping with conservation areas, i.e. Kruger National Park), represented 51% of the 1507 species in the database once. Although the cut-off value of 90% protected is as arbitrary as most other conservation targets, e.g. 10% of all vegetation types (Soulé & Sanjayan, 1998), this stringent precondition is an attempt at maximising the probability that all species recorded within a grid cell are protected.

Figure 4a illustrates the efficiency of the unconstrained rarity-based algorithm (Nicholls & Margules, 1993) at representing the remaining 735 species. However, applying this "naive" algorithm, without taking land-cover data into account, resulted in the selection of grid cells that were highly modified or transformed (Figure 2). Seeking efficiency during reserve selection by minimising land requirements, clearly provided results that were impractical conservation options. In accordance with previous findings (Nantel *et al.*, 1998), the present study illustrated that attempts to avoid conflict with other land-uses entails selecting a larger number of areas (between 40 and 55% more) to achieve the same conservation goals. To increase the percentage natural vegetation within the selected set with 7.8%, required an additional 42 grid cells, thus increasing the percentage of grid cells selected from 24% (77 / 319) to 37% (119 / 319)(Figures 4a, 5a & 5b).

Figures 4a and 4b clearly illustrate how the LUC algorithm compromised efficiency to avoid transformed areas. The LUC algorithm accelerated and slowed down periodically as it attempted to represent the maximum number of species within successive sets of grid cells containing specified areas of modified or transformed land (at 10% increments) (Figure 4a). This is in contrast to the results of the unconstrained algorithm which varied considerably in terms of the extent of modification and transformation in the grid cells selected (Figure 4b).

To represent the final 34 species (4.6%) (Appendix I), the LUC algorithm had no other option but to select 17 highly transformed (more than 50% transformed) grid cells (Figure 5d) which were also selected by the unconstrained algorithm (Figures 2 & 3). The overall effectiveness of the land-use constraint (Figure 5b) at maximising the amount of natural habitat within a selected set of areas depends on the availability of alternative areas for the representation of rarely recorded species. Therefore, this effectiveness would have been higher if the number of rare species recorded within highly transformed areas were lower (Table 1; Appendix I). Whether or not portions of these highly transformed grid cells

(Figure 3) should be included in a protected area network can not be determined from the available coarse scale biodiversity (15' x 15' grid cells) and the land-cover data (1:250000).

These results therefore illustrate how this regional biodiversity assessment can highlight areas where the nature and reality of potential conflict between land-uses and conservation interests should be thoroughly investigated at a local scale (Erhardt, 1985; Herkert, 1991; Delphey & Dinsmore, 1993; Nantel *et al.*, 1998). Although the present study presented a simple method of incorporating land-use (land-cover) information into the conventional reserve selection algorithms (Nicholls & Margules, 1993; van Jaarsveld *et al.*, 1998a) as a constraint, multi-criteria analyses which allow trade-offs between conservation and development, have previously been employed to select protected areas based on the principle of complementarity (Faith & Walker, 1996).

Species within conflict areas

The conservation status of species only recorded in grid cells which are more than 50% modified or transformed, are summarised in Appendix I. Many of the butterfly species and one bird species (Burchell's courser, *Cursorius rufus*) are common elsewhere and are therefore not conservation priorities for the study area (Appendix I). It may however, prove useful to include "regional occupancy" and "relative endemism" scores into similar future analyses in order to prioritise species for conservation within a specific study area (Freitag & van Jaarsveld, 1997; Freitag *et al.*, 1998).

Where conflict areas are identified by this regional assessment, crucial habitats within these highly transformed grid cells can be identified and protected to ensure the survival of the specific species. The regional assessment revealed that one of the butterfly species, *Alaena margaritacea* (Wolkberg Zulu), which is listed as vulnerable by the Red Data Book (Henning & Henning, 1989), is currently confined to a single known locality in the Northern province, that is 30% transformed by forestry and 20% degraded. Two other butterfly species, *Coeliades anchises* (One-pip Policeman) and *Deudorix penningtoni* (Pennington's Playboy) which are respectively listed as uncommon and common to the study area (Pringle, Henning & Ball, 1994), have only been recorded in highly transformed or modified areas and therefore warrant further investigation.

The two bat species listed in Appendix I are rare vagrants throughout Africa and are therefore not necessarily conservation priorities within the study area. Within South Africa the Mozambique woodland mouse (*Grammomys cometes*) is restricted to northern KwaZulu-Natal and south-eastern Mpumalanga (Skinner & Smithers, 1990), where more than 47% of the single grid cell in which it has been recorded is transformed by forestry. Of the birds in Appendix I, the stripped flufftail (*Sarothrura affini*) is listed as threatened (Brooke, 1984), while 13 and 42% of its range in the grasslands of the study area has been transformed by agriculture and forestry respectively.

Two of the plant species in Appendix I are listed as rare (Hilton-Taylor, 1996). *Aloe peglerae* (Turk's cap or Mountain Aloe) is listed as rare and only occurs in areas around Pretoria and west of

Johannesburg, which have been in highly transformed by cultivation and urban development. Although *Borassus aethiopum* (Borassus palm) is found elsewhere in Africa, it has a protected status in South Africa (Palgrave, 1983), where isolated plants occur in the intensively cultivated (30%) and degraded (21%) area south of Tzaneen.

This regional biodiversity assessment also allows us to investigate the land-use circumstances within the ranges of other important species. Of the grid cells where the globally threatened blue swallow (*Hirundo atrocaerulea*) has been recorded, only 51% of the original grassland remains, while some 38% is transformed by forestry and 5% by cultivation. Within the study area, the area of occupancy of the globally threatened Southern bald ibis (*Geronticus calvus*) (Collar, Crosby & Statterfield, 1994; Harrison *et al.*, 1997) has been degraded (12%) and also transformed by both cultivation (17%) and forestry (11%). The endangered Juliana's golden mole (*Amblysomus julianae*) is endemic to the study area and has a very limited and fragmented distribution (Skinner, In Press). The type locality of this species has however been almost completely transformed by urban development and sand mining along the eastern outskirts of Pretoria (Bronner, 1995).

Vandermeer & Perfecto (1997) suggested that conservation biologists should start thinking of agroecosystems as legitimate objects of study and begin asking the same questions about agroecosystems they ask of "pristine" or "natural" systems, in an endeavor to preserve biodiversity through sustainable agriculture (Srivastava, Smith & Forno, 1996b; Smith, 1996). Therefore there is an urgent need in South Africa for studies on the effects of various land-uses on biodiversity across a hierarchy of spatial and temporal scales.

Conclusions

The benefit of maximizing the area of natural habitat within a selected set of areas by incorporating a land-use constraint, carries the cost of selecting a larger total number of areas (grid cells), while the representation of all recorded species may require some level of protection for crucial habitats within highly transformed areas. It is however, unlikely that all the areas identified in these analyses (Figures 2 & 3) can be formally protected and therefore the long-term conservation of biodiversity also depends on maintaining hospitable environments within managed landscapes (Noss & Harris, 1986; Western, 1989; Soulé, 1991; Pimentel *et al.*, 1992; Pressey & Logan, 1997; White *et al.*, 1997). The regional assessment presented here is an effective tool for identifying areas where the future of specific species may rely on well coordinated "off-reserve" management (Keith, 1995; Pressey *et al.*, 1996).

Moreover, methods are needed for predicting potential impacts of various land-uses on biodiversity across a hierarchy of spatial and temporal scales to make land-use planning both clearer and better informed (Freemark, 1995; White *et al.*, 1997). As rudimentary reserve selection algorithms, based purely on biogeography, evolve into more practical tools by, for example, including land-cover data (Pimm & Lawton, 1998), they should be incorporated into regional land-use planning decision support systems (Ive & Cocks, 1988; Bedward *et al.*, 1992; Pressey *et al.*, 1995), where they could systematically stake a claim for biodiversity.

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Appendix I: Species which only occur in grid cells that are more than 50% modified or transformed.

Species	Common name	Status	Comments
Butterflies			
Hyalites cerasa (previously *Acraea cerasa*)	Tree-top Acraea	Common elsewhere	Coastal forest species and forests of Mozambique.
Alaena margaritacea	Wolkberg Zulu	Vulnerable[1]	Confined to vicinity of Wolkberg mountains in Northern province.
Antanartia hippomene	Southern Short-tailed Admiral	Common elsewhere	Common to woodlands and forests south of study area.
Cnodontes pallida	Pale Buff	Common elsewhere	Very rare in S.A., common to Botswana and northern Namibia.
Coeliades anchises	One-pip Policeman	Uncommon	Occurs in bushveld region of study area.
Deudorix penningtoni	Pennington's Playboy	Common	Found in a few localities within Mpumalanga and Northern province.
Lepidochrysops letsea	Free State Blue	Common elsewhere	Occasionally recorded in Gauteng.
Neptis alta	Old Sailer	Common elsewhere	Only a few known records south of Limpopo river, i.e. S.A.
Neptis kiriakoffi	Kiriakoff's Sailer	Common elsewhere	Very rarely recorded in South Africa, but common in Mozambique and Zimbabwe
Spialia agylla	Grassveld Sandman	Common	Wide range throughout southern Africa, including Gauteng.
Stygionympha robertsoni	Robertson's Brown	Common elsewhere	Rarely recorded in study area, common throughout most of the arid south-western Africa.
Stygionympha vigilans	Western Hillside Brown	Common elsewhere	Rarely recorded in study area, common along mountain ranges of south-western Cape of S.A.
Mammals			
Eidolon helvum	Straw coloured fruit bat	Uncommon	Migrant of tropical African forests.
Scotophilus nigrita	Giant yellow house bat	Uncommon	Very rare throughout Africa.
Grammomys cometes	Mozambique woodland mouse	Uncommon	Widespread through Africa, also found in south-eastern Mpumalanga and northern Kwazulu-Natal.
Birds			
Sarothrura affini	Stripped flufftail	Threatened[2]	Occurs in montane grassland of Mpumalanga.
Cursorius rufus	Burchell's courser	Common elsewhere	Common to dry western region of southern Africa.
Turtur afer	Bluespotted dove	Uncommon	Occurs in evergreen and riverine forests.

Motacilla cinerea	Grey Wagtail	Uncommon	Palearctic migrant, non-breeding visitor to Africa.
Plants (Endemic, i.e. within South Africa only recorded in study area.)			
Aloe alooides (Bolus)	Graskop aloe	Locally common	Common in inaccessible mountains of Mpumalanga.
Aloe lutescens	Aloe family	Uncommon	Found between Soutpansberg and Limpopo river.
Aloe marlothii subsp. marlothii	Mountain aloe	Uncommon	Found in Gauteng, Pretoria, Magaliesberg, Suikerbosrand.
Aloe parvibracteata	Aloe family	Uncommon	Occurs in Mpumalanga, but also possibly in Kwazulu-Natal.
Aloe peglerae	Turk's cap, Mountain aloe, Red hot poker	Rare[3]	Rare and confined to Magaliesberg and Witwatersberg in Gauteng.
Blechnum australe var. australe	Fern	Uncertain	Also recorded elsewhere in Africa, i.e. Zimbabwe, Kenya.
Blechnum sp.	Fern	Uncertain	Undescribed species of cosmopolitan genus with six species in S.A. and three varieties endemic to eastern parts of subcontinent.
Borassus aethiopum	Borassus Palm.	Rare[3]	Rare and protected in Northern province, but also found north of Limpopo river.
Cheilanthes inaequalis var. inaequalis	Ferns and fern allies	Uncertain	Found in north-eastern parts of S.A., but also elsewhere in Africa.
Cyperus elephantinus	Cyperaceae family, Sedge family	Uncertain	Occurs in Northern province and tropical Africa.
Cyperus fulgens var. contractus	Cyperaceae family, Sedge family	Uncertain	Occurs in Northern province and tropical Africa.
Dryopteris athamantica	Pannae-radix	Uncertain	Eastern parts of Southern Africa and tropical Africa
Eriocaulon sp.	Pipewort family	Uncertain	Undescribed species, possibly also occurs elsewhere in wet parts of S.A.
Marsilea capensis	Fern	Uncertain	Widespread in Africa, i.e. Zambia and Egypt.
Scirpus ficinioides	Cyperaceae family, Sedge family	Uncertain	Found in Mpumalanga and Gauteng, but also elsewhere in Africa.

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1. South African Red Data Book – Butterflies, Henning & Henning (1989).
2. South African Red Data Book – Birds, Brooke. (1984).
3. Red Data List of Southern African Plants, Hilton-Taylor (1996).