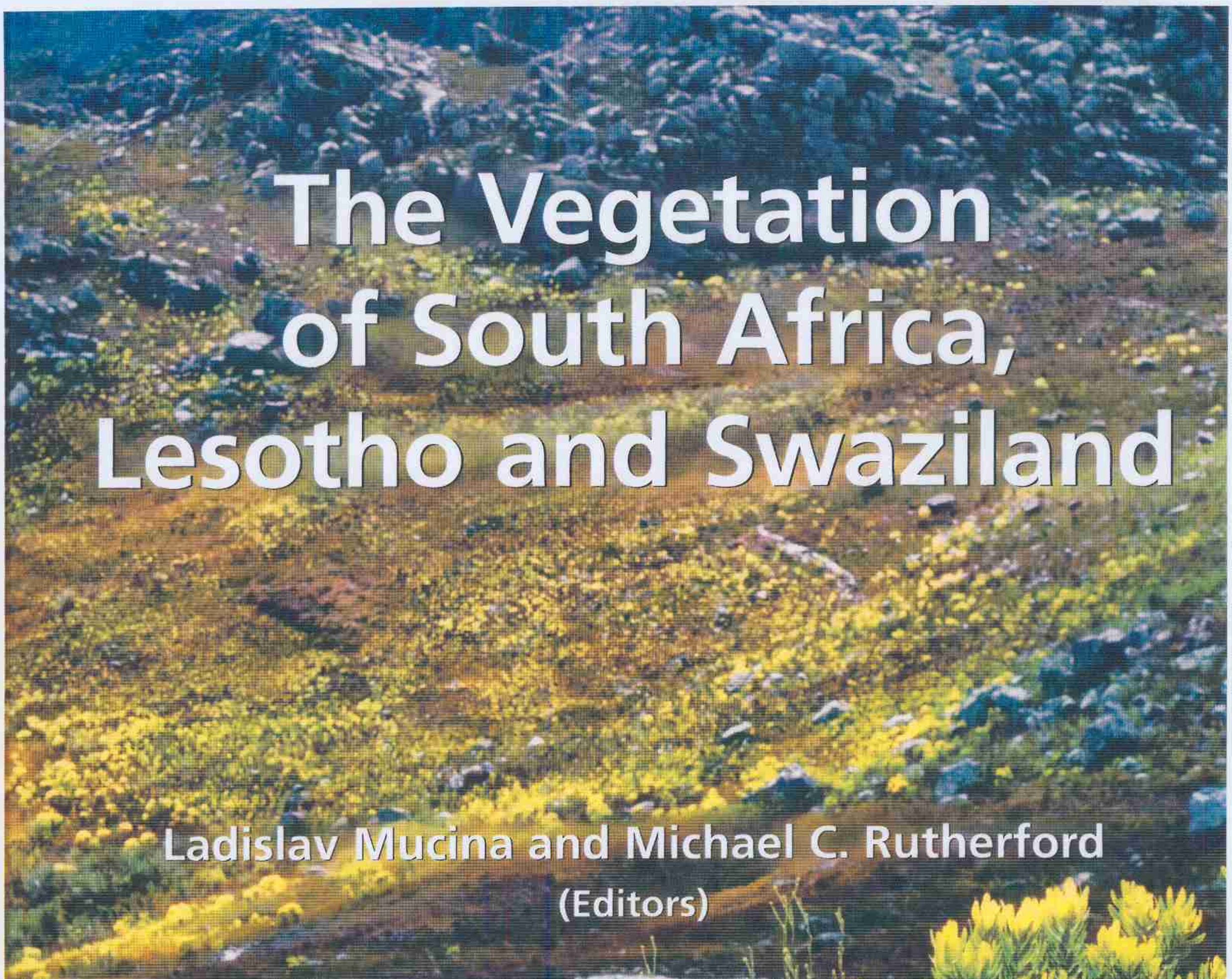

The Vegetation of South Africa, Lesotho and Swaziland

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(Editors)

17

Vulnerability Assessment of Vegetation Types

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Figure 17.1 A small patch of shale fynbos surrounded by expanding upmarket suburbs in Gordon's Bay (Western Cape) at the foot of the Hottentots Holland Mountains. Populations of two local proteoid endemics (*Leucospermum bolusii* and *Paranomus spicatus*) share this vacant lot with other rare fynbos flora.

Mucina

1. Introduction

Humans have transformed almost half of the world's land surface area into agriculture and urban systems (Chapin et al. 2000). The most severe biodiversity loss occurs when a natural ecosystem is converted to an artificial system (Geneletti 2003). This does not only affect ecosystems by altering their composition and processes, but also has important consequences for water supply and other ecosystem services upon which humans depend (Kunin & Lawton 1996, McCann 2000). Land conversion can be due to several causes, e.g. agriculture, urbanisation, road development and deforestation. When the land is converted from a natural or semi-natural state to one of these forms of land cover, many species are unable to persist (Dale et al. 1994) as a result of direct and indirect loss of habitat.

Mapping expected future loss of natural habitat or ecosystem function can be very useful in scheduling implementation of conservation actions. Focusing first on areas of high biodiversity value that are also highly vulnerable to future habitat loss or degradation is usually recognised as the most effective way to minimise biodiversity loss (Pressey 2004).

South Africa is one of the top 25 countries in the world in terms of biodiversity (WCMC 1992), with a greater part of its biodiversity occurring on agricultural land than in current conservation areas. Due to the expansion of cropland or urban areas, some of that biodiversity will be lost in the near future (Wessels et al. 2000).

Few studies done at different scales have outlined the land use pressures in South Africa (Wessels et al. 2003). This assessment focuses on the potential loss of natural habitat due to habitat transformation and degradation processes, which will threaten the biodiversity of the area. These processes can be land use-related where untransformed areas with a high suitability to a particular land use (e.g. cultivation, afforestation) are highly vulnerable. In these areas, not only natural habitat will be lost, but the species composition can also be completely altered. Alternatively these processes may be linked to the modification or degradation of biodiversity pattern and processes of an area (e.g. alien invasion and habitat fragmentation). These processes may not necessarily lead to complete loss of natural habitat, but do modify the composition of an area sufficiently to threaten ecosystem function.

We refer to the potential loss of natural habitat or ecosystem function defined above as vulnerability. In this assessment, two classes of vulnerability are referred to as *land use vulnerability* (population growth, land capability—dryland agriculture, afforestation and mining) and *degradation vulnerability* (habitat fragmentation and alien plant invasion). Vulnerability was summarised for each vegetation type.

The objective of this chapter is to describe the relationship between biodiversity pattern (defined by 433 of the 435 mainland vegetation types—two were too small for analysis), landscape structure and land use pressures in natural habitats of South Africa and to interpret this relationship in terms of vulnerability.

2. Approach

In this assessment we used several databases (see Box A) to quantify the vulnerability of vegetation types to a suite of future pressures in order to identify vegetation types of concern. We mapped and quantified land use vulnerability based on land capability, afforestation potential, mining potential and population growth. We also mapped and quantified degradation vulnerability based on habitat fragmentation and alien plant invasion. Fine-scale habitat degradation (related to over-grazing, bush encroachment, over-harvesting of natural resources) has not been mapped comprehensively for South Africa. The only information available was the assessment done by Hoffman & Ashwell (2000) at a district level. Due to the coarse scale, this could not be used for assessing the degradation status of vegetation types. However, such information can be used at the scale of the priority areas identified by the National Spatial Biodiversity Assessment (Driver et al. 2005).

All the vulnerability layers were rasterised using a 100 m cell size. For each vulnerability type, vulnerability was scored from 0 (not vulnerable) to 100 (highly vulnerable). Each layer thus had a very low vulnerability class (0–25), a low vulnerability class (25–50), a medium vulnerability class (50–75) and a high vulnerability class (75–100). Care was taken to ensure that all rescaled values represented the original vulnerability classes well.

In order to produce one layer on vulnerability across the country, we needed to combine these various datasets. All the datasets, with the exception of the mining potential, were continuous datasets and could therefore be combined arithmetically. Combining multiple threats raises several challenges, e.g. whether an area susceptible to more than one threat is more vulnerable than one susceptible to only one threat.

We produced two sets of vulnerability indices. One was an average vulnerability score for each 100 × 100 m grid cell across the country based on all vulnerability layers. This product would thus highlight areas vulnerable to a large number of future pressures. For areas currently untransformed within each vegetation type, we calculated the average score for each vulnerability type (degradation and land use). The degradation vulnerability layer was derived using the average per grid cell of the alien plant invasion and habitat fragmentation layers (see later in Habitat Fragmentation section). Land use vulnerability was derived using the average per grid cell of the land capability, afforestation and population change layers. An overall vulnerability index was calculated by averaging land use and degradation vulnerability. Vulnerability to climate change was not considered.

The second was a map of all areas in the country, which are highly vulnerable to any threat. This highlights highly vulnerable areas irrespective of the number of pressures. The raster layers produced for each type of vulnerability were used to extract areas of high vulnerability to any pressure. Pixels with a vulnerability of higher than 75 for afforestation, land capability, mining, population change, habitat fragmentation and alien plant invasion were extracted and combined to produce maps of high future pressures. Vulnerability to land use and to habitat degradation were differentiated.

In order to identify the degree of vulnerability of each vegetation type, we then summarised the average vulnerability value and the percentage of the natural area under high pressure per vegetation type.

3. Land Use Vulnerability

3.1 *Land capability*

Land capability reflects the land suitability to crop production and also to other less intensive uses such as pasture, natural grazing, forestry and wildlife (see Figure 17.2). Land capability was modelled based on soil and terrain features and climate of an area. Low nutrient status was not considered a limitation,

Box A: Description of the databases used to derive vulnerability layers in South Africa.

Several databases on vulnerability are available in South Africa at a national scale. These databases were investigated and either selected for the analysis or discarded based on characteristics in the database. Table A1 provides a list of these databases and reasons for their selection or rejection.

Table A1 Various datasets used in the vulnerability assessment.

Database	Source	Description	Limitations	Used
Land use vulnerability				
Land capability	ARC (ISCW)	Total suitability for use, in an ecologically sustainable way, for crops, grazing, woodland and wildlife	Mapped at a broad scale	Yes
Grazing potential	CSIR	Areas which have the potential to support a similar number of herbivores per unit land area	Does not imply pressure unless poorly managed	No
Afforestation	CSIR	Potential for pine and eucalypt species based on bioclimatic variables	Only mapped for some provinces (LP, MP, KZN, EC, WC)	Yes
Mining	Council for Geoscience	Mapped mineral deposits, fields, layers and provinces	Categorical data	Yes
Population growth	StatsSA	Change in population density per municipality from 1996 to 2001 census products	Broad units of municipalities	Yes
Degradation vulnerability				
Fragmentation				
Landscape resistance	NLC	Incorporates connectivity and surrounding land uses		Yes
Extent of natural habitat	NLC	Area of untransformed habitat		Yes
Fragment size	NLC	Size of remaining habitat		Yes
Plant invasion	SANBI/ CSIR	Numbers of alien invasive species that could occur in a region		Yes
Degradation	Hoffman & Ashwell (2000)	Soil and vegetation degradation per magisterial district	Very broad units for vegetation analysis	No

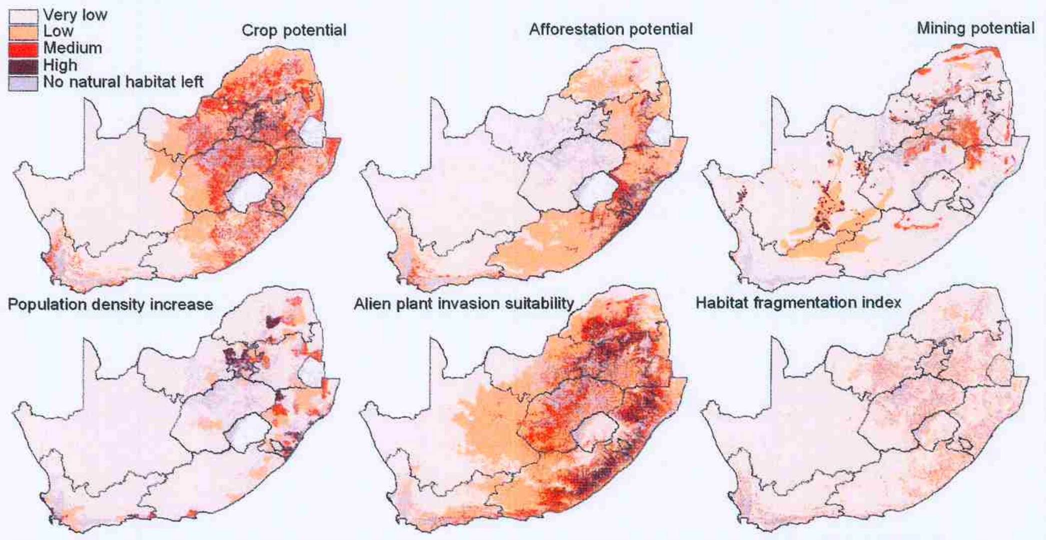

Figure 17.2 Vulnerability to future land use change (crop potential, afforestation potential, mining potential, population density increase) and habitat degradation (alien plant invasion suitability and habitat fragmentation index) in South Africa.

since it is assumed that inherent nutrient deficiencies/toxicities will be rectified by appropriate liming and/or fertilisation. The land capability classification system applies only to rain-fed agriculture. Land suited to crop production is also suited to other less intensive uses such as pasture, natural grazing, forestry and wildlife. Most of the conversion of natural habitats with a high agricultural production potential to cultivated areas took place in the last 50 years and has considerably reduced the extent of several vegetation types. These vegetation types are mostly communities of the Grassland Biome (Macdonald 1989) and Renosterveld shrublands of the Western Cape, which presently occupy a fraction of their original range (Heydenrych & Littlewort 1995).

Land capability potential, averaged per vegetation type, varies quite considerably. Out of 433 vegetation types, 189 vegetation types have very low land capability; 180 vegetation types, low; 64 vegetation types, medium; and no vegetation types have high land capability. The top six vegetation types that are under medium land capability pressure include the Eastern Highveld Grassland, Tembe Sandy Bushveld, Swartland Alluvium Renosterveld, Maputaland Wooded Grassland, Western Maputaland Sandy Bushveld and Makatini Clay Thicket.

3.2 *Afforestation Potential*

Afforestation is the planting of trees for commercial purposes, usually on land supporting non-forest veld types, e.g. grassland or fynbos. Afforestation potential maps were modelled using fuzzy tolerance models, based on bioclimatic parameters. The bioclimatic factors used in these models were soil, rainfall and temperature (Fairbanks 1995). Although these maps were only generated for five provinces in South Africa, these provinces were found to coincide well with the areas suitable for wood production across southern Africa and thus the layer could be used in a national assessment. Each 1 km^2 grid was assigned an average suitability value for pine and eucalypt species. These values ranged from 0 (low suitability) to 100 (very high suitability) (Figure 17.2).

Natural habitats most severely affected by current afforestation include wetlands, grasslands, fynbos and indigenous forests (Heydenrych & Littlewort 1995). Based on this afforestation model (see Figure 17.2), 238 vegetation types have very low afforestation potential; 136 vegetation types, low; 52 vegetation types, medium; and seven vegetation types have a high afforestation potential. The top six vegetation types highly threatened by afforestation are the Pondoland-Ugu Sandstone Coastal Sourveld, Mangrove Forest, KwaZulu-Natal Sandstone Sourveld, Southern KwaZulu-Natal Moist Grassland, Midlands Mistbelt Grassland and Northern Escarpment Afromontane Fynbos.

3.3 *Population Density Change*

Due to the lack of data on urban and peri-urban sprawl in South Africa, we decided to use the change in population density as an indicator of human pressure. Data from the national censuses in 1996 and 2001 were used for this purpose. Both datasets were aggregated to the municipality level from the original enumerator areas. The difference in population between the two census periods was used to calculate the change in population density. This change in density is mostly related to the movement of people across the country towards urban areas, as well as natural population growth. Each municipality was thus assigned a value of the change in population density, which ranged from 19 to 356 people per km^2 and re-scaled from 0 to 100 (Figure 17.2). From this assessment, 343 vegetation types occur in areas with very low population growth, 71 vegetation types in areas with low population growth, 12 in areas with medium population growth and seven in areas with high population growth. The top six highly threatened vegetation types are the Egoli Granite Grassland, Peninsula Granite Fynbos, Peninsula Shale Renosterveld, Peninsula Sandstone Fynbos, Lourensford Alluvium Fynbos and Cape Flats Sand Fynbos.

3.4 *Mining Potential*

No layer was readily available for mapping mining potential; Box B describes how we used mining resource field to map and categorise mining potential. Mining potential was determined based on the accuracy of the deposit mapping, its size, and the type of commodities. For example, areas of high mining potential consist of large mines/deposits or mineralised fields for 13 economically important commodities (Figure 17.2).

Mining potential is concentrated in few parts of the country (such as the West Coast) with only 2.1% of the whole country (1.8% of the untransformed natural habitats) under high mining potential.

Due to its categorical nature, mining potential could not be averaged per vegetation type. Instead we calculated the percentage of the untransformed area of each vegetation type of high mining potential. There are 195 vegetation types with no mining potential. A total of six vegetation types have 50% of their natural area occurring in medium mining potential areas and another four have 50% of their natural area occurring in high mining potential areas (see Table 17.1). The vegetation types most vulnerable to mining are: Namib Seashore Vegetation, Richtersveld Coastal Duneveld, Northern Escarpment Dolomite Grassland and Subtropical Seashore Vegetation.

Box B: Mining potential in South Africa.

The mining dataset was obtained from the Council for Geoscience.

It includes mineral points subdivided into two types, namely mines and mineral deposits. Mines can be dormant mines, continuously producing (active) mines, abandoned mines and intermittently producing mines. The mineral deposits can be exploited or unexploited. The dataset also contains information on mineralised fields (areas of high concentration of commodity) and mineralised provinces (broad areas where a given commodity occurs) as well as mineralised layers (veins of high concentration of commodity—linear feature).

Mines and deposits were buffered by 500 m and the mineralised layers by 1 000 m (less accurate).

The mining potential was determined based on the accuracy of the deposit mapping, its size and the type of commodities.

We considered four types of deposit mapping (arranged from high spatial accuracy to low):

- Mines and deposits (500 m radius).
- Mineralised layers (1 km buffer).
- Mineralised fields (high concentration of commodity).
- Mineralised provinces (broad area where commodity occurs).

The commodities were classified into two groups, namely economically important and other minerals. The minerals of economic importance (13) were obtained from the website of the Council for Geoscience. Table B1 lists the 13 minerals of economic importance in South Africa.

Table B1 Minerals of economic importance in South Africa.

Mineral	Symbol
Gold	Au
Platinum Group Metals	Pt
Diamonds (alluvial & kimberlite)	Da, Dk
Chromite	Cr
Manganese	Mn
Vanadium	V
Titanium	Ti
Zirconium	Zr
Antimony	Sb
Aluminum Silicates	Al
Coal	C
Fluorspar	F
Vermiculite	Vm

Table B2 illustrates how we classified mining potential into three categories: high, medium and low. We associated areas where an economically important commodity (such as gold) occurs in large deposits/mines, or where a mineralised field/layer of such commodity was mapped.

Table B2 Criteria used to map mining potential in South Africa.

Category	Type	Commodity
High	Large deposits/mines OR Mineralised fields/layers	Economically important
Medium	Medium mines OR Mineralised provinces	Economically important
	Large deposits/mines	Other
Low	Small deposits/mines OR Mineralised layers/fields/ provinces	Any

Table 17.1 Top vegetation types with high or medium mining potential in South Africa, ranked from the highest to the lowest potential. Percentage of the vegetation type area with high and medium mining potential is shown.

Vegetation types	% High	% Medium
Namib Seashore Vegetation	100	0
Richtersveld Coastal Duneveld	76	0
Northern Escarpment Dolomite Grassland	66	0
Subtropical Seashore Vegetation	53	0
Arid Estuarine Salt Marshes	49	0
Namaqualand Seashore Vegetation	0	0
Wakkerstroom Montane Grassland	0	90
Nwambyia-Pumbe Sandy Bushveld	0	84
Eastern Highveld Grassland	0	71
Springbokvlakte Thornveld	0	61
Soweto Highveld Grassland	0	60
Delagoa Lowveld	0	53

4. Degradation Vulnerability

4.1 Habitat Fragmentation

We considered three elements to derive the habitat fragmentation layer at landscape level. These were the surrounding land use (matrix resistance), the average fragment size and connectivity (distance between natural fragments). The first aspect is based on the assumption of different species movement to land cover types, by relating the species movements between different land use types to the resistance value. Landscape resistance thus represents the difficulty of a species to cross a certain land use type (Nikolakaki 2004). The approach is described in Box C. An overall habitat fragmentation index was derived by averaging the three aspects (Figure 17.2).

From this assessment, 244 vegetation types occur in areas with very low habitat fragmentation, 171 vegetation types in areas with low habitat fragmentation, 16 in areas with medium habitat fragmentation and two in areas with high habitat fragmentation. Highly fragmented vegetation types (last quartile of overall habitat fragmentation index) are listed in Table 17.2. The analysis of average fragment size separated vegetation types that are naturally fragmented (i.e. very small fragment size but high percentage extent) from those that have been fragmented due to anthropogenic change (i.e. very small fragment size and low percentage extent). For example, vegetation types such as Northern Afromontane Forest are naturally fragmented.

Table 17.2 Total number of highly fragmented vegetation types (11). Habitat fragmentation was quantified in terms of extent of habitat fragmentation (extent value), resistance to species movement (resistance value) and average fragment size (fragment size). The overall habitat fragmentation index ranged from 0 (not fragmented) to 85 (highly fragmented).

Vegetation types	Extent value	Resistance value	Fragment size	Overall index
Lourensford Alluvium Fynbos	91.0	82.7	80.5	84.8
Swartland Silcrete Renosterveld	96.7	57.0	72.7	75.5
Cape Lowland Alluvial Vegetation	90.4	43.4	57.5	63.8
Rûens Silcrete Renosterveld	93.9	40.8	56.4	63.7
Saldanha Granite Strandveld	85.0	45.9	56.9	62.6
Swartland Shale Renosterveld	85.0	43.2	57.4	61.9
Western Rûens Shale Renosterveld	82.0	44.0	59.3	61.7
Eastern Rûens Shale Renosterveld	82.0	43.9	58.9	61.6
Swartland Alluvium Renosterveld	79.0	46.2	57.6	60.9
Central Rûens Shale Renosterveld	84.0	42.1	56.3	60.8
Knysna Sand Fynbos	87.0	40.8	53.9	60.6

Box C: Habitat fragmentation.

1. Resistance Layer

The land cover map (including roads) was reclassified to reflect resistance to species movement. The types that allow minimal resistance were given a value of 0 (e.g. natural areas), while other types offer a greater resistance (Table C1). The layer was aggregated to 1 km distance in order to average the resistance value for fragments that are within the prescribed dispersal distance (1 km) using Grid Analyst in Arc View GIS. This produced a resistance layer with values ranging from 0 to 100. The cut-offs used for resistance values were as follows: 0–25, very low; 25–50, low; 50–75, medium; 75–100, high. We summarised the resistance values per vegetation type to classify vegetation types into four categories of habitat fragmentation in terms of resistance to species movement using equal interval categories.

Table C1 Land use classification based on the estimated landscape resistance value. Note: estimated resistance values were not species-specific.

Land use types	Landscape resistance value
Forests & Woodlands	0
Thicket & Bushland	0
Grassland	0
Wetlands	0
Waterbodies	25
Degraded land	50
Minor roads	50
Cultivated land	75
Forest plantation	75
Mines & Quarries	85
Major roads	85
Urban/Built-up Land	100

2. Extent of Habitat Transformation

To derive the extent of habitat transformation, we reclassified the NLC layer into natural and transformed areas (where natural areas = 0 and transformed areas = 1). The layer was then aggregated to 1 km using a sum method to calculate the percentage of habitat transformation within 1 km blocks. Values ranged from 0 (natural 1 × 1 km block) to 100 (transformed 1 × 1 km block). The layer was then summarised per vegetation type, which were reclassified into four categories of habitat fragmentation in terms of habitat transformation extent using equal interval categories.

3. Fragment Size

A unique value was assigned to each fragment of natural habitat per vegetation type (using the Arc Info command 'region group'). We then determined the area of each fragment of natural vegetation per vegetation type. The average fragment size was calculated for each vegetation type. We re-scaled the average fragment size value from 0 (average fragment size: 22 641 ha) to 100 (average fragment size: 1 ha). We reclassified vegetation types into four categories of habitat fragmentation in terms of fragment size using equal intervals.

4. Habitat Fragmentation Index

The overall habitat fragmentation index was derived per vegetation type. We averaged the values obtained for resistance to species movement, extent of habitat transformation and average fragment size. Vegetation types were then classified into four categories (very low, low, medium and high) of habitat fragmentation using equal intervals.

4.2 *Alien Plant Invasion*

We quantified alien plant invasion potential based on an assessment of the climatic correlates of distribution of 71 important invasive alien plants (Nel et al. 2004, Rouget et al. 2004). We assumed that alien plant species would have the potential to spread in areas identified as climatically suitable by a climatic envelope model (see Box D). Figure 17.3 illustrates the approach for three species. The index derived (re-scaled from 0 to 100) relates to the potential number of invader plants. This was then summarised per vegetation types and categorised into four categories.

A total of 157 of the vegetation types have low invasion potential where fewer than five species can invade, and five vegetation types have high invasion potential, being potentially suitable for more than 25 of the invader plants.

Box D: Mapping alien plant potential.

Climate Envelope Models (CEMs) are very useful at a broad scale to develop a general picture of where species are most likely to invade, especially in this region with marked climatic gradients. In this study, we used a variant of CEMs based on an oblique ellipse model, which calculates the Mahalanobis distance to the 'optimal' climate conditions. Such models are supported by the niche theory which assumes the existence of optimal environmental conditions for a species and that any deviation from this optimum is associated with a lower climatic suitability. These models are an improvement on traditional CEMs in that a continuous range of climatic suitability values can be equated with probability of occurrence. We derived climatic suitability surface for 71 major invader plants.

Preliminary analyses suggested that the relative importance of climatic factors was species-specific, making it difficult to identify a few 'generic' climatic variables that could be applied for all our species. We therefore reduced the large number of possible explanatory variables to three components (principal component axes 1, 2 and 3) using Principal Component Analysis (PCA). The first three components of the resulting PCA explained over 95% of the initial variation, based on the seven climatic variables with the greatest influence on plant species distribution. We then used these three climatic indices to derive the CEMs. We assumed that alien plant species would have the potential to spread in areas identified as climatically suitable by the CEMs. Rouget et al. (2004) describe the approach in more detail. Ideally, CEMs for alien plants should also be based on their bioclimatic occurrence in their continent of origin (Rutherford et al. 1995) and any other areas of the world where they are invasive.

Species potential distributions were derived on a grid of 1-minute resolution. We quantified alien plant invasion potential by calculating the number of alien plants that could potentially invade each 1-minute cell (i.e. for which the climate is suitable). The index was re-scaled from 0 to 100.

Most species are currently confined to 10% or less of the region, but could potentially invade up to 40%, based on their climatic envelope. Depending on the species, between 2% and 79% of the region is climatically suitable for species to invade, and some areas were suitable for up to 45 invader plants. Over one third of the major invader plants considered here have limited potential to substantially expand their distribution.

The number of potential invaders was then averaged per vegetation type to produce an index of alien plant invasion potential per vegetation type. This was classified into four categories (very low, low, medium and high) based on equal intervals.

5. Overall Vulnerability of Vegetation Types

Not all the vegetation types of the country are affected by land use pressures and degradation (Figure 17.4) in the same way. Out of 433 vegetation types, 207 vegetation types have a very low overall vulnerability index. A total of 217 vegetation types have a low overall vulnerability index. However, nine vegetation types have a medium overall vulnerability index (i.e. average greater than 50 for all vulnerability types).

The six vegetation types that are the most likely to be affected (based on the combined vulnerability index of land use and degradation) are (in decreasing order): Lourensford Alluvium Fynbos, Knysna Sand Fynbos, Algoa Sandstone Fynbos, Cape Flats Sand Fynbos, Egoli Granite Grassland and KwaZulu-Natal Sandstone Sourveld. Table 17.3 lists the three most threatened vegetation types for each land use and degradation pressure.

One can also analyse vulnerability in terms of the areas highly vulnerable to any land use or degradation pressure (score >75 for one or more of the six vulnerability types considered).

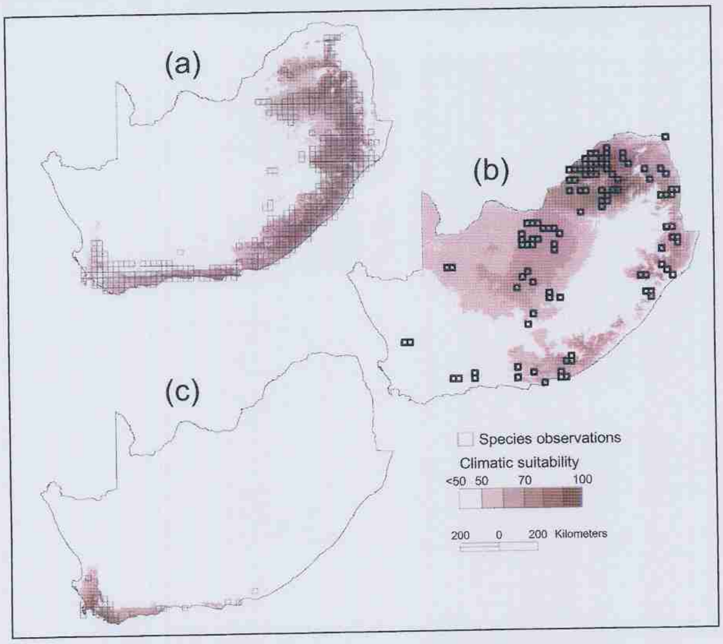

Figure 17.3 Species presence observations and climatic suitability derived from climatic envelope models for three characteristic species in South Africa, Lesotho and Swaziland: (a) *Acacia mearnsii*, a very widespread and abundant invader; (b) *Opuntia stricta*, a widespread and common invader; and (c) *Hakea drupacea*, a localised and abundant invader (from Rouget et al. 2004).

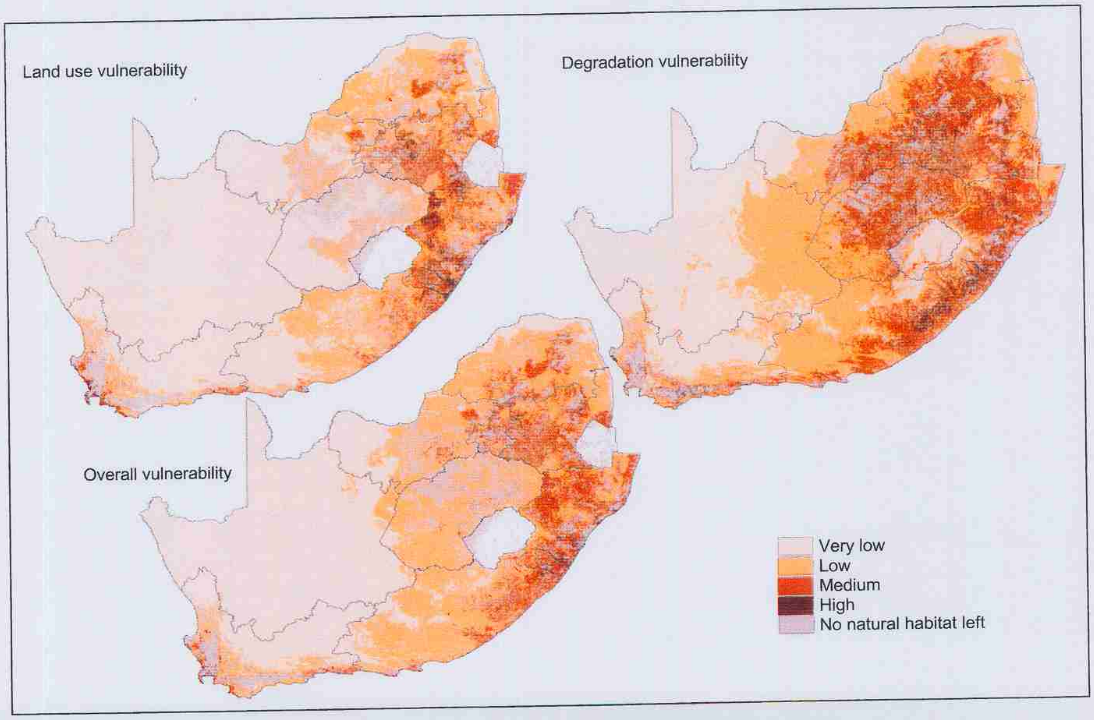

Figure 17.4 Average vulnerability of land use pressure, habitat degradation and overall vulnerability.