CHAPTER 1

General Introduction

"Only after the Last Tree has been cut down,
Only after the Last River has been poisoned,
Only after the Last Fish has been caught,
Only then will you find that
Money Cannot Be Eaten."
Cree Indian Prophecy

Biodiversity, the diversity of organisms, their genes and the environment in which they interact, faces large threats mostly in the form of human population growth and associated land transformations (Soulé, 1991; Dale *et al.*, 1994; Sala *et al.*, 2000). The resultant, mostly human-induced, species extinction rates rival mass extinctions of the geological past and threaten not just the natural world, but also the ecological products and services on which we depend (Kunin & Lawton, 1996; Chapin *et al.*, 2000; Pimm & Raven, 2000; Tilman, 2000). The importance of these natural resources and services is irrefutable, however existing global conservation efforts are mostly inadequate (Pressey, 1994a; Lombard, 1995a,b; Rodrigues *et al.*, 1999). Many of the present day conservation areas were proclaimed in an *ad hoc* and opportunistic fashion and include areas with high scenic values, high tourism potential and low potential for other forms of land-use (e.g. agriculture or forestry) (Pringle, 1982; Pressey *et al.*, 1993; Freitag *et al.*, 1996). This form of conservation area selection is highly inefficient, providing a biased representation of regional biodiversity and is less cost effective in the long run (Pressey & Tully, 1994; Rodrigues *et al.*, 1999). These shortcomings have highlighted a need for effective and systematic conservation area selection techniques in order to identify areas essential to biodiversity conservation (Williams, 1998; Margules & Pressey, 2000).

Conservation area selection techniques

These techniques run on a database of biodiversity features and the sites or areas in which these features occur (Margules *et al.*, 1988; Margules & Redhead, 1995; Pressey & Logan, 1998). Features can include species, land facets, vegetation types or any other spatial features. Techniques include the traditional hotspots approach where sites with many features (richness hotspots), many rare features (rarity hotspots) and many endemic features (endemicity hotspots) are identified as priority conservation areas (Prendergast *et al.*, 1993; Lombard, 1995b; Williams *et al.*, 1996). Scoring procedures were applied in the 1980's as a conservation area selection technique. Here sites were ordered according to a combined score from a variety of criteria such as diversity, rarity, size and naturalness of the sites and then selected from the top site down until all features are represented a required number of times (Pressey & Nicholls, 1989). Understandably this leads to an overrepresentation of many features, as well as a biased set of sites depending on the criteria used. However, since then there has been much development in the field of conservation area selection.

With the advent of the principles of complementarity, efficiency and flexibility, among others, these selection techniques have become powerful land-use planning tools (Pressey *et al.*, 1993). The principle of complementarity ensures that it is not just the site with the most features that is chosen, but rather the site that contains the most so far unrepresented features. This then helps ensure the principle of efficiency whereby maximum biodiversity features are represented in the minimum number of sites possible. Flexibility implies that for features that do occur in alternate sites, these sites are also highlighted as possible selections to allow for flexibility of choice in land-use planning. This principle of flexibility is related to an additional component of conservation area selection and that is the concept of irreplaceability. The irreplaceability of a site is a measure of how important that site is to the conservation goals within a region. In other words, how would the loss of that site impact on conservation options in the region. The site's irreplaceability depends on the conservation targets set. A site that is totally irreplaceable, for a conservation target of 100% species representation, will be one that contains a species found nowhere else in the region. Irreplaceable sites decrease the flexibility of conservation options within a region (Pressey *et al.*, 1994; Ferrier *et al.*, 2000).

The successful inclusion of these principles and others into heuristic iterative algorithms and optimising linear programming algorithms has made for powerful conservation planning tools (Church *et al.*, 1996; Csuti *et al.*, 1997; Williams, 1998; Margules & Pressey, 2000). Heuristic algorithms proceed in a step-wise fashion selecting sites with the most so far unrepresented features (richness-based algorithms) or the highest number of so far unrepresented rare features (rarity-based algorithms) (Kirkpatrick, 1983; Margules *et al.*, 1988; Pressey & Nicholls, 1989; Bedward *et al.*, 1992; Nicholls & Margules, 1993; Margules *et al.*, 1994a; Freitag *et al.*, 1997; Pressey *et al.*, 1997; van Jaarsveld *et al.*, 1998). Optimising linear programming algorithms utilise what operations researchers call a maximal coverage problem and often find the most optimal solution for representing maximum features in the minimum amount of area, although this optimality comes with a trade-off of computational time required (Church *et al.*, 1996; Csuti *et al.*, 1997). However, these techniques have increased in sophistication, power and speed over recent years.

There are however, several shortcomings associated with this suite of conservation area selection techniques. These include incomplete feature databases, inadequate representation of ecosystem processes, patterns of spatial and temporal feature turnover, shifting anthropogenic threats, and the need to take current and potential development opportunities into account (Balmford *et al.*, 1998; Williams, 1998; Maddock & Du Plessis, 1999; Margules & Pressey, 2000; Nicholls, 1998; Wessels *et al.*, 2000 (see Addendum II); Mace *et al.*, 2000).

Shortcomings in conservation area selection

Databases

The aim of conservation area selection techniques is to represent biodiversity within selected sites.

However, the difficulties with sampling the full complexity of biodiversity in order to represent it are often almost insurmountable. Thus the selection of representative minimum-set conservation areas often depends on substitute or surrogate biodiversity data which can be surveyed in a more cost and time efficient manner (Noss, 1990; Vane-Wright *et al.*, 1991; Ryti, 1992; Belbin, 1993; Gaston & Williams, 1993; Pressey, 1994b; Williams & Gaston, 1994a,b; Margules & Redhead, 1995; Pressey & Logan, 1994; Faith & Walker, 1996b; Gaston, 1996a; Williams, 1998). These data include higher taxa, phylogenetic diversity, species richness and broad-scale environmental measures. Areas rich in higher taxa (e.g. families or orders) are assumed to be rich in lower taxa (e.g. species) and therefore contain much biodiversity (Gaston & Williams, 1993; Williams & Gaston, 1994a; Balmford *et al.*, 1996). Data on higher taxa are often more easily obtainable than data on the lower levels. Phylogenetic diversity measures how closely related the species in an assemblage are in evolutionary terms, and thus captures more of the biodiversity than other surrogate measures (Vane-Wright *et al.*, 1991; Faith, 1992; 1994; Williams & Humphries, 1994). These data, however, are very labour intensive to obtain and are, more often than not, unavailable.

Species richness is one of the most common currencies of biodiversity measurement (Heywood, 1994; Gaston & Spicer; 1998). These data are widely and often well collected, especially for some taxa e.g. mammals, birds and vascular plants. It is often the form of data used by conservation area selection techniques, and usually comprises the distribution of species recorded as presence/absences in sites such as grid cells, forest reserves and water catchments. However, species distribution data have many shortcomings. The taxa employed are often poorly known taxonomically and incompletely surveyed with biased survey records for a region. As Polasky *et al.* (2000) point out existing methods for the selection of areas important for species conservation rely on data on the presence or absence of species in various sites. These data are seldom available since not all of the sites have been sampled for all species and therefore the probability of false absences is high. It has therefore been suggested that a useful surrogate or substitute for species richness data could be indicator taxa (Prendergast *et al.*, 1993; Lombard, 1995b; Williams *et al.*, 1996; Flather *et al.*, 1997; Balmford, 1998; Howard *et al.*, 1998; van Jaarsveld *et al.*, 1998). These are taxonomic groups that are well-known taxonomically and well surveyed within the region of interest. The word 'indicator' in this study as in biodiversity indicator, indicator taxon etc. implies a group or taxon used to locate areas of high biodiversity and thus help in conservation planning. It is not used in the sense of indicator species which are employed in assessing environmental quality and human impacts (Caro & Doherty, 1999). It is then assumed that patterns in these indicator groups reflect patterns in other unsurveyed taxa. However, this assumption has seldom been assessed and results are often conflicting as to the validity of indicator taxa as surrogates for biodiversity. Chapter 2 provides a regional assessment of indicator taxa in an effort to test this assumption.

These surrogate measures all have important contributions to make toward the quantification of biodiversity patterns and the identification of areas important to its conservation. However, the assumed relationship between these measures and the underlying biodiversity has seldom been investigated and due to the inadequacy of most biodiversity data will remain difficult to investigate. There are a variety of techniques available for the assessment of the effectiveness of biodiversity surrogates each of which provide different levels of support for the use of surrogates. These techniques include assessments of the degree of overlap and representativeness of conservation areas based on different biodiversity surrogates (Prendergast *et al.*, 1993; Lombard, 1995b; Gaston, 1996b; Flather *et al.*, 1997; Howard *et al.*, 1998; van Jaarsveld *et al.*, 1998). Chapter 3 investigates the impacts these various assessment techniques have on the degree of support offered for the use of indicator taxa as biodiversity surrogates. It is, however, also argued that species comprise just one level of the biodiversity hierarchy and as such are an inadequate representation of the diversity found within nature's hierarchy (Noss, 1990; 1996; Faith & Walker, 1996a; Maddock & Du Plessis, 1999).

A final surrogate for biodiversity is broad-scale biological and environmental data. This form of data includes vegetation types, land facets, land classes and land systems, and because it comprises a higher level of the biodiversity hierarchy is expected to capture much diversity found in lower hierarchical levels (Pressey; 1994b; Pressey & Logan, 1994; Wessels *et al.*, 1999; Fairbanks & Benn, 2000). Chapter 4 provides a regional assessment of the broad-scale biodiversity surrogates of vegetation and landtypes and their success at representing regional species diversity.

Biodiversity processes and feature turnover

A recurrent problem with most existing conservation area selection techniques is that although they may achieve varying levels of success in representing existing biodiversity, they concentrate primarily on biodiversity pattern. Representation of current patterns of species diversity, vegetation types or land classes in conservation areas is only one facet of successful biodiversity representation. This form of representation ignores the dynamic nature of biodiversity features e.g. the movement of individuals, populations, migration, population processes and viability, disturbance regimes, climate change and the ecological interactions between species and their environment within a community (Balmford *et al.*, 1998; Cowling *et al*, 1999). This tends to suggest that a pattern-only based approach towards the identification of conservation areas will not guarantee the long-term maintenance of both biodiversity pattern and the processes responsible for that pattern (Nicholls, 1998; Williams, 1998). Conservation of ecosystem processes that sustain ecosystem structure and function, and evolutionary processes that sustain lineages and generate diversity, are essential for achieving the long-term maintenance of biodiversity in conservation areas (Nicholls, 1998; Cowling *et al.*, 1999; Margules & Pressey, 2000). Very little work has been done on the effects of these processes on the continued representation of biodiversity within selected conservation areas. Some initial work has shown that conservation areas based on biodiversity patterns at one moment in time will not continue to represent that biodiversity some years down the line (Rodrigues *et al.*, 2000).

Another shortcoming of this pattern-based approach is that although it focuses on the representation of diversity, this diversity is mostly alpha diversity. Alpha diversity is the number of species within a homogenous community (Whittaker, 1972; 1977); beta diversity on the other hand is concerned with species turnover or the rate at which species are replaced by others along habitat gradients (Whittaker, 1972). This form of diversity is of crucial importance in conservation area identification, as it provides an indication of feature turnover both in space and in time and is an important determinant of regional species richness patterns. Conventional reserve selection techniques aim to represent all species in a complementary fashion based on a brief snapshot of their distribution patterns. However ignoring the dynamic nature of these patterns, as they change through time and space, may result in conservation areas able to represent current biodiversity patterns, but unable to maintain biodiversity in the long-term (Margules *et al.*, 1994b; Virolainen *et al.*, 1999; Rodrigues *et al.*, 2000). Chapter 5 applies spatial surrogates of biodiversity processes and feature turnover in conservation area selection.

Anthropogenic threats

The basic role of conservation areas is to protect elements of biodiversity from external processes and factors that threaten their existence (Margules & Pressey, 2000). Very few of the existing methods for identifying conservation areas include measures of threat into the selection process (Balmford *et al.*, 1998; Faith & Walker, 1996c; Williams, 1998). Some of these threats are natural and include demographic, genetic and environmental fluctuations and stochasticity, which can be further aggravated by human impacts. Most of the threats facing biodiversity today are anthropogenic in origin and include land development and the associated fragmentation, degradation and land transformation, over-exploitation, artificial species introductions and translocations, and pollution (Lande, 1998). Human population expansion and the development of land results in land-cover changes, mainly due to agriculture and urban development, and present the single most important threat to global biodiversity (Soulé, 1991; Dale *et al.*, 1994; Sala *et al.*, 2000).

Many sites identified by traditional conservation area selection procedures as important to biodiversity conservation may in reality be largely transformed and the features said to exist there may now be extinct (especially in the case of historic data) (Wessels *et al.*, 2000 (see Addendum II)). Or else these areas, being so heavily transformed, may not be able to sustain biodiversity features and processes without intensive and costly management (Baudry, 1993; Di Benedetto *et al.*, 1993; Hobbs, 1993; Freemark, 1995; Allan *et al.*, 1997). Methods therefore need to be developed to identify these areas in order to either avoid them in conservation area selection, or if this is not possible, due to high irreplaceability values of particular sites, then to highlight these areas for immediate conservation (Lombard *et al.*, 1997; Nantel *et al.*, 1998; Wessels *et al.*, 2000 (see Addendum II)). Chapter 5 includes land-cover information into conservation area selection in an effort to address this shortcoming.

Development opportunities

The final shortcoming identified in conservation area selection techniques in the present study is the fact that they do not usually allow for the consideration of future development opportunities and their impacts on biodiversity (Dale *et al.*, 1994; Freemark *et al.*, 1995; White *et al.*, 1997; Pressey, 1998). Sustainable development or "development that meets the needs of the present generation without compromising the needs of future generations" was a phrase made familiar by the World Commission on Environment and Development in 1987. This need to simultaneously address environmental and developmental requirements was highlighted. Thus the integration of conservation and development is essential in order to achieve sustainability now and for future generations.

Chapter 5 provides a useful method for the inclusion of current and past land-uses into conservation planning, it is, however, important to remember that human land-use impacts are not static and will continuously expand as populations and their land-use needs evolve. This has important implications for conservation as it increases costs, decreases conservation options and increases the amount of conflict between the various forms of land-use and conservation. It is therefore essential that natural areas with high potential to become transformed by other land-uses be identified as early as possible in order to identify areas where future conflict between such potential developments and biodiversity are likely. A conservation area selection technique which avoids areas that are currently largely transformed, identifies areas crucial to biodiversity conservation and needing immediate intervention (see Addendum II) and also identifies untransformed areas that are suitable for future developments will hopefully contribute to the persistence of regional biodiversity (Pressey *et al.*, 1996; Williams, 1998). A better understanding of the current and future threats facing biodiversity will allow for more effective trade-offs between achieving biodiversity conservation goals and realising development opportunities (Faith, 1995; Faith & Walker, 1996d), as well as a more efficient immediate allocation of limited conservation resources towards areas most at risk (Margules & Pressey, 2000).

Pressey (1997) and Cowling *et al.* (1999) highlight the fact that many of the existing conservation area selection techniques say nothing about the relative needs of areas selected for protection. Funding and resource shortages dictate that although a large number of areas may be identified as important for the representation of biodiversity, only a fraction of them can be protected in the near future. In order to maximise the retention of biodiversity features within a region, one must minimise the extent to which the original representation goals are compromised by habitat loss while the conservation area network is developing (a process that can take decades) (Cowling *et al.*, 1999). It is therefore crucial to identify areas of high conservation value or urgency within this selected set of areas. These are areas with a high biodiversity value, as well as a high threat or vulnerability value (Faith & Walker, 1996c; Pressey *et al.*, 1996; Pressey, 1997; Pressey, 1998; Cowling *et al.*, 1999).

Much work has been done on measuring biodiversity values of areas (Williams *et al.*, 1996; Williams, 1998; van Jaarsveld *et al.*, 1998) and includes measures of biodiversity pattern (Chapters 2, 3

& 4) and biodiversity processes and turnover (Chapter 5) (Pressey, 1994; Pressey *et al.*, 1994; Noss 1996; Balmford *et al.*, 1998; Pressey, 1998; Maddock & du Plessis, 1999; Ferrier *et al.*, 2000; Rodrigues *et al.*, 2000). However, there is a considerable need for work on the inclusion of threat or vulnerability values of areas into conservation planning. (Addendum II; Faith & Walker, 1996c; Pressey *et al.* 1996; Williams, 1998).

Therefore as a final concluding assessment for this thesis, Chapter 6 brings together all the results and outputs of the previous analyses in order to put together a regional multicriteria-based conservation plan for the Northern Province. Using these results it determines the biodiversity values of areas in the province based on measures of biodiversity pattern, process and turnover. It then proceeds to provide threat values for these areas by identifying currently transformed areas as well as untransformed areas suitable for future land-uses in an attempt to include both current and future land-use patterns into conservation area selection. This is done in order to evaluate the threats these existing and future land-uses pose for regional biodiversity and conservation planning. Through the incorporation of threat values into conservation planning Chapter 6 provides an assessment of the relative need of areas with high biodiversity value for immediate conservation action.

Aims

This study therefore aims to address these shortcomings in existing conservation area selection techniques by:

i) Assessing the assumed relationship between indicator taxa and the non-target species they are meant to represent in the identification of conservation areas (Chapter 2).

ii) Evaluating the effects of the different methods of assessment, used in Chapter 2 and other studies, on the validity of indicator taxa as biodiversity surrogates (Chapter 3).

iii) Investigating the value of broad-scale environmental classes as surrogates for regional biodiversity (Chapter 4).

iv) Determining the impact of the inclusion of feature turnover and measures of beta diversity into conservation area selection (Chapter 5).

v) Assessing the value of land-use data in conservation area selection in an effort to minimise threat in conservation areas and highlight areas of potential conflict (Chapter 5).

vi) Identifying currently untransformed areas suitable for alternate land-uses in an effort to identify future land-use threats to biodiversity (Chapter 6).

vii) Finally, through the use of all methods investigated in previous chapters of this thesis, areas with high biodiversity value will be identified. These areas will then be investigated as to their current and potential threat values in an effort to determine their relative conservation urgency (Chapter 6).

Study area

The study area comprises the Northern Province of South Africa, which lies between the lines of latitude 22° 00' S to 24° 00' S, and from 26° 00' E to 32° 00' E. One of the nine provinces of South Africa, it occupies about 10% (122305 km^2) of the country and lies at the northeastern tip of South Africa. It borders on the countries of Mozambique to the east, Botswana to the west and Zimbabwe to the north. Its southern boundary is made up of three South African Provinces, the Mpumalanga, Gauteng and North West Provinces (Figure 1).

The province includes the northern end of the Drakensberg escarpment which separates the low-lying, warm and more humid Lowveld region in the east from the higher lying, drier and cooler Bushveld plateau region in the west (Figure 1). The Limpopo River forms the northern and northeastern boundary of the province where it borders on the neighbouring states of Botswana and Zimbabwe. This Limpopo River valley is separated from the Lowveld and central Bushveld plateau by the Soutpansberg and Blouberg mountain ranges (Figure 1). These mountain ranges are of ecological, economic and social importance. Steep environmental gradients imply a diversity of species and habitat, which in turn implies a high conservation value. In addition, spectacular scenery provides good opportunities for conservation based tourism. The area also has a high potential for forestry and agriculture in places (Butt *et al.*, 1994). An expanding and generally poor human population is an additional feature of these ranges. The Waterberg mountain range falls within the central Bushveld plateau region and together with the escarpment encircles the Springbok flats, a clay substrate basin within the Bushveld plateau with a long history of dryland cultivation (Figure 1).

Climate and vegetation

The climate of the Northern Province is primarily a lowveld dry tropical and dry subtropical one. Rainfall is low, highly variable and seasonal with a distinct dry season during the winter months. Humidity is low and day temperatures are high even in the winter. However, the mountainous areas of the escarpment, Waterberg, Blouberg and Soutpansberg ranges provide marked climatic gradients due to the influence of extreme physiographic relief (Fairbanks, 1997). These mountainous areas have a marked moist tropical to moist subtropical climate with an average to high rainfall that is variable and distinctly seasonal. Here winter minimum temperatures can be low and frost often occurs in valley areas, while humidity can be very high in summer.

The province consists primarily of the savanna biome, with small areas on the escarpment covered by grasslands and forest biomes (Low & Rebelo, 1996). The savanna biome, also referred to as the woodland biome, has a grassland understorey with a woody upperstorey of trees and tall shrubs. Tree cover varies from sparse to almost closed-canopy cover (Rutherford & Westfall, 1986). Grasses are the dominant vegetation in the grasslands biome, with geophytes and herbs also well represented (Low & Rebelo, 1996).

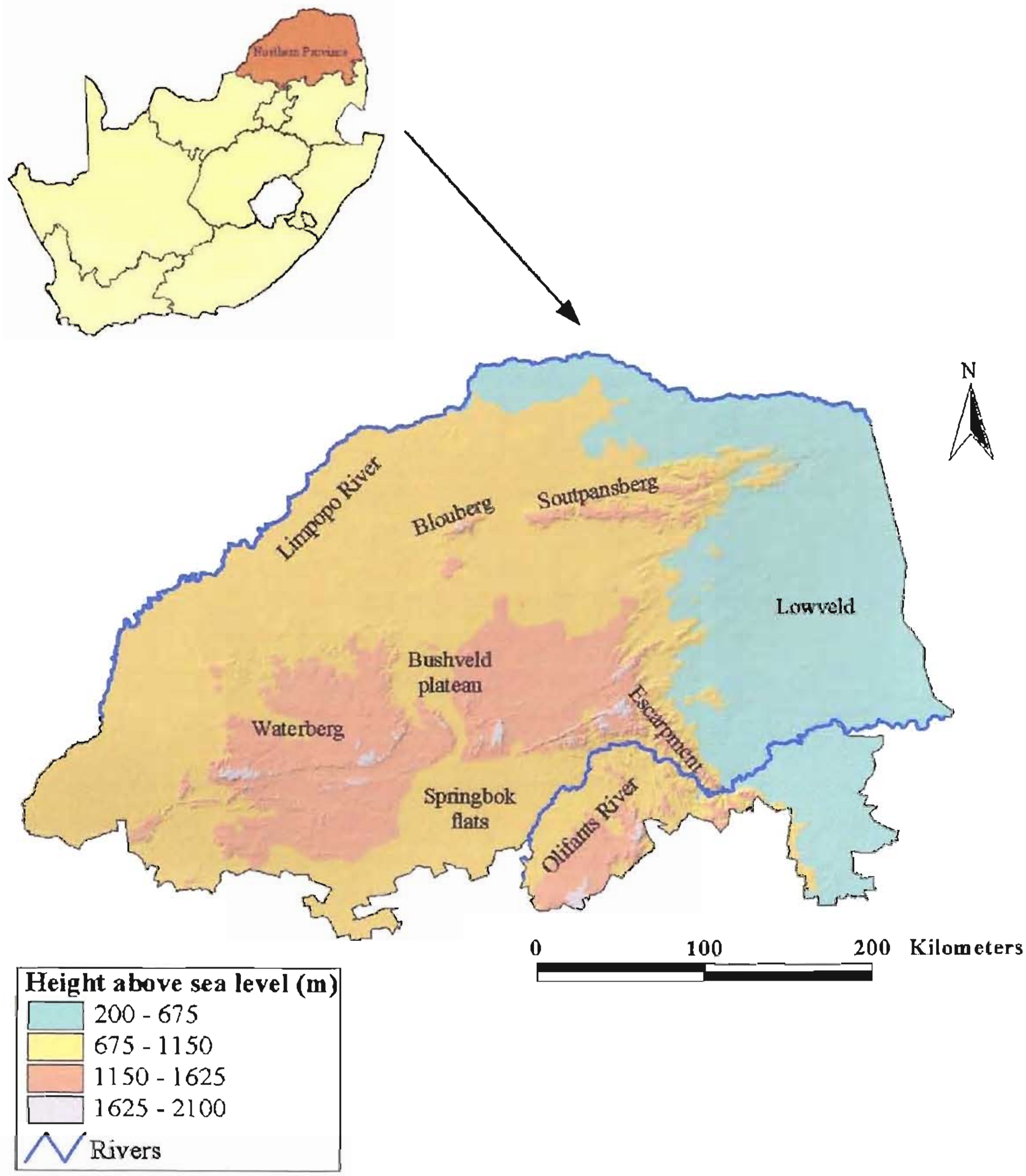

Figure 1: Map of the study area of the Northern Province, showing topography, major rivers, mountain ranges and broad biogeographical zones.

High summer rainfall, frequent fires, frost and grazing are responsible for the exclusion of trees and shrubs and thus the maintenance of these grasslands (Low & Rebelo, 1996). Tree cover in the forest biome is almost continuous and includes mostly evergreen species (Rutherford & Westfall, 1986). Below the canopy vegetation is multi-layered and there is thick leaf litter and little ground vegetation. Forests occur in frost-free regions with high rainfall and infrequent fires. There are 15 recognised vegetation types that fall within the Northern Province of which 12 are within the savanna biome, two within the grasslands biome and one within the forest biome (Table 1; Figure 2).

Current land-uses

The principle urban centres include Pietersburg and Louis Trichardt in the Lowveld, and Tzaneen on the Escarpment (Figure 3). The province includes extensive areas of arable land and as a result 14% of the province has been transformed by cultivation (Table 2; Figure 4). However due to the relatively low rainfall in most parts of the province, dryland cultivation at a commercial scale, which makes up two percent of the total cultivation in the province, is limited to the escarpment, mountainous regions and Springbok Flats, where it is a viable option. In the rest of the province rainfed agriculture is not possible at a commercial scale and is limited to temporary and subsistence level cultivation, making up 38 and 48% of the total area under cultivation in the province respectively. Other areas under cultivation require irrigation. Because of the aridity of the province this form of cultivation is very limited making up three percent of the total cultivation at a commercial level and eight percent at a temporary level (Table 2; Figure 4).

Urbanisation (1.6%) and forestry plantations (0.8%) account for the remaining land transformations (Thompson, 1996; Fairbanks *et al.*, 2000). Therefore the study area has not been excessively degraded and transformed since 73% is still covered by natural vegetation and 11.36% is under formal protection in provincial and national protected areas (Figure 4). This large amount of protected area coverage is due mostly to the Kruger National Park, a National Park with an area of 19600 km^2 of which just over 50% falls within the Northern Province (Figure 3). There are about 50 other formally protected provincial and national parks in the Northern Province (Figure 3) (DEAT, 1996).

Potential land-uses

Although current land-use impacts on the province have been of a restricted nature, taking into consideration South Africa's expanding human population and the likely increased demands on land and resources, it can be expected that land-use impacts will increase. The ability to identify currently untransformed areas where these land-uses will be expected to impact is of critical importance for the maintenance and future protection of biodiversity. Afforestation, cultivation and mining are considered to be major land-uses that threatened biodiversity.

Table 1: Vegetation types, the biomes in which they occur and the extent of each within the Northern Province. (Low & Rebelo, 1996)

Vegetation types	Biomes	Area (km^2)	%
Afromontane Forest	Forest	242.11	0.20
Clay Thorn Bushveld	Savanna	8328.83	6.78
Kalahari Plains Thorn Bushveld	Savanna	110.15	0.09
Lebombo Arid Mountain Bushveld	Savanna	438.44	0.36
Mixed Bushveld	Savanna	35065.86	28.54
Mixed Lowveld Bushveld	Savanna	9327.76	7.59
Moist Sandy Highveld Grassland	Grassland	47.15	0.04
Mopane Bushveld	Savanna	20532.01	16.71
Mopane Shrubveld	Savanna	2590.80	2.11
North-eastern Mountain Grassland	Grassland	3800.49	3.09
Sour Lowveld Bushveld	Savanna	7788.47	6.34
Soutpansberg Arid Mountain Bushveld	Savanna	4788.61	3.90
Sweet Bushveld	Savanna	17212.01	14.01
Sweet Lowveld Bushveld	Savanna	250.01	0.20
Waterberg Moist Mountain Bushveld	Savanna	12356.45	10.06

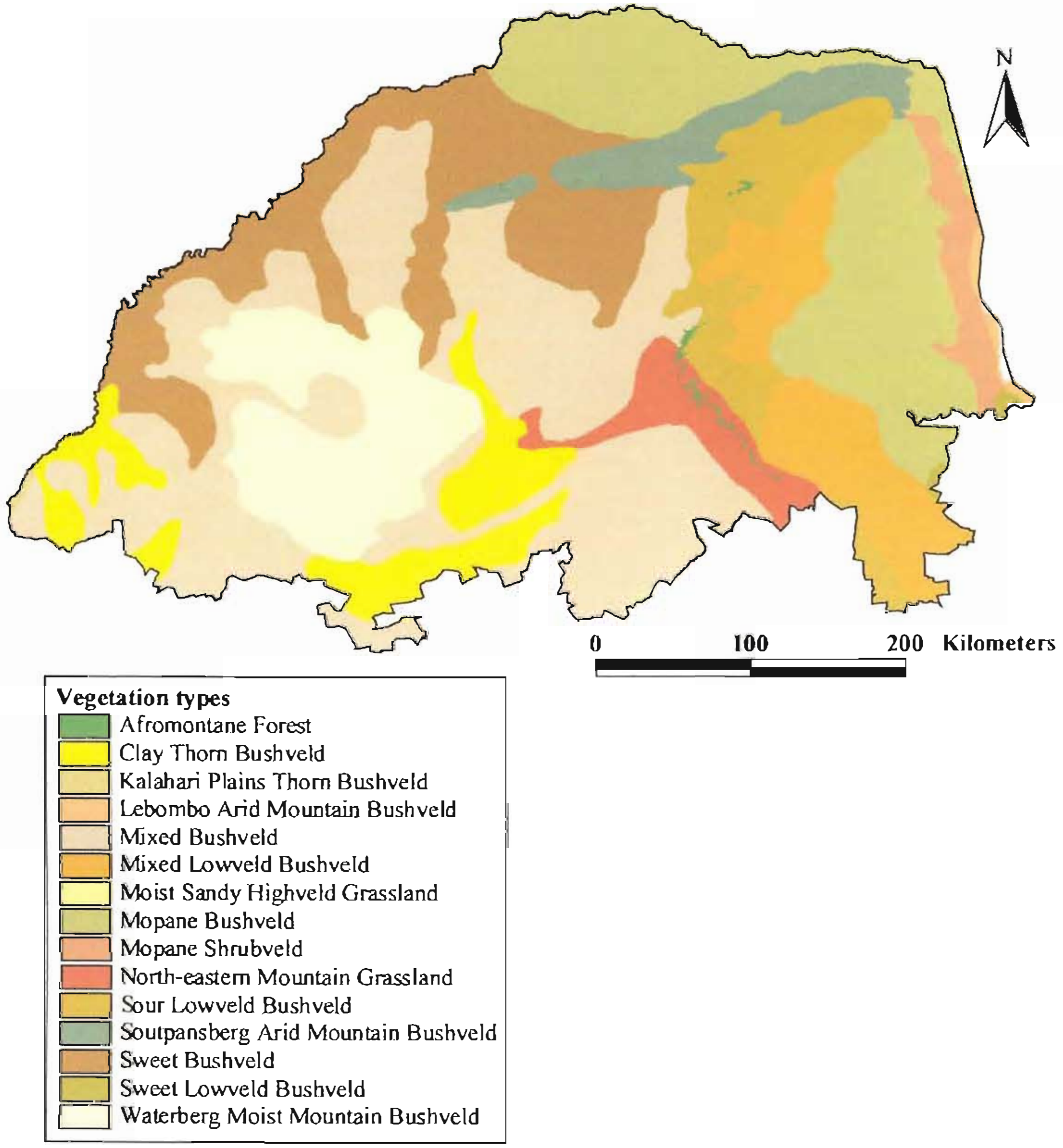

Figure 2: Vegetation types of the Northern Province as defined by Low and Rebelo (1996).

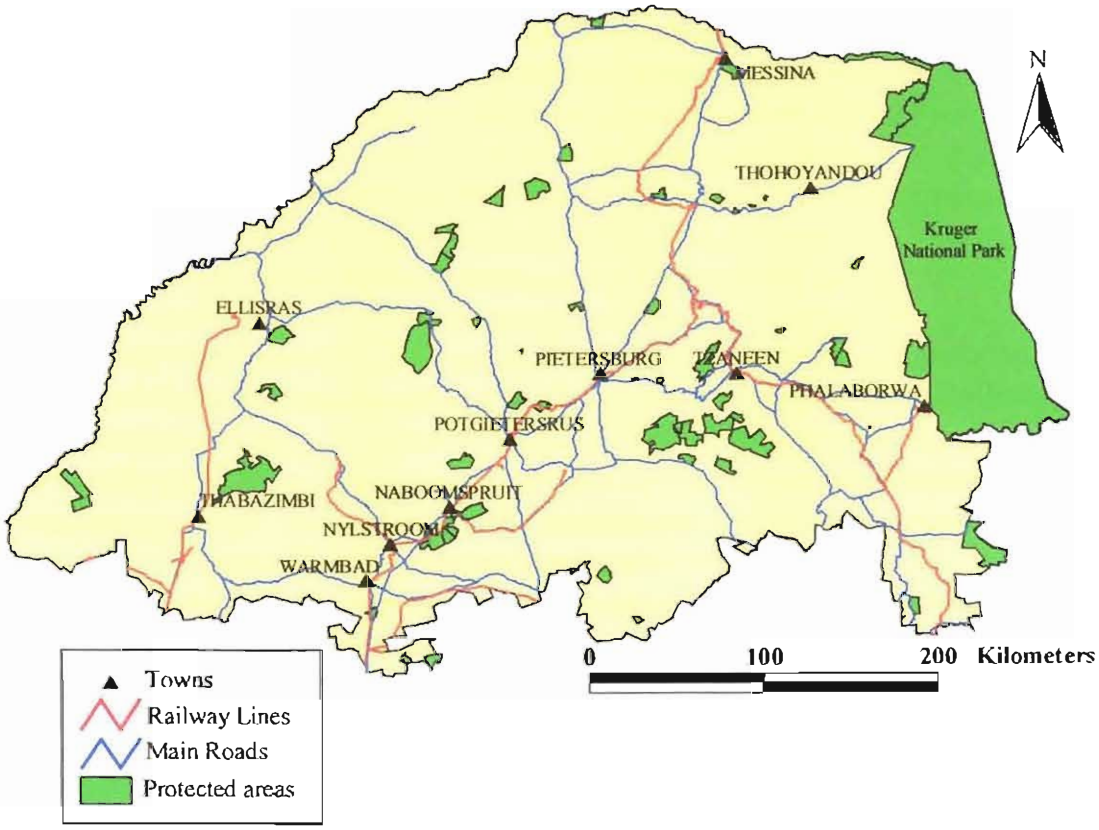

Figure 3: Map of the study area showing towns, transport routes and national and provincial protected areas.

Table 2: Areas of land-cover categories in the Northern Province of South Africa, illustrating the percentage coverage of each category within the province (extracted from Fairbanks *et al.*, 2000).

Land-cover category	**Area (km^2)**	**%**
Barren rock	65.96	0.05
Cultivated: permanent - commercial dryland	411.37	0.34
Cultivated: permanent - commercial irrigated	587.04	0.48
Cultivated: permanent - commercial sugarcane	0.00	0.00
Cultivated: temporary - commercial dryland	6599.67	5.39
Cultivated: temporary - commercial irrigated	1606.17	1.31
Cultivated: temporary - semi-commercial / subsistence dryland	7999.27	6.53
Degraded: herbland	0.00	0.00
Degraded: forest and woodland	6476.89	5.29
Degraded: shrubland and low fynbos	0.00	0.00
Degraded: thicket and bushland (etc)	5515.35	4.51
Degraded: unimproved grassland	150.43	0.12
Dongas and sheet erosion scars	77.77	0.06
Forest	376.50	0.31
Forest and Woodland	40165.35	32.81
Forest plantations	992.36	0.81
Herbland	0.00	0.00
Improved grassland	3.89	0.00
Mines & quarries	145.13	0.12
Shrubland and low Fynbos	29.43	0.02
Thicket and bushland (etc)	47792.13	39.04
Unimproved grassland	1359.51	1.11
Urban / built-up land: commercial	14.60	0.01
Urban / built-up land: industrial / transport	27.75	0.02
Urban / built-up land: residential	1727.05	1.41
Urban / built-up land: residential (small holdings: bushland)	60.02	0.05
Urban / built-up land: residential (small holdings: grassland)	0.00	0.00
Urban / built-up land: residential (small holdings: shrubland)	0.05	0.00
Urban / built-up land: residential (small holdings: woodland)	84.34	0.07
Waterbodies	128.16	0.10
Wetlands	17.60	0.01

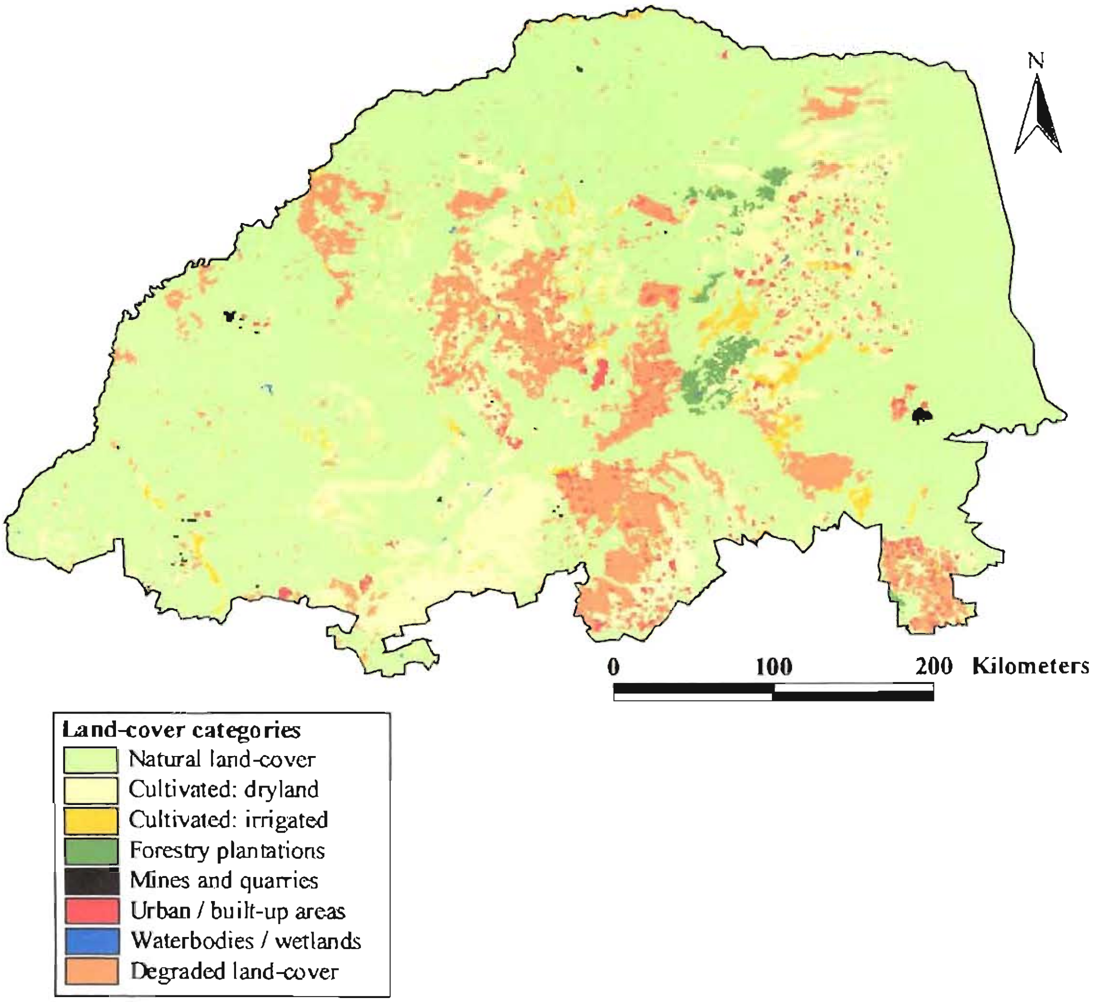

Figure 4: Land-cover categories of the Northern Province, illustrating natural, transformed and degraded land-cover.

The Northern Province, being a low rainfall area, does not contain much potential for further afforestation or dryland cultivation, except through specialised species (Fairbanks, 1997).

The Northern Province, although not one of the most important mining provinces in South Africa, is still particularly dependent on the contribution of the mining sector. The province's export and local mineral sales made up 10% of South Africa's sales for 1995 (Wilson & Anhaeusser, 1998). There are however, several mineral and dimension stone fields, provinces, as well as deposits within the province that still remain unexploited (Figure 5) (Wilson & Anhaeusser, 1998). The effects of the potential mining of these areas on surrounding environments and biodiversity should be carefully considered.

Finally, 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). 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. 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.

Therefore the potential impacts of expanding areas under cultivation or forestry plantations, mining developments, as well as the effects of road networks on biodiversity within the province are an essential component of real-world conservation planning.

Databases

Several forms of data were employed in this study including species distribution data for a variety of taxa, broad-scale environmental data (e.g. vegetation types), current land–cover data and various potential land-use datasets.

Species distribution data

Species distribution data for the Northern Province, as well as the rest of South Africa, are only available at a quarter degree grid cell resolution. These 15' x 15' cells measure approximately 700 km^2 in the province. Information on species presence within these grid cells (n = 215) were collated for birds (Aves), butterflies (Lepidoptera: superfamilies Hesperioidea, Papilionoidea), buprestid beetles (Buprestidae), scarab beetles (Scarabaeinae), Termites (Isoptera), mammals (Mammalia), Neuropterans (Myrmeleontidae) and vascular plants (Plantae) (Table 3). Information on avian distribution was collated from the South African Bird Atlas Project (Harrison, 1992; Harrison *et al.*, 1997).

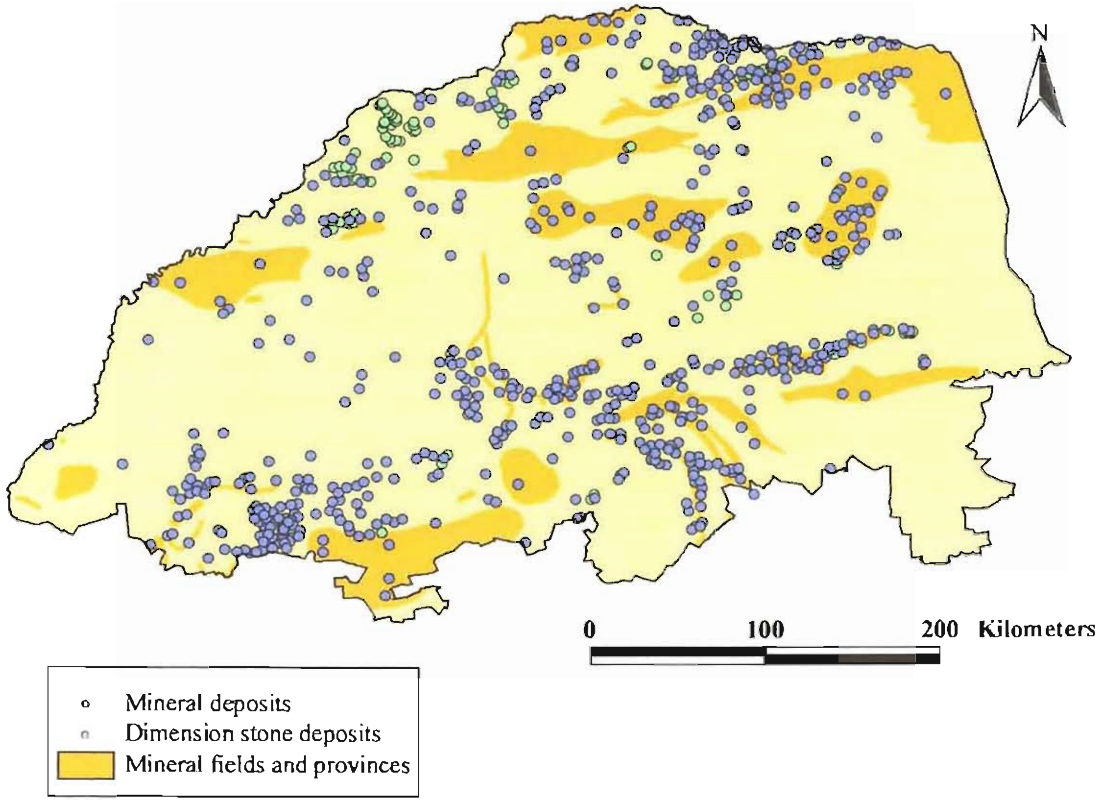

Figure 5: Mineral fields, provinces and deposits as well as dimension stone deposits in the Northern Province.

The presence/absence of 574 avian species, which comprise 60% of the bird diversity recorded in the Southern African sub-region (South Africa, Lesotho, Swaziland, Namibia, Botswana, Zimbabwe and southern Mozambique), was recorded from 1980 – 1992. This is the only true presence/absence species database available for South Africa and thus results based on other databases should be treated with caution due to the prevalence of false absences in what are actually presence only databases.

Mammal distribution data were based on primary data collections and species lists of the National Flagship Institute (formerly the Transvaal Museum), United States National Museum African Mammal Collection, National Parks Board (specifically the Kruger National Park), the South African Defence Force, KaNqwane Parks, Rautenbach (1982) and other published and unpublished records (Freitag *et al.*, 1996). These data varied in resolution from point localities to grid cell data of varying resolutions and were therefore generalised to quarter degree grid cells, a grid size determined by the coarsest data resolution. These taxa are all well surveyed within the study area and reflect little survey bias (Harrison, 1992; Freitag & van Jaarsveld, 1995; Freitag *et al.*, 1998)

An extensive butterfly distribution data set as well as buprestid, scarab, termite and neuropteran data sets were collated for South Africa from National Flagship museum records. Sampling localities were transformed to 15' x 15' grid cells with the aid of a gazetteer, resulting in unique distribution records for 613 butterfly, 247 buprestid, 218 scarab, 16 termite and 22 neuropteran species in South Africa (Freitag & Mansell, 1997; Hull *et al.*, 1998; Muller, 1999; Koch *et al.*, 2000). Much work has been done on the systematics and distribution of South African Lepidopterans and only a few remain undescribed (<5%, Owen, 1971). However, the rest of the invertebrate taxa, as is the case for many distribution databases worldwide, are poorly known taxonomically and have biased survey records (Freitag & Mansell, 1997; Hull *et al.*, 1998; Muller, 1999; Koch *et al.*, 2000); their use was therefore limited within this study.

The National Botanical Institute collated higher plant species distribution records at the quarter degree grid cell resolution. These records include 42055 unique distribution records for 5711 species. However a data set of this size sets unattainable formal conservation goals, requiring over 50% of the study area to represent all species only once (Chapter 4). Therefore only endemic plant species (species that were not recorded outside of the former Transvaal Province) were included in the analyses. It is important to note that throughout this study species distribution data, as well as many other forms of spatial data, were collated at a quarter degree grid cell resolution, an area of approximately 700 km^2. It has been demonstrated that the spatial scale of biological data will affect conservation planning outputs, as well as evaluations of congruency and prediction accuracy of indicator groups (Pearson & Carroll, 1999; Schwartz, 1999). However, this is the best available data for the study region and is still useful in illustrating basic trends and principles. It is important to remember that these analyses highlight large areas of conservation importance, which can then be investigated at a local scale.

Table 3: Species distribution data

Taxon	Unique records	Unique species	Rare species	Endemic species	Grids surveyed	Survey date
Well known taxa						
Birds (Aves)	49089	574	141	63	214 (99%)	1980-92
Butterflies (Hesperioidea & Papilionoidea)	2062	328	79	4	84 (39.1%)	1905-80
Mammals (Mammalia)	5218	214	56	1	183 (85.1%)	1980-95
Endemic vascular plants (Plantae)	2694	472	125	472	190 (88.4%)	1900-96
Combined	*59063*	*1588*	*353*	*540*	*215 (100%)*	
Less well known taxa						
Buprestid beetles (Buprestidae)	977	247			119 (55%)	1900-96
Scarab beetles (Scarabaeinae)	1372	218			124 (58%)	1900-92
Termites (Isoptera)	464	16			160 (74%)	1972-80
Neuropterans (Myrmeleontidae)	126	22			41 (19%)	1900-96
Combined	*2939*	*503*			*194 (90%)*	
Total combined	*61975*	*2091*			*215 (100%)*	

Vegetation data

Shortcomings with species distribution data as a useful measure of biodiversity have led to a shift in the focus for conservation. This has resulted in recommendations towards a more holistic approach of protecting biodiversity in the aggregate, the so-called 'coarse-filter' approach (Noss, 1990; 1996). The goal of coarse-filter conservation is to preserve all or most species in a region by protecting sufficient (>20000 ha) samples of every plant community type (Scott *et al.*, 1993). Other hierarchical methods have included species assemblages, land facets, or landscapes (Pressey 1994b; Pressey & Logan, 1994; Wessels *et al.*, 1999; Fairbanks & Benn, 2000).

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 and was employed in the present study. The vegetation types within the study region have already been described in Table 1.

In a recent study on the threat status of the vegetation types of South Africa (see Addendum I), four of the vegetation types found within the Northern Province (Kalahari Plains Thorn Bushveld, Clay Thorn Bushveld, Mixed Bushveld and Sour Lowveld Bushveld) fell within the top 20 most threatened vegetation types within South Africa. This is due to a combination of large transformed and degraded areas and few protected areas within the vegetation type.

Environmental data

In the assessments requiring environmental data, the factors and processes that have been hypothesised to account for spatial patterns of species diversity are climatic extremes, climatic stability, productivity, and habitat heterogeneity (Brown, 1995; Wickham *et al.*, 1997). Data were compiled from existing sources to represent these factors (Table 4), including interpolated weather stations (Schulze, 1998) and topographic contours (SA Surveyor General, 1993a) mapped in a geographic information system (GIS; ESRI 1998) using Albers equal area projection. This GIS database had a grid cell resolution of 1km x 1km, which was determined by the cell size of existing rasterised data sets and a cell size that could be used in future analyses.

Land-cover data

Current land-cover data

The recent advent of the National Land-cover database (NLC) has allowed for national level assessments of current land-cover in South Africa. This national database was derived using manual photo-interpretation techniques from a series of 1:250000 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 future analyses in the present study the 31 land-cover classes (Table 2) were reclassified into three categories: natural, degraded and transformed land-cover (Table 5; Wessels *et al.*, 2000 (see Addendum II)). 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). Grazed areas are not included in this degraded category, unless they are severely over-grazed. In general it can be assumed that all areas of remaining natural vegetation are rangelands used for either domestic or wild livestock grazing. 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.

Potential land-cover data

Potential land-cover data were obtained from multiple sources. Potential afforestation was determined by bioclimatic prediction (BIOCLIM) and fuzzy sets logic modeling (Fairbanks, 1997; Fairbanks & Smith, 1995) based on soil information and bioclimatic parameters (e.g. growth days and growth temperature). These variables were provided by Centre for Computing and Water Research (University of Natal) and the ARC - Institute for Soil, Climate and Water. Suitability for agriculture was calculated for both rain-fed and irrigated cultivation by the Institute for Soil, Climate and Water, using data on soil patterns, rainfall, slope and water availability (Schoeman *et al.*, 1986; Smith, 1998).

In the past, suitability mapping was based on Boolean operations, regression models and expert estimates for classifying areas of land. An area was tested on its attribute values as to whether it fell within each set or not, and any entity not matching all criteria was rejected. However, this method assumes that real world criteria can be modelled as discrete entities with exact attributes, and in reality most environmental questions are more complex than this.

Table 4: Codes and definitions of environmental variables used.

Code	**Definition**
Topography	
DEMMEAN	Elevation (m)
DEMSTD	Elevation heterogeneity (std. Deviation)
Climate	
GDMEAN	Number of days per annum on which sufficient water is available for plant growth
MAP	Mean annual precipitation (mm)
GTMEAN	Annual mean of the monthly mean temperature (°C) weighted by the monthly GD
NGTMEAN	Mean temperature (°C) during negative water balance
MAT	Mean annual temperature (°C)
MAXMNTHMN	Mean temperature of the hottest month, usually January (°C)
MINMNTHMN	Mean temperature of the coldest month, usually July (°C)
EVANNMN	Total annual pan evapotranspiration (mm)
PSEAS_MN	Precipitation seasonality from the difference between the January and July means
TSEAS_MN	Temperature seasonality from the difference between the January and July means
MXSEAS_MN	Maximum temperature seasonality from the difference between January and July

Table 5: Land-cover classes reclassified into broad categories (after Wessels *et al.*, 2000 (see Addendum II)).

Transformation category	**% Area occupied in Northern Province**	**Land-cover class**
Natural land-cover	73.36	Wetlands, grassland, shrubland, bushland, thicket, woodland, forest
Degraded land-cover	10.09	Degraded land, erosion scars, waterbodies
Transformed land-cover	16.55	Cultivated lands, urban/built-up areas, mines and quarries, forestry plantations

In addition, because spatial variation is not directly measurable in its entirety but is reconstructed from point data, the resulting input attributes will have errors, this is especially a problem for attributes with values near the boundaries of the sets. The replacement of Boolean sets with fuzzy sets (or continous classes) replaces the finite boundary of the Boolean set with a gradual transition zone, and allows for partial set membership. This then prevents the exclusion of attributes with values just outside the class boundaires. As Fairbanks (1997) points out the use of strict Boolean algebra with simple TRUE/FALSE logic is inappropriate for land suitability evaluation, because of the continuous nature of environmental data and the inexactness of formulating queries.

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 (road-effect zone) can be used as an ecological indicator that directly represents impacts on biodiversity. The affected distances were estimated in a hierarchical fashion from the reviews mentioned above, as well as from local studies (Milton & Macdonald, 1988). National routes and freeways were assumed to affect biodiversity for a greater distance from the roadway (1km on each side) than farm roads (100 m; Table 6). Road segments from the South African Surveyor General (1993b) 1:500000 scale map series files (SA Surveyor General, 1993b) were buffered in a standard geographic information system operation to the distance related to its class (Figure 6). 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.

Geographic Information Systems (GIS) analysis

The species distribution data collated at a quarter degree grid cell resolution was the coarsest resolution data used within the study and therefore determined the resolution of the remaining data. Thus the vegetation, land-cover and environmental data were overlaid with the 15' x 15' grid (Figure 7). An aggregated mean statistic was recorded for each grid cell for the vegetation, environmental and topographical features found within that grid cell. The extent of current and potential land-cover classes, as well as national and provincial protected areas within each grid cell was calculated using ArcInfo. All GIS analyses were conducted in ArcView and ArcInfo (ESRI, 1998) in Albers equal area projection, with Spheroid Clarke 1880 and using the parameters of reference longitude 24° 00' 00" E and standard parallels of -18° 00' 00"S and -32° 00' 00" S.

Conservation area selection

Traditional methods of conservation area selection comprising identification of hotspots of species richness and rarity were used for some aspects of this study (Williams, 1998). However, complementarity-based iterative algorithms were the chief conservation area selection tool employed (Nicholls & Margules, 1993).

Table 6: 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

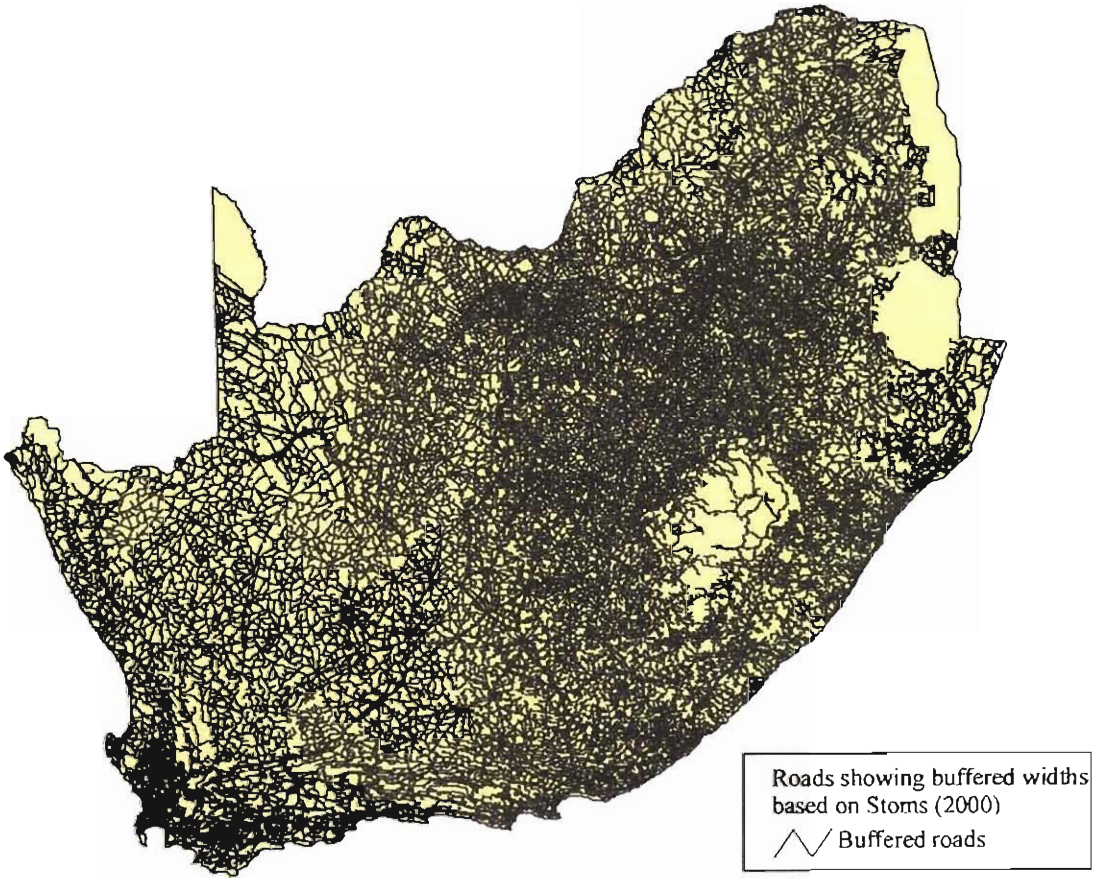

Figure 6: Buffered road network of South Africa.

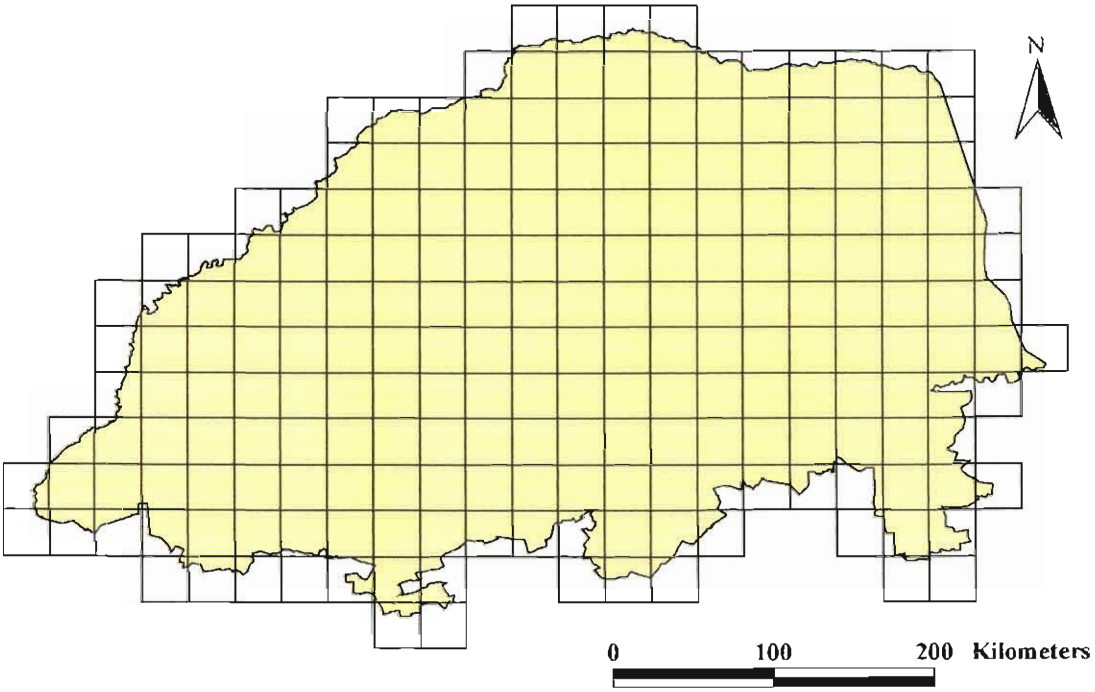

Figure 7: Quarter degree grid cells (n = 215) of the Northern Province.

Basic richness- and rarity-based algorithms were programmed and used in many of the analyses. These algorithms were adapted and reprogrammed to meet the requirements of later analyses. An iterative algorithm able to represent a specified percentage of broad-scale surrogate classes was programmed and used in Chapters 4 and 6. Additional adaptations are described in more detail in Chapters 5 and 6 and Addendum II, and include reprogramming for the incorporation of land-use information and beta diversity into conservation area selection. In most cases a 25 to 50% level of preselection was employed. This implies that any biodiversity feature occurring in a site more than 25 to 50% protected is assumed to be already represented and is excluded from future selection.

The terms reserve network, conservation area, priority conservation area and protected area all refer to existing or identified sites for the conservation of biodiversity. These areas include existing formal protected areas (IUCN categories I and II) as well as areas identified as important to biodiversity conservation by this study. The areas identified can then be formally protected or, in the case of land and budgetary constraints, rely on some form of off-reserve management (Pressey & Logan, 1997).

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