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A Co-evolutionary Landscape Ecology Framework for Analyzing Human Effects on KwaZulu-Natal Province Landscapes and its Relevance to Sustainable Biodiversity Conservation

by

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A Co-evolutionary Landscape Ecology Framework for Analyzing Human Effects on KwaZulu-Natal Province Landscapes and its Relevance to Sustainable Biodiversity Conservation

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Abstract

The conservation of biotic diversity is a growing challenge within southern Africa at the beginning of the 21st century. Growing populations and trends toward a questionable Western development model place demands on the use of land for food, fiber, and fuel production. The traditional establishment and use of formal conservation areas is being challenged against the needs of humans and the past unbalances created by colonial rule. Conservation areas, as isolated islands in a sea of change driven by interconnected economic and social systems, may not be a basis for sustainable biodiversity conservation. This thesis examines characteristics of avian species diversity response to abiotic environmental variables and land transformation. Environmental and land-use correlates of species gradients, species diversity patterns, and the spatial patterning of bird assemblages varied with location. The findings supported a conceptual model of multi-scaled controls on bird distribution, and the related notion that local community structure is the result of both regional environmental and local-scale landscape pattern that must be taken in to account in regional conservation planning assessments. An analytical framework including an landscape model, use of complementary-based reserve selection procedures, gradient analysis, and inclusion of the total spatial economy and development needs of the KwaZulu-Natal Province proved to be important for developing an integrated conservation plan for sustainable avian conservation. Pattern recognition results of the spatial economy and landscape pattern revealed the strong dichotomy in Western economic versus rural African landscapes, which have lead to strong differences in avian assemblage patterns. The research described in this thesis targets specific objectives of the Sustainable Biosphere Initiative by addressing requirements for landscape level analysis of humans and ecosystems in an integrated analytical framework. The development of a co-evolutionary landscape ecology framework for examining human-ecosystem interaction provides a strong basis for supporting targeted conservation planning within regions rather than supporting a generic conservation planning framework.

Keywords: biodiversity, birds, conservation, co-evolution, landscape ecology, gradients, spatial statistics, sustainability, KwaZulu-Natal Province, South Africa.

Disclaimer

This thesis consists of a series of chapters and appendices that have been prepared for submission to, or publications in, a range of scientific journals. As a result, styles may vary between chapters and appendices in the thesis and overlap may occur to secure publishable entities.

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Preface

The following is from a dialog between the late American journalist Bill Moyers and the late Joseph Campbell, which seems to me to nicely tie together one of the great issues of society and sustainable ecological management:

> *Moyers*: Zorba says, "Trouble? Life is Trouble."
>
> *Campbell*: Only death is not trouble. People ask me, "Do you have optimism about the world?" And I say, "Yes, it's great just the way it is. And you are not going to fix it up. Nobody has ever made it any better; it is never going to be any better. This is it, so take it or leave it. You are not going to correct or improve it."
>
> *Moyers*: Doesn't that lead to a rather passive attitude in the face of evil?
>
> *Campbell*: You yourself are participating in the evil, or you are not alive. Whatever you do is evil for somebody (or something). This is one of the ironies of the whole of creation (and the paradox of management).
>
> *Moyers*: What about this idea of good and evil in mythology, of life as a conflict between the forces of darkness and the forces of light?
>
> *Campbell*: ...In other traditions, good and evil are relative to the position in which you are standing. What is good for one is evil for the other. And you play your part, not withdrawing from the world when you realize how horrible it is, but seeing that this horror is simply the foreground of a wonder.
>
> Joseph Campbell, *The Power of Myth*, 1988.

Therefore, for conservationists and others engaged in issues of sustainability though the situation in the world may look sorrowful, it is necessary to participate in the game. It wouldn't be life if there were not temporality involved, which is sorrow—loss. It is a wonderful opera set on a diverse geographic backdrop—except that it hurts. Within conservation and sustainability circles we must affirm that this is the way it is, the challenges with re-integrating societies goals with the requirements of ecosystems will not be won or lost, but will evolve through knowledge to something that is better than it was before but never to the level that we want it to be. Affirmation is difficult, and as a discipline, we are always trying to affirm with conditions (i.e., I will affirm the world on condition that it gets to be the way Aldo Leopold said it ought to be). By accepting the evolution of societies and ecosystems and our role as conservationists, landscape ecologists, and geographers as adding components to its guidance, we will be able to make a difference in creating future landscapes with a level of ecological integrity acceptable for that time. This may be all we can accomplish, however this is a tremendous amount to accomplish, and therefore should not be seen as a loss. This thesis work provides empirical evidence of how the human socio-economic-political and ecosystem response game has been played so far in the KwaZulu-Natal Province, South Africa.

1. Introduction

This thesis examines the co-evolutionary nature of human development on landscapes and the consequent shaping of species assemblages, which affect biodiversity conservation strategies in Southern Africa. A model is proposed to address the development nature of humans on the environment. Where this model may fit into current conservation biology principles and within the field of landscape ecology is discussed. This study then moves into a series of examinations of the landscapes of KwaZulu-Natal Province, South Africa, focussing on an assessment of avian diversity conservation, human development patterns, and human action in shaping avian communities, and an application of a co-evolutionary development model.

Techniques used include complementary-based reserve selection algorithms, ecological gradient analysis, pattern recognition programs, multivariate statistics, spatial statistics, geostatistics, and mathematical transformations of species assemblage data. Timely data products, such as the *South African National Land-cover database* (Fairbanks et al., 2000), the *1996 South African Population Census* (Stats SA, 1998), and the *1997 KwaZulu-Natal Sustainability Indicators Project* (Kok et al., 1997), which records the regions socio-economic and development status, were used to develop causal relationships. The 1997 *Atlas of Southern African Birds* (Harrison et al., 1997), representing the results from the largest biological inventorying project conducted in Africa, and its predecessor, the 1980 *Bird Atlas of Natal* (Cyrus and Robson, 1980) covering Natal and Zululand, are used as the biological relation to the biophysical and human development patterns.

A number of analyses are performed to describe attributes of the biodiversity hierarchy (Noss, 1990) that are affected by evolved human development patterns, including impact on avian distributions, avian diversity variation, and spatial autocorrelation. The organization scales of landscapes, communities, and species were studied in order to describe and attribute their dynamics to human disturbance gradients. Typically, effort is given to studying structure when assessing regions for biodiversity conservation, but this falls short of the main issue of functioning, which is a dynamic product of changes in structure. This research targets specific objectives of the Ecological Society of America's Committee on the Application of Ecological Theory to Environmental Problems by addressing requirements for understanding and monitoring changes in biodiversity associated with land-uses that are specifically associated with human dimensions of global change (National Research Council, 1994; Lubchencho et al., 1991). These include three ecological problems at two different levels of organization:

- **Community Level**
    - Community structure: What do the collective properties of communities, including various community indices, tell us about their functioning?
    - Biotic diversity: What are the patterns, causes, and consequences of spatial and temporal variation in species diversity?
- **Intra-ecosystems Level**
    - Landscape ecology: How do land-use patterns influence the ecology of component systems, including all levels of ecological organization up to the scale of the landscape itself?

The biodiversity databases used in this study are of a coarser resolution than could be implemented for local conservation assessment. The described research, however, may provide a valuable foothold for identifying commonalities in the biodiversity pattern-abundance, spatial expression of land-use/land-cover classes, and relevant information, for the multistage effort that would be required by such a local conservation assessment and planning effort. The application of a number of different analysis strategies on the same data sets provides greater opportunity for comparison and understanding than is available from the numerous unrelated case studies, which have been performed to date. Typically, these case studies employ a presence/absence species database with a standard land-cover map, are limited by geographical variability in biological, environmental and human response, treat human impacts in a limited fashion, and reflect on only a local subset of the possible universe of human-ecosystem responses. Though this study will be limited by many of the same considerations, the results provide a starting point from which to assess the validity of applying general systematic reserve selection schemes to the developing areas of Southern Africa.

1.1 Current Biodiversity Conservation Strategies

Conservation planning strategies rely on several contested methods (e.g., Mace et al., 2000) to provide the best case for conservation action. These include complementary-based reserve selection algorithms, gap analysis, species richness "hot spots", keystone species surrogates, and environmental surrogates.

In the last decade, the conservation community has made significant contributions to developing systematic reserve selection procedures (Bedward et al., 1992; Church et al., 1996; Csuti et al., 1997; Freitag and van Jaarsveld, 1995; Kirkpatrick, 1983; Lombard, 1995; Margules et al., 1988; Nicholls and Margules, 1993; Pressey et al., 1996; Rebelo and Siegfried, 1992). Conceptually, the need for systematic approaches to represent the protection of as many natural features (i.e., species, communities, or environments) as possible is well acknowledged. The use of the principles of complementarity, flexibility, and irreplaceability (see Pressey et al., 1993) for selecting priority regions and regional reserves makes for computationally elegant solutions. These protocols for priority conservation area selection, however, have several weak points: use of poorly surveyed taxa or habitat databases (Maddock and du Plessis, 1999); use of dangerously simple surrogate information (Faith and Walker, 1996a; Reyers et al., 2000); and more to the point, the efforts to date have generally not taken into account human influences, landscape pattern and processes. The systematic conservation techniques could also ignore interrelated attributes and feedback's that a more thoughtful and comprehensive approach might illustrate. In some cases, the spatial pattern of development in an area might be biodiversity "friendly" (e.g., Gadgil et al., 1993; Norgaard, 1994; Dahlberg, 1996; Fairhead and Leach, 1996; Zimmerer and Young, 1998; Shackelton, 2000) and have evolved with the resident human culture, but would not be acknowledged in formal protection based approaches. Increasingly, the shortcomings of the systematic reserve selection concepts to take into account the current or future biological sustainability of the areas selected, or to have the ability to spread the risk of species extinctions through proper spatial planning, is becoming evident.

Biological conservation strategies have traditionally centered on biological reserves, where a reserve is 'an area with an active management plan in operation that is maintained in its natural state and within which natural disturbance events are either allowed to proceed without interference or are mimicked through management' (Scott et al., 1993). The gap analysis school of biodiversity protection planning attempts to identify the gaps in representation of biological diversity in areas managed exclusively or primarily for the long-term maintenance of populations of native species and natural ecosystems. It is proposed that once identified, gaps be filled through new reserve acquisitions or designations, or through changes in management practices. The goal is to ensure that all ecosystems and areas rich in species are represented adequately in protected areas. Whereas the complementary reserve selection concept is an elegant and logical solution, though unrealistic, the gap analysis procedure is simple, scale dependent, and assumes that large tracts of land are still available for conservation. Large reserves (e.g., > 10 000 ha) are the most common strategy to maintain biotic communities over long periods in areas undergoing large-scale conversion from natural vegetation to agricultural and urban systems (Shafer, 1990; Noss et al., 1997). The gap analysis procedure can make only a partial contribution within South Africa since the vast majority of land is under communal or private tenure (see Christopher, 1982), highly fragmented in the ecologically important biomes (see Fairbanks et al., 2000), and the methodology does not provide for a representative (e.g., species, habitat) system. In areas of extensive habitat conversion, as found in parts of South Africa, the design of reserve systems is typically based on a model of reserves as isolated islands of habitat for native species (e.g., Rebelo and Siegfried, 1992; Lombard et al., 1997). The ultimate viability of a reserve system, however, is based on the size, shape, and connectedness of these remnant habitat areas (Forman, 1995; Fahrig, 1997), which should be designed within associated environmental processes (e.g., Cowling et al., 1999).

To be sure, the most important consideration, which is typically ignored, in any of these systematic methodologies is the role human societies, values, and economics play as threats and protectors to biodiversity. A logical framework for understanding human threats has not been considered in species or broad model approaches, but are root causes of the loss of biodiversity (Ehrlich and Wilson, 1991). Conservation planning needs to incorporate socio-economic variables, as well as the landscapes, ecosystems, and species of an area, to be relevant within developing countries. The case for integrated conservation planning in developing countries must take into account all factors inherent in and relevant to the landscape environment, which includes human needs. The importance of flexibility in conservation planning becomes important in discussing issues of persistence, since there are typically many different complementary networks, these can be exploited to reveal those networks that are currently sustainable based on their socio-economic, cultural, and landscape ecological situation.

1.2 Biodiversity Conservation Strategies in the Modern African Context

This thesis is concerned with the issue of sustainable biological conservation within southern Africa. In 1995, South Africa signed and ratified the *United Nations Convention on Biological Diversity* (UNCED, 1992), its objectives are: the conservation of biodiversity, the sustainable use of biological resources, and the fair and equitable sharing of benefits arising from the use of genetic resources. In 1997, the published response to this signing became the policy and strategy document *White Paper on the Conservation and Sustainable Use of South Africa's Biological Diversity* from the national government (South Africa, 1997). Internationally and nationally, it is acknowledged that if there is to be global cooperation to conserve biodiversity, recognition needs to be given to its uneven distribution around the world:

> 'Two-thirds of the world's biodiversity is located in developing countries, collectively termed "The South", and provides an important resource for the economic development of such countries. Biodiversity conservation thus carries a heavier burden for developing countries than for the biologically poorer "North", comprising the industrialized countries. Furthermore, it has largely been private companies in industrialized countries, which have benefited from the South's biological riches. Thus, it is argued by developing countries that issues such as the equitable sharing of benefits from the conservation and use of biodiversity, must be included in any global agreements concerning biodiversity.'
>
> \- *White Paper on the Conservation and Sustainable Use of South Africa's Biological Diversity*, 1997

Under this policy climate, rather than promoting the typical objectives for the preservation of biological diversity (i.e., ecological health or biological integrity), which cannot be (without much research and difficulty) formulated into scientifically defensible biological indicators, the principle goal of ecological management should be social, to maximize human capacity to adapt to changing ecological conditions (Reid, 1994; Goodland, 1995). Reid (1994) explains that in order to adapt to change, humanity needs both the diversity from which innovations can be created, and the productive ecological systems that provide biological and economic capital to invest in those innovations. Thus, maintaining biodiversity is a prerequisite for maximizing humanities ability to respond to changing conditions, as is maintaining the productivity of agricultural systems, the yield from forests and fisheries, clean water, and clean air (e.g., Daily, 1997). Conserving biodiversity should not only be seen as a luxury or competing land-use, but rather it is the embodiment of sustainable development within developing regions of the world.

The socio-economic situation in southern Africa can no longer promote large reserves without social concessions (i.e., Peace Parks). A large portion of the common, public, and private land is managed for renewable natural resources (i.e., livestock range, fuel wood, water, etc.), as well as, dryland and irrigated agriculture, exotic tree plantations, and urbanization. All of these activities lead to some level of landscape fragmentation. The use of a Biodiversity Management Area (BMA) system in these various landscapes could serve as a model to provide quality core habitat for many species (sensu Davis et al., 1996). These ecologically managed areas would be for those biological components that are negatively impacted by human activities. Their arrangement on the landscape would be based on ideals of persistence as well as representation, while acknowledging that human impacts and influences will be happening around them. In this respect, BMAs are extended to communal, private, and public lands and across multiple habitats. Human "quality of life" development should be allowed to go forward to the extent that they are compatible with the goal of maintaining native species and ecosystem diversity. The concept of a BMA is to monitor and manage in a hierarchical fashion from local ecosystem, to landscape, to regional levels in order to reduce risk.

The goal of conserving biological diversity is to ensure population viability or persistence over time within the required habitats. Sustainable conservation management must be seen in an integrated fashion, acknowledging components of population biology, landscape ecology, economics, and social needs. A major constraint to future biodiversity protection in South Africa is that state land will not go towards conservation, but will be provided for retribution to those landless individuals created by past British colonial and South African apartheid policies (South Africa, 1997). In any case, the amount of available state land is low, as the almost total transfer of land in the formerly White areas of South Africa from government to private ownership had occurred by the mid 1930's (Christopher, 1982). This is unique in colonialism, as it did not happen in other former British colonial areas outside of South Africa (i.e., Kenya, Australia, Canada, USA, etc.). The current land ownership and land development patterns strongly reflect the political and economic conditions of the apartheid era (Fairbanks et al., 2000).

In many regions, South Africa's biological conservation must also be viewed as managing natural remnants. Fragments of natural landscape that are available for conservation have two important considerations: isolation and human influence from within the landscape matrix. Isolation primarily affects the interior species. Therefore, patch size; shape, number, and configuration are critical, as are, corridor width, and connectivity. Patches must have characteristics adequate to support the interior species, and both corridors and patches must have a configuration that permits rapid recolonization when an interior species becomes locally extinct.

Management of the flow of objects from the matrix to fragments or formal reserves is the other focus. Human influence proceeds to minimize or eliminate these flows: there needs to be a balance of structure. Maintaining and creating large patches, and then surrounding these with a high density of corridors and small patches containing edges may be a possible solution (Forman and Collinge, 1995; Yu, 1996; Forman and Collinge, 1997). Recently, landscape ecologists and conservation biologists have distilled their experiences into a number of conservation principles that can be used as a basis for planning (Noss et al., 1997). These include: (1) species that are well distributed across their historical range are less prone to extinction; (2) large patches that support large populations support them for longer periods of time; (3) habitat patches that are continuous (less-fragmented) support long-term viability; (4) patches that are sufficiently close together allow dispersal and thus support long-term viability; (5) patches that are connected by corridors provide better dispersal; (6) patches of habitat that have minimal or no human influence are better; and (7) populations that naturally fluctuate widely are more vulnerable than stable populations.

Inevitably, this discussion leads to the appropriate integration of biodiversity protection with competing economic pressure and social value. These three broad themes generally play off each other in an area, which then evolves landscapes into complex mosaics that natural resource management institutions are faced with managing. Faith (1995) and Faith and Walker (1996b; 1996c) present a multi-criteria trade-off analysis as one type of an analytical framework to assess a region's sustainability (Figure 1.1). Regional sustainability as defined by Faith (1995), will reflect the region's success (or potential for success) in achieving effective trade-offs between conservation and development (or other criteria).

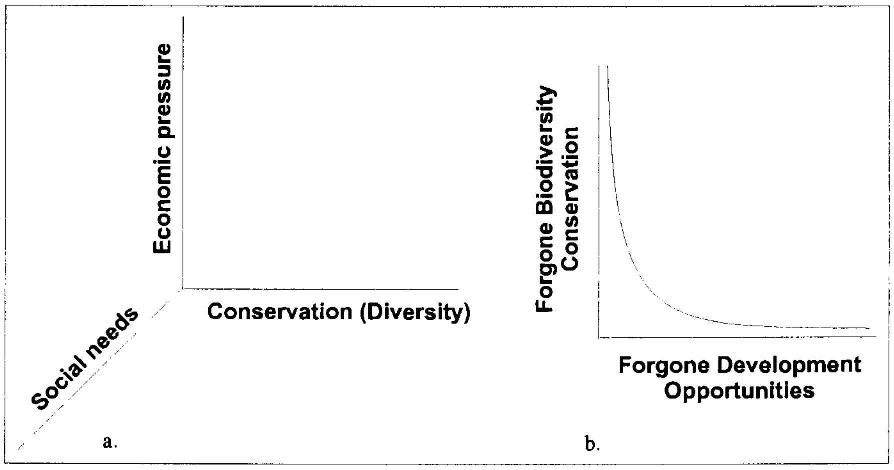

Figure 1.1: (a) The multiple interplay between the three broad themes in sustainable development analysis; and (b) a trade-off or regional optimization space curve. A given allocation of area to conservation or development will result in a total cost and total forgone biodiversity, so that the allocation can be plotted as a point in this space (Faith, 1995).

Faith and Walker's (1996b; 1996c) approach is simple, and probably dangerous to implement, but it does clearly present the competing goals commonly encountered. This dissertation takes these ideas a step further by setting them in a co-evolutionary construct within which to view conservation planning. One of the principle aims of a co-evolutionary dynamics model is to establish human-ecosystem interaction within an interpretative/interrogative framework. This analytical framework allows for the integration of complex environmental and socio-economic indicators to provide information needed to answer questions pertinent for sustainable biodiversity conservation. However, persistence will depend not only on land-use allocations (spatially) for sometimes competing land-uses, but also the degree to which appropriate implementation criteria and management for an area satisfies multiple goals.

1.3 Methodological Background

This section outlines the study site, data acquisition, and initial data processing used in this study.

1.3.1 Study Site

The study site used in this thesis corresponds to the KwaZulu-Natal Province within the Republic of South Africa (Figure 1.2). The province was chosen for its range of land-use/land-cover, contrasting development patterns representing third world southern African and first world Western influenced landscapes, availability of environmental and socio-economic data sets, and access to both detailed historical and contemporary bird distribution databases.

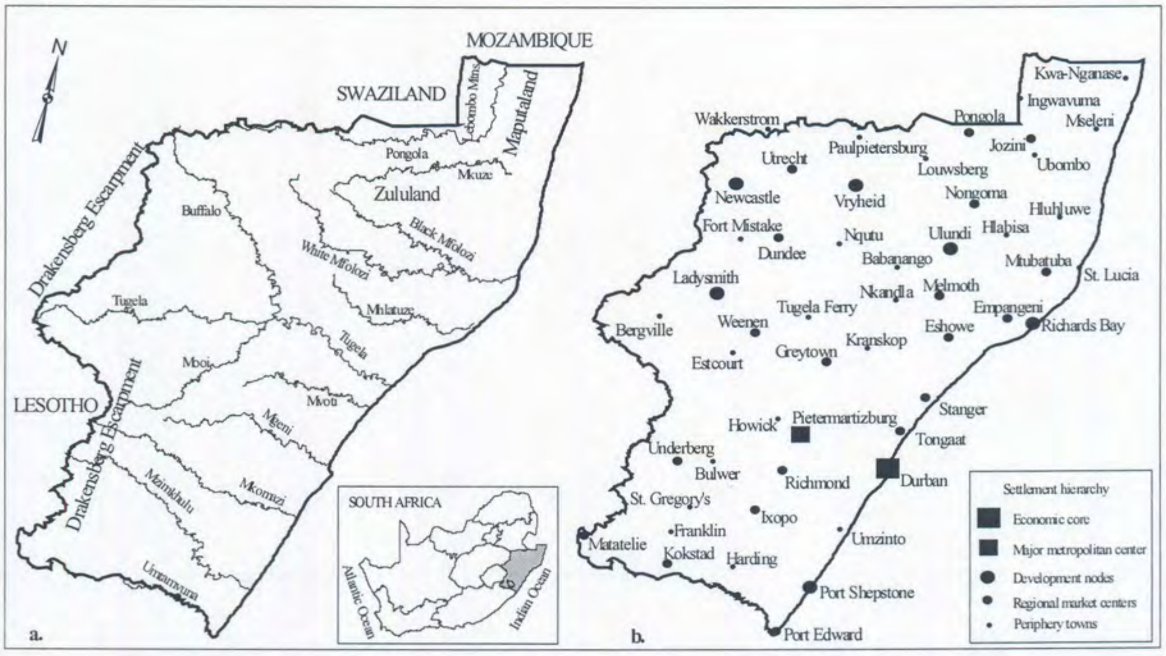

Figure 1.2: (a) Location of the KwaZulu-Natal Province study region within South Africa; and (b) major place names and their economic hierarchy within KwaZulu-Natal Province.

Analytical work conducted in Chapter 5 also utilizes data at the national South African extent.

KwaZulu-Natal Province is located on the east coast of South Africa and borders the countries of Lesotho, Swaziland, and Mozambique. KwaZulu-Natal covers just 7.6% of the land area of South Africa, but contains the largest population base (20.7%) of any province (Stats SA, 1998). The province is an important sub-tropical agricultural and tree plantation region, and over the last 20 years has seen increased development pressure in direct conflict with its active expansion of conservation based tourism (Thorrington-Smith et al., 1978; Armstrong et al., 2000).

Climatically, the province is characterized by the influence of the Indian Ocean's warm Agulhas current. This creates a wide coastal region of sub-tropical climate, with high humidity, high temperatures, and high summer rainfall. In southeast Africa the relief, which is in the form of a number of ascending steps, is such that, in general, the inland isotherms tend to run in a north-south direction, parallel to the coast. KwaZulu-Natal's western border is defined by the Drakensberg Escarpment, which forms a marked climatic gradient. There is a pronounced difference in temperature between the hot eastern coastlands and the cooler interior highlands, and at the same time, temperatures along the coast increase gradually northwards. The climatic transition from the coast to the westerly plateau is, however, gradual.

Rainfall at the coast ranges from about 760 to 1400 mm per annum, and is heaviest at the northern and southern districts of the area considered. Inland, on the seaward-facing escarpments, rainfall is about 1750mm per annum, but on the intervening surfaces, it is considerably less. Most of the rainfall is received during summer (September - March), but this characteristic is far more pronounced inland than at the coast. Consequently, the region has warm, wet summers and cool, dry winters.

The vegetation ranges from complex in the north-east, being made up of a number of different ecological associations, which include mangrove forest, swamp forest, dune forest, sand forest, coast forest, riverine woodland, and savanna woodland (Figure 1.3). To the south of this area and towards the Drakensberg Escarpment, there is a marked thinning out of this complexity. Bush clump grasslands and moist woodland dominant along the coast (south of St. Lucia), grasslands interspersed with afromontane forests occur in the southern-central interior and along the escarpment, dry thornwoodlands cover the western region of Zululand and a valley thicket complex dominants the incised river valleys (e.g., Tugela River).

1.3.2 Data Sets Used in Study

The multi-disciplinary nature of this study required several strategic databases and used many of the commonly available biophysical data layers. Among the processes that have been hypothesized 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 processes (Table 1.1); they included climate surfaces (Schulze, 1998) and a digital elevation model (Surveyor General 1993), as well as potential vegetation (Low and Rebelo, 1996), and land-use/land-cover types (Fairbanks et al., 2000) mapped in a raster-based geographic information system (GIS; ESRI, 1998). The GIS database has a raster cell resolution of 1 km by 1 km. Both geographic and projected Albers equal area cartographic systems were used.

1.3.2.1 Potential Vegetation

Vegetation type is a primary determinant of ecosystem type (Peters, 1992), playing a major role in determining the associated fauna. Two potential vegetation map products are available for South Africa: Acock's (1953) vegetation types, which is largely based on the agricultural potential of the vegetation, and Low and Rebelo's (1996) vegetation types, which is based on both structure and floristics, but is essentially a re-assessment of Acocks. The vegetation potential map of Low and Rebelo (1996) was mapped at a scale of 1:500 000. The 26 vegetation types that occur in KwaZulu-Natal were classified into eight functional community groupings (Table 1.2; Low and Rebelo, 1996; Cowling et al., 1997) for analysis (Figure 1.3).

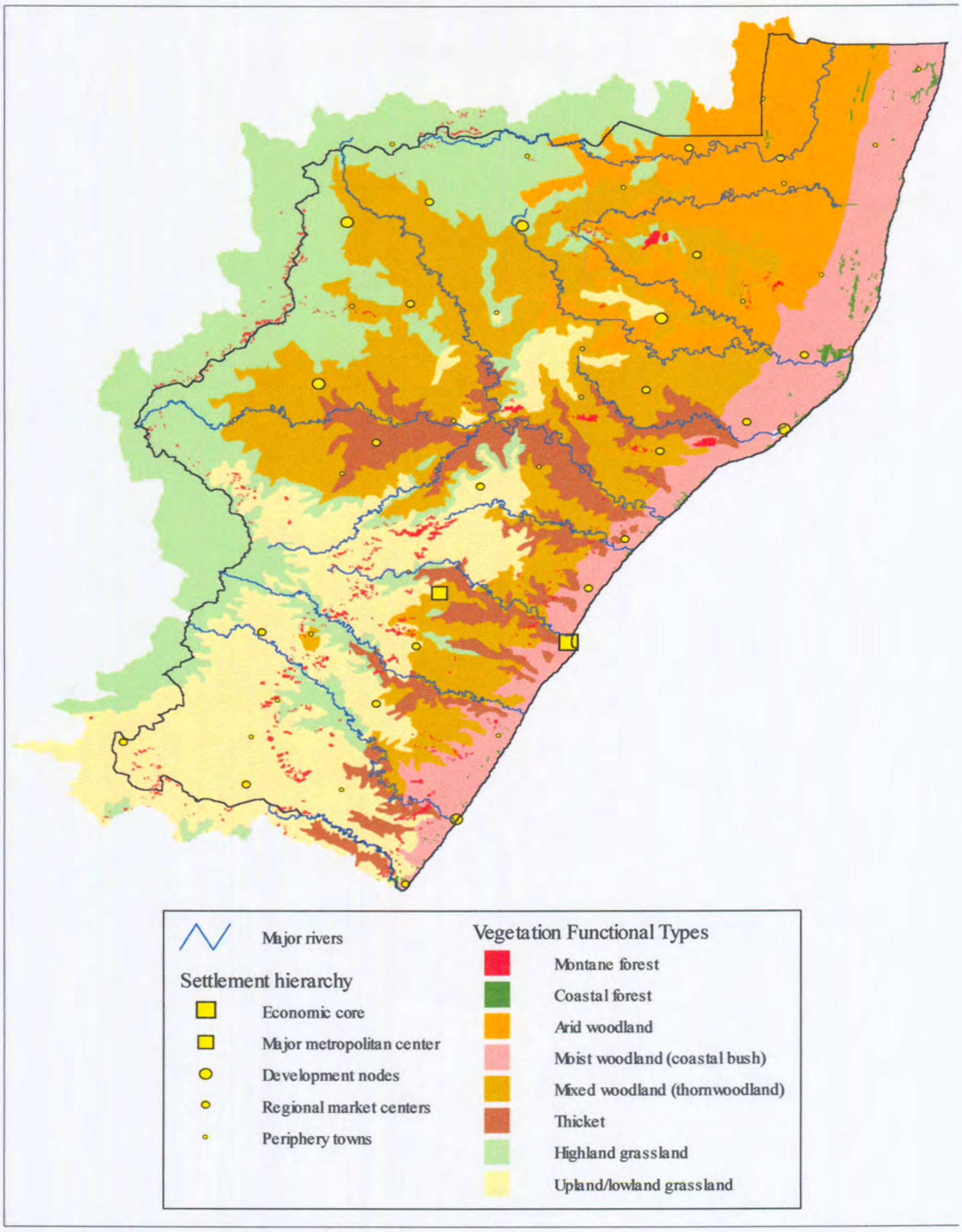

Figure 1.3: Functional vegetation types found within KwaZulu-Natal Province based on vegetation types described by Low and Rebelo (1996).

Table 1.1: Codes and definitions of explanatory variables, by variable subset, used in Chapters 3, 4, and 5.

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 monthly grow days
NGTMEAN	Mean temperature (°C) during negative water balance
MAT	Mean annual temperature (°C)
HOTMNTHMN	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 (mm)
TSEAS_MN	Temperature seasonality from the difference between the January and July means (°C)
MXSEAS_MN	Maximum temperature seasonality from the difference between January and July (°C)
Land Types	
LAND†	Variety of defined landscapes from a maximum of 24
LANDVEG	Variety of combined landscape and vegetation types from a maximum of 217
LANDVEGF	Variety of combined landscape and functional vegetation types from a maximum of 126
VEG	Variety of defined vegetation types from a maximum of 26
VEGF	Variety of defined functional vegetation types from a maximum of 8
LCLUTYPES	Variety of defined land-cover/land-use types from a maximum of 29
LCLULAND	Variety of combined landscape and land-cover/land-use types from a maximum of 334

† Landscapes derived from analysis presented in Chapter 3.

Table 1.2: Functional vegetation classification of the 1:500 000 National Botanical Institute Vegetation of South Africa, Lesotho and Swaziland (Low and Rebelo, 1996).

Original potential vegetation types	Functional classification
Afromontane forest	Montane forest
Coastal forest	Coastal forest
Sand forest†	Coastal forest
Eastern thorn bushveld	Arid woodland
Lebombo arid mountain bushveld†	Arid woodland
Mixed lowveld bushveld	Arid woodland
Natal lowveld bushveld†	Arid woodland
Sour lowveld bushveld	Arid woodland
Subarid thorn bushveld	Arid woodland
Subhumid lowveld bushveld†	Arid woodland
Sweet lowveld bushveld	Arid woodland
Coastal bushveld grassland†	Moist woodland
Coastal hinterland bushveld†	Mixed woodland
Natal central bushveld†	Mixed woodland
Valley thicket	Thicket
Coastal grassland	Upland/lowland grassland
Moist upland grassland	Upland/lowland grassland
Short mistbelt grassland†	Upland/lowland grassland
Afro-mountain grassland	Highland grassland
Alti-mountain grassland	Highland grassland
Moist clay highveld grassland	Highland grassland
Moist cold highveld grassland	Highland grassland
Moist cool highveld grassland	Highland grassland
Moist sandy highveld grassland	Highland grassland
North-eastern mountain grassland	Highland grassland
Wet cold highveld grassland	Highland grassland

†Endemic vegetation types to KwaZulu-Natal

1.3.2.2 Topography

Topographic position has been found in other studies to significantly influence ecosystem variability patterns, especially the control of water movement (Kratz et al., 1991; Forman, 1995). A digital elevation model (DEM) of South Africa was available from the South African Surveyor General (1993) with a horizontal resolution of 400 m by 400 m and a vertical resolution of 20 m (Figure 1.4a). This was used to derive elevation information and a topographic landform index (ridge, valley, slope) using standard GIS routines (Figure 1.4b; Fairbanks, 2000). The percent slope surface was transformed to a surface representing flat-undulating (< 4%) and ridge landscapes (> 35%) and then a linear function scaled the slope data between the two extremes.

1.3.2.3 Climate

The principal controlling factor in southern African ecosystems is the soil water balance (Cowling et al., 1997; Scholes and Walker, 1993). The mean number of days per annum on which sufficient water is available to permit plant growth was considered a biologically meaningful index of water availability. Ellery et al. (1992) developed such a water balance index, which calculates the water budget from available climatology data. The index, called 'growth days' (GD) is defined as the sum of the monthly ratios of precipitation to potential evaporation, where the ratio is not permitted to exceed 1 in any given month (i.e., if rainfall is larger than evaporation, it is not carried over into subsequent months, but is assumed to have been lost as runoff). This is achieved by multiplying the monthly ratios by the number of days in the month and summing over the year. Intuitively it can be thought of as the number of days per year when soil moisture does not limit plant growth. The GD index was calculated on the 1 km by 1 km grid covering the entire country (Figure 1.4c), from monthly mean rainfall (1960-1990) and the monthly means of maximum and minimum daily temperatures (Dent et al., 1989). The annual mean of the monthly mean temperature weighted by the monthly growth days was recorded as growth temperature (GT), giving an indication of energy supply during the growing season (Ellery et al., 1992), while no growth temperature (NGT) is derived from the months weighted by no available growth days. The GT and NGT were calculated from available mean monthly temperature surfaces (Schulze, 1998). Other climatic variables considered for use included median annual precipitation, summed mean minimum and maximum rainfall for the driest and wettest quarters, mean annual temperature, and mean minimum and maximum temperatures for the coldest and hottest months. The seasonal variability with precipitation, temperature, and evapotranspiration were calculated from these raw datasets (Table 1.1).

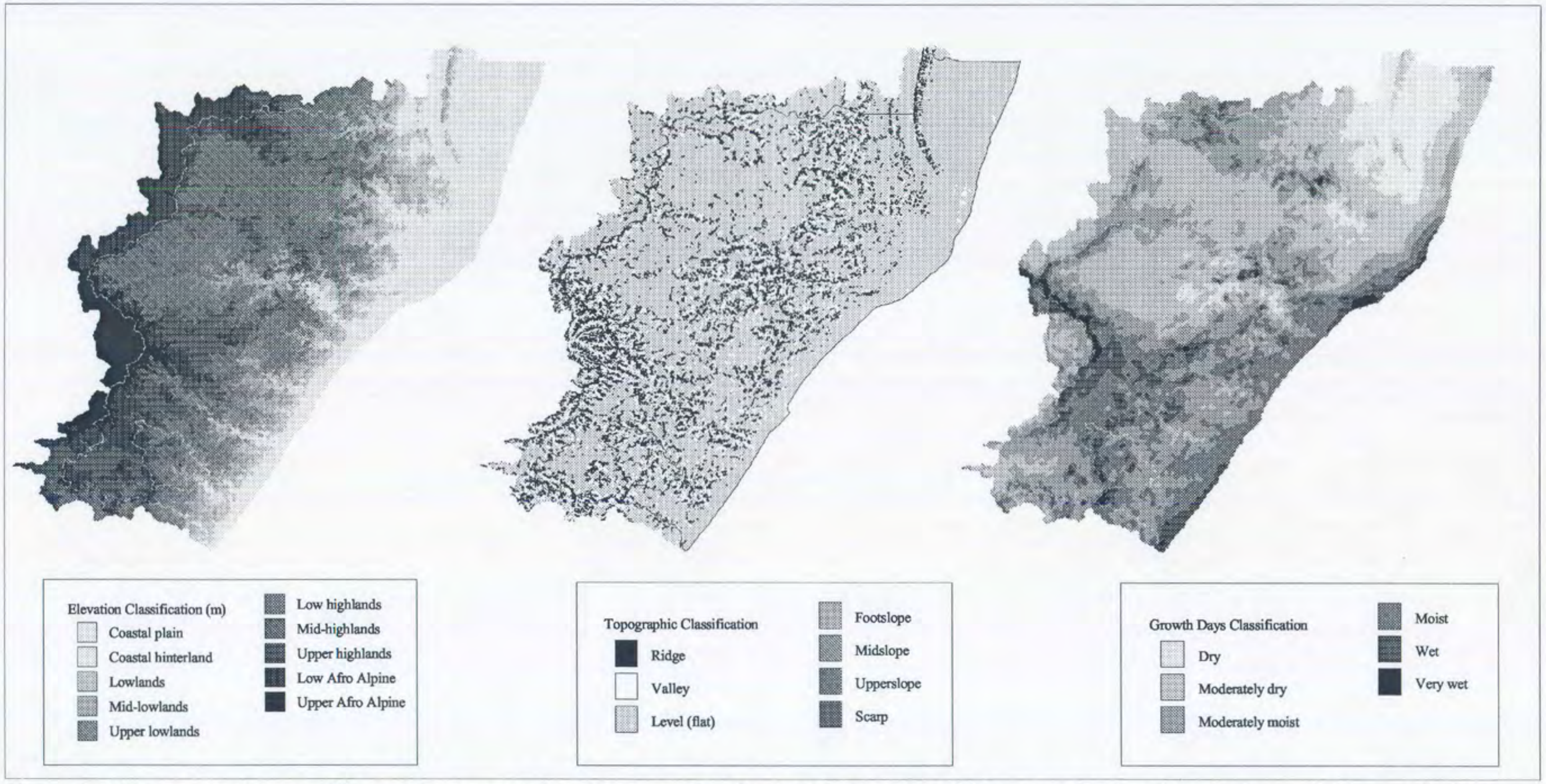

Figure 1.4: Examples of some of the environmental data layers used in thesis: (a) elevation; (b) topographic landform index; and (c) growth days.

1.3.2.4 Avian Distribution and Diversity

Biological atlases had their precedent made when Perring and Walters (1962) published the *Atlas of the British Flora*. Using a 10 km by 10 km gridded map, plant distributions were plotted on a presence/absence basis. This pointed the way for similar comprehensive and equally objective mapping of the breeding birds of Britain (Sharrock, 1976). This British tradition in naturalist field biology was adopted during the 1970s in South Africa by the Natal Bird Club. They developed a project whose aim was to map the distributions, by presence/absence per month, of all bird species occurring in KwaZulu-Natal during the decade 1970-79 (with emphasis on 1975-79), using the national quarter-degree grid (15 min x 15 min; ~24 km x 28 km, hereafter referred to as a grid cell). Each of these grid cells represents one of the maps in the 1:50 000 topocadastral map series produced by the South African Surveyor General (Figure 1.5). The objectives were to present occurrences of birds in KwaZulu-Natal, against which future changes in the avifauna could be measured. Data collection was conducted by means of fieldcards submitted by club members, Natal Parks Board, and the authors of the atlas. In 1980, Cyrus and Robson published the *Bird Atlas of Natal*, which represented a thorough account of the birds found in the province during the 1970s.

Starting in 1987, the Southern African Bird Atlas project (Harrison, 1992) was initiated by the Avian Demography Unit (ADU), University of Cape Town. The aims of their project were the same as for the Cyrus and Robson (1980) survey, but designed to cover the entire Southern African sub-region (South Africa, Lesotho, Swaziland, Namibia, Botswana, and Zimbabwe). The same procedures as used by Cyrus and Robson were adhered to (Nigel Robson was appointed as a science steering committee member), along with the continued use of the grid cell. The presence/absence of species was recorded during 1987-1992 (see Underhill et al., 1991; Harrison, 1992; Harrison et al., 1997 for details).

In the original forward to Cyrus and Robson (1980), Gordon Maclean (author of *Robert's Book of South African Birds*, 1984) explained that the greatest apparent shortcoming of any biological atlas is that it is out of date even as it comes off the press. This is as it should be, because it illustrates the dynamic nature of biological systems, especially in the face of anthropogenic impact. Therefore, an atlas becomes increasingly valuable as it highlights the changes that are constantly occurring. Baselines for future comparisons become more necessary every day, so an atlas of distribution in time and space becomes an invaluable tool in the hands of planners, geographers, and conservation biologists. KwaZulu-Natal forms less than one percent of the Afrotropical Region (Africa south of the Sahara), yet its economy in the late 1970s may have been the largest per unit area, and its rate of progress close to the highest on the whole continent. Maclean made note, at that time, that a measure of the natural resources of KwaZulu-Natal had become more critical than ever.

The Cyrus and Robson (CR) dataset comprises 33689 unique distribution records of 633 species covering 165 grid cells. The ADU dataset, clipped to cover the same number of grid cells, includes 40036 unique distribution records of 604 species of resident and visiting birds, which comprise 65% of the bird diversity recorded for the Southern African sub-region. The reporting rates for both datasets show observer bias in and around the Durban and Pietermaritzburg areas, and the Drakensberg and the Zululand game reserves (Figure 1.6). Nevertheless, for each survey period > 90% of the grid cells had at least one fieldcard returned for recording for each month of the year. In the case of the ADU survey the intensity of the recording during the 5-year survey (1987-92) allowed for an average of 105 fieldcards returned per grid cell. This level of reporting allowed the transformation of the number of times a species was recorded into relative abundance values, which were used to analyze avian assemblage structure in Chapter 5. Unfortunately, this type of data was not recorded within the CR atlas.

Investigations of the patterns in these bird atlases have been conducted using several biological and practical classifications. For each atlas, the birds were first grouped by life history class and then, for only the ADU atlas birds, grouped by primary ecological habitat requirement. Waterbirds were not analyzed separately as Guillet and Crowe (1985; 1986) had previously examined them. Wetland and waterbody sites are also already protected under the South African signing of the RAMSAR convention for wetland conservation (Cowan and Marneweck, 1996). Table 1.3 describes each of these datasets and provides the dataset name, as it will be referred to throughout the thesis. The conservation dataset is the only dataset not based on biological reasoning, but instead on the requirements of the local conservation authorities for planning purposes conducted in Chapter 4.

1.3.2.5 Land-cover/land-use Database

The South African National Land-Cover database (NLC; Fairbanks and Thompson, 1996; Fairbanks et al., 2000) was used to derive land-cover/land-use (LCLU) and transformation percentages for each grid cell. This national database was derived using photo-interpretation techniques from a series of 1:250,000 geo-rectified hardcopy satellite imagery maps, based on seasonally standardized, single date Landsat Thematic Mapper satellite imagery, captured principally during the period 1994-95 (Fairbanks and Thompson, 1996). It provides the first single standardized database of current LCLU information for the whole of South Africa, Lesotho, and Swaziland (see Fairbanks et al., 2000). For the purpose of this thesis, the 31 LCLU classes were reclassified into three categories: un-transformed, low intensity transformation, and high

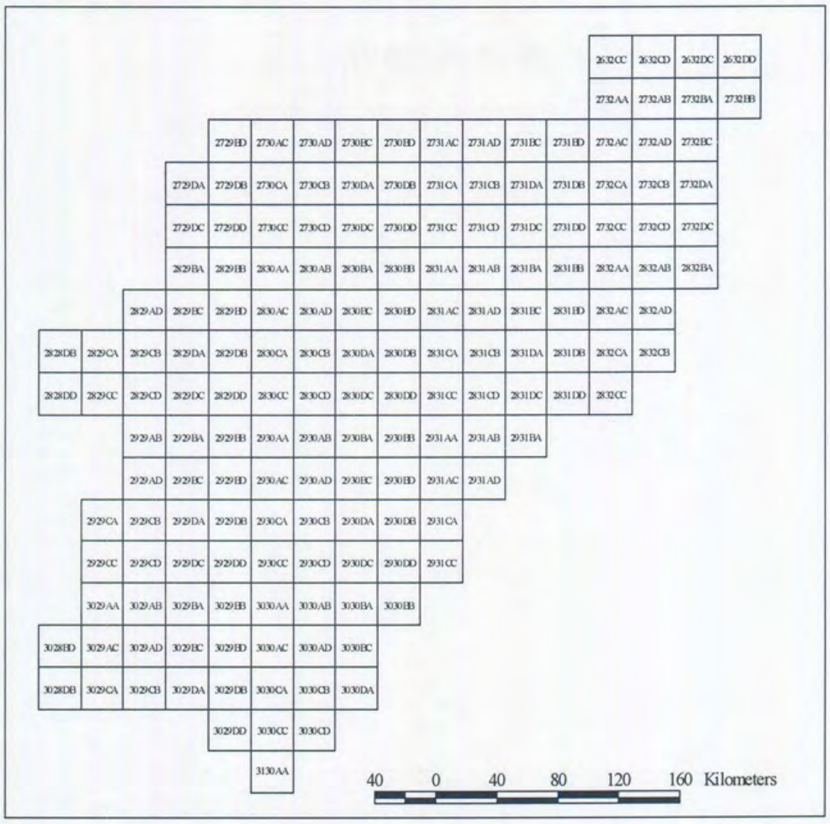

Figure 1.5: The 1:50 000 mapsheet system of grid cells for KwaZulu-Natal used to record bird distribution data during both survey periods.

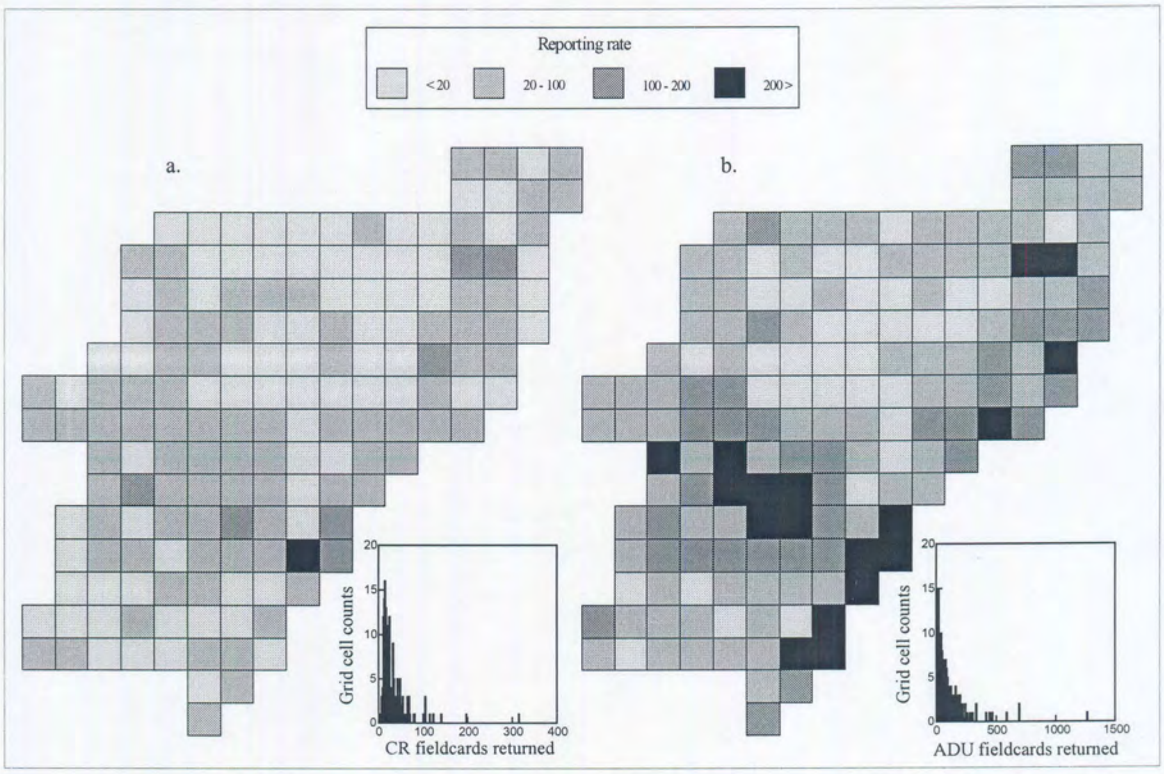

Figure 1.6: Spatial distributions of returned fieldcards and histograms distributions: (a) Cyrus and Robson (1980); and (b) Harrison et al. (1997).

Table 1.3: Bird datasets and descriptions used in this thesis.

Dataset	Description
Life History	
All birds	All birds found in each dataset. 633 in the Cyrus and Robson (1980) survey and 604 in the ADU (Harrison et al., 1997) survey.
Summer	Birds recorded during the months September-March.
Winter	Birds recorded during the months April-August.
Passerine	Birds classified as passerine in the descriptions provided by Harrison et al. (1997). Chiefly altricial songbirds of perching habits.
Non-passerine	Birds classified as non-passerine in the descriptions provided by Harrison et al. (1997). Relating to an order of arboreal birds including the rollers, kingfishers, hornbills, cranes, raptors, etc.
Breeding	Birds classified as breeding in South Africa and in particular to KwaZulu-Natal as provided by Harrison et al. (1997).
Non-breeding	Birds classified as not breeding in South Africa or KwaZulu-Natal as provided by Harrison et al. (1997).
Human influenced	Birds classified as being positively influenced, usually by habitat and therefore distribution, by human activity and/or land-use as described by Harrison et al. (1997).
Non-human influenced	Birds classified as either neutral to or negatively influenced by human activity and/or land-use as described by Harrison et al. (1997).
Ecological habitat	
Woodland†	Birds primarily associated with savanna woodland habitat.
Forest†	Birds primarily associated with indigenous evergreen forest (afromontane, coastal, and sand forest).
Thicket†	Birds primarily associated with thickets, bushland, and bush clumps.
Grassland†	Birds primarily associated with perennial grasslands.
Planning	
Conservation‡	Birds considered for representation in conservation efforts within KwaZulu-Natal (derived from personal analysis; Important Bird Areas of South Africa (1999); KwaZulu-Natal Nature Conservation Services).

† Relative abundances derived from the reporting rate in the ADU dataset were used instead of presence/absence measure.
‡ Only created from the more current ADU bird database.

intensity transformation land (Table 1.4; Figure 1.7a,b). Un-transformed class included all natural vegetation, e.g., forest, woodland, thicket, and grassland. Degradation, erosion, and subsistence agriculture dominated the low intensity category. These areas have a very low vegetation cover in comparison with the surrounding natural vegetation cover and were typically associated with rural population centers and subsistence level farming, where fuelwood removal, over-grazing, and subsequent soil erosion were noticeable within the satellite imagery (Thompson, 1996; Fairbanks et al., 2000). The high intensity 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, urbanized areas, and mines/quarries. The LCLU classes are essentially a measure of transformation status in the context of threats to biodiversity (Figure 1.8).

Landscape pattern metrics

The developing field of landscape ecology has provided a strong conceptual and theoretical basis for understanding landscape structure, function, and change (Forman and Godron, 1986; Urban et al., 1987; Turner, 1989). Landscape ecology is largely founded on the notion that the patterning of landscape elements (patches) strongly influences ecological characteristics, including vertebrate populations. Therefore, the ability to quantify landscape structure is a prerequisite to the study of landscape function and change. For this reason, much emphasis has been placed on developing methods to measure landscape structure (e.g., O'Neill et al., 1988; Turner, 1990; Turner and Gardner, 1991; Li et al., 1993). While a number of investigators have quantified landscape structure in a variety of ecosystems (e.g., Krummel et al., 1987; Turner and Ruscher, 1988; Gustafson and Parker, 1992), few have examined the relationship between landscape structure and landscape function (e.g., Romme, 1982; Franklin and Forman, 1987; Baker, 1992; Baker, 1993).

The growing concern over the loss of biodiversity has challenged traditional local conservation strategy into developing better ways to examine and manage landscapes at a variety of spatial and temporal scales. Remote sensing developments have made it possible to analyze and manage entire landscapes to meet multi-resource objectives. As part of this study, in addition to LCLU proportions calculated per grid cell, a number of common landscape mosaic and class type pattern metrics were calculated (Table 1.5 and 1.6) for use in Chapters 5 and 6. The program FRAGSTATS (McGarigal and Marks, 1995) was used to calculate the spatial configuration of the LCLU within each grid cell and magisterial district. Landscape mosaic and class indices were calculated using the raster grid option. The LCLU data was converted to a grid cell resolution of 100 m, which is considered appropriate for the NLC database (Fairbanks and Thompson, 1996), development of pattern metrics (O'Neill et al., 1996), and the coarse-scale of this study.

Twenty-eight landscape mosaic indices of LCLU configuration were used that were considered appropriate for the land area of KwaZulu-Natal (Table 1.5) and 28 class level indices were calculated for each of the general vegetation types mapped (Table 1.6; woodland, forest, thicket, and grassland). These pattern indices quantify different aspects of configuration, although many are redundant and simply represent alternative formulations of the same formulation (McGarigal and Marks, 1995). The landscape boundary was considered the edge of the grid cell or magisterial district for the purpose of calculating all the metrics. The implications of this procedure means that the true sizes of patches will decrease because of the closing

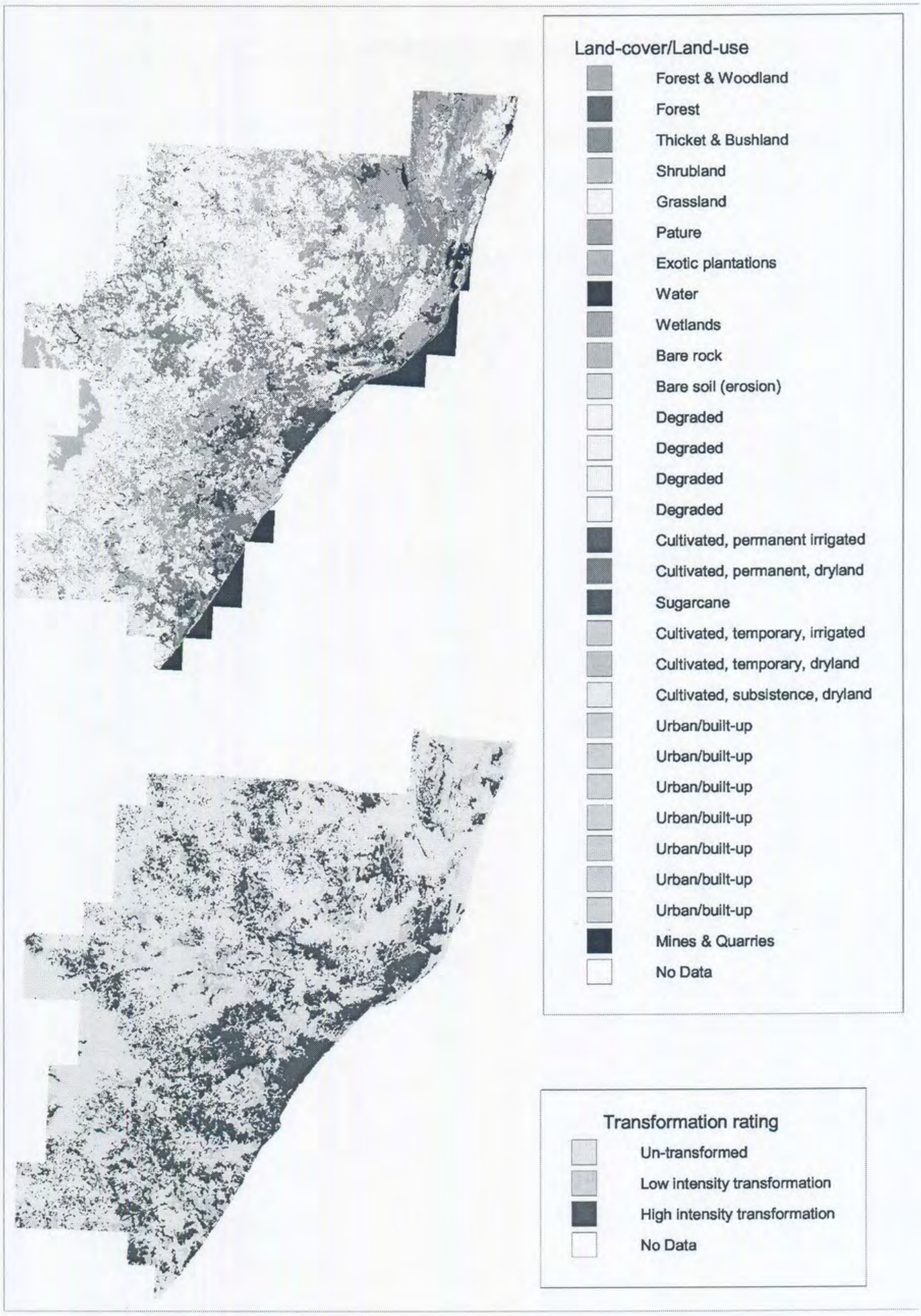

Figure 1.7: (a) Simplified map of land-cover/land-use distribution across KwaZulu-Natal province; and (b) three level transformation map derived from Table 1.4.

Table 1.4: Land-cover/land-use classes used in the South African National Land-Cover (NLC) database and the re-coded transformation classes used for this study.

NLC code	Original NLC Classes	Transformation Classes
1	Forest and Woodland (savanna)	Un-transformed
2	Indigenous Forest	Un-transformed
3	Thicket, Bushland, or Bush Clumps	Un-transformed
4	Low Shrubland and/or Fynbos	Un-transformed
5	Herbland	Un-transformed
6	Grassland	Un-transformed
7	Improved Grassland (pasture, recreational fields)	High intensity
8	Forest Plantations (exotic tree spp.)	High intensity
9	Waterbodies	Un-transformed
10	Wetlands	Un-transformed
11	Bare Rock & Soil (natural)	Un-transformed
12	Bare Rock & Soil (erosion surfaces)	Low intensity
13-17	Degraded Vegetation (NLC codes 1,3,4,5,6)	Low intensity
18-22	Cultivated lands (variations of commercial permanent/temporary crops, irrigated/dryland, and sugarcane)	High intensity
23	Cultivated lands (dryland subsistence)	Low intensity
24	Urban/built-up land (residential)	High intensity
25-28	Urban/built-up land (residential small holdings by subdivided vegetation; NLC codes 1,3,4,5,6)	Low intensity
29	Urban/Built-up land (commercial)	High intensity
30	Urban/Built-up land (industrial/transport)	High intensity
31	Mines and Quarries	High intensity

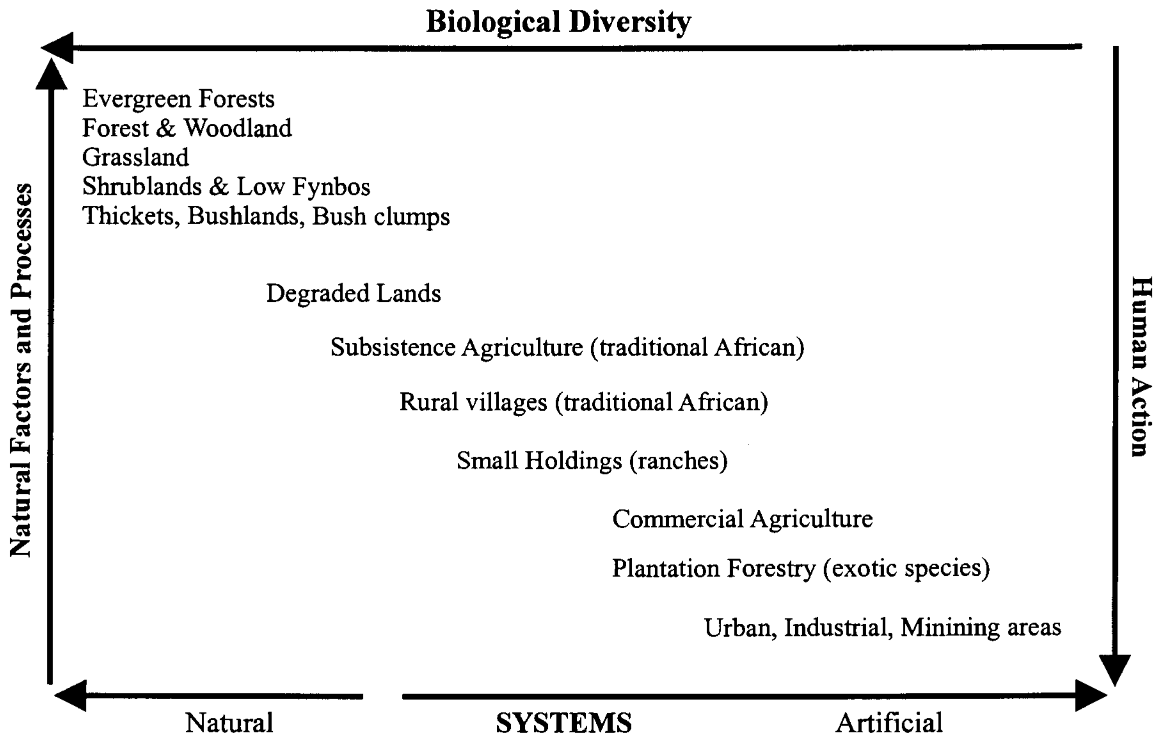

Figure 1.8: Conceptual model of the impacts of increasing levels of human developed land-use on biodiversity and natural processes (modified from Reid et al., 1993).

Table 1.5: Codes and definitions of explanatory landscape mosaic indices used in Chapters 5 and 6, by variable subset.

Acronym	Description[†]
Landcover	
POPTOT96	Total population from 1996 census
POPDEN96	Population density from 1996 census
FOR_PER	Percent woody cover
GRS_PER	Percent grass cover
WET_PER	Percent wetland and waterbody cover
LOWI_PER	Percent subsistence agriculture cover
PLNT_PER	Percent exotic plantation and woodlot cover
DRY_PER	Percent commercial dryland agriculture cover
IRR_PER	Percent commercial irrigated agriculture cover
URB_PER	Percent urbanization cover
M_PER	Percent low intensity transformation
T_PER	Percent high intensity transformation
T_TOTAL	Percent total transformation cover (i.e. combined low and high intensity transformation)
ROAD_INDEX	Percent road density cover
Patchiness	
LPI	Largest patch index (%) - percent of landscape composed of the largest patch
NP	Number of patches
PD	Patch density (no./100 ha)
MPS	Mean patch size (ha) – average size of patches in landscape
PSSD	Patch size standard deviation (ha) – absolute measure of patch size variability
CI	Contagion index – measure of clumpiness of patches within the landscape (contiguity across landscape).
Shape	
MSI	Mean shape index – mean patch shape complexity; equals 1 when all patches are circular and increases as patches become non-circular
AWMSI	Area-weighted mean shape index – similar to MSI, but patch shape index weighted by patch area
FD	Fractal dimension – measure of shape complexity as a departure from simple Euclidean geometry
MPFD	Mean patch fractal dimension – mean patch shape complexity; approaches 1 for simple geometric shapes (e.g., circle, square) and 2 for complex shape; adjusted to correct for bias in perimeter
AWMPFD	Area-weighted mean patch fractal dimension
Interior	
MCAPP	Mean core area per patch (ha) – sum of core areas divided by the number of patches
PCASD	Patch core area standard deviation (ha) – square root of the sum of the squared deviations of each patch core area from the mean core aras per patch, divided by the number of patches of the same type
MAPDC	Mean area per disjunct core (ha) – sum of the disjunct core areas of each patch, divided by the number of disjunct core areas
DCASD	Disjunct core area standard deviation (ha)
DCACV	Disjunct core area coefficient of variation (ha)
Isolation	
MNND	Mean nearest-neighbor distance (ha) – sum of distance to nearest patch divided by number of patches
NNSD	Nearest-neighbor standard deviation
MPI	Mean proximity index – sum of patch area divided by nearest edge-to-edge distance squared between the patch and the focal patch of all patches of the corresponding patchy type whose edges are within 500 m
II	Interspersion index (%) – measure of patch type adjacency against all other patch types (i.e., maximally interspersed and juxtaposed to other patch types)
Richness	
CR	Class richness
CRD	Class richness density
Heterogeneity	
SHDI	Shannon diversity index
SDI	Simpson diversity index
MSDI	Modified Simpson diversity index
Evenness	
SHEI	Shannon evenness index
SEI	Simpson evenness index
MSEI	Modified Simpson evenness index

[†] See McGarigal and Marks (1995) for a complete description and definition of each index.

Table 1.6: Codes and definitions of explanatory class level pattern indices used in Chapter 5, by variable subset.

Acronym	Description†
Patchiness	
LAND%	Percentage of the landscape composed of the corresponding patch type
LPI	Largest patch index (%) - percent of landscape composed of the largest patch
NP	Number of patches
PD	Patch density (no./100 ha)
MPS	Mean patch size (ha) – average size of patches in landscape
PSSD	Patch size standard deviation (ha) – absolute measure of patch size variability
PSCV	Patch size coefficient of variation (%) – relative measure of patch size variability
Shape	
MSI	Mean shape index – mean patch shape complexity; equals 1 when all patches are circular and increases as patches become non-circular
AWMSI	Area-weighted mean shape index – similar to MSI, but patch shape index weighted by patch area
MPFD	Mean patch fractal dimension – mean patch shape complexity; approaches 1 for simple geometric shapes (e.g., circle, square) and 2 for complex shape; adjusted to correct for bias in perimeter
AWMPFD	Area-weighted mean patch fractal dimension
Interior	
CADI	Core area density index (%) – percentage of the landscape composed of core areas of the corresponding patch type
TOTAL_CA	Total core area (ha) – total amount of core area of the corresponding patch type; core areas were defined by eliminating a 100 m wide buffer along the perimeter of each patch
NCA	Number of core areas – number of core areas, as defined above
CAD	Core area density (no./100 ha) – density of core areas, as defined above
MCAPP	Mean core areas per patch (ha)
PCASD	Patch core area standard deviation (ha) – square root of the sum of the squared deviations of each patch core area from the mean core aras per patch, divided by the number of patches of the same type
PCACV	Patch core area coefficient of variation (ha)
MAPDC	Mean area per disjunct core (ha) – sum of the disjunct core areas of each patch, divided by the number of disjunct core areas
DCASD	Disjunct core area standard deviation (ha)
DCACV	Disjunct core area CV (ha)
TCA%	Total core area index (%) – total percentage of the class type that is core area
MCA%	Mean core area index (%) – average percentage of a patch that is core area
Isolation	
MNND	Mean nearest-neighbor distance (ha) – sum of distance to nearest patch divided by number of patches
NNSD	Nearest-neighbor standard deviation
NNCV	Nearest-neighbor coefficient of variation
MPI	Mean proximity index – sum of patch area divided by nearest edge-to-edge distance squared between the patch and the focal patch of all patches of the corresponding patchy type whose edges are within 500 m
II	Interspersion index (%) – measure of patch type adjacency against all other patch types (i.e., maximally interspersed and juxtaposed to other patch types)

†See McGarigal and Marks (1995) for a complete description and definition of each index.

of the patches by an artificial study area boundary. Since there is nothing simple that can be done about this, conclusions drawn from the analysed data are appropriately tempered. Several core area indices were calculated based on a specified edge width, which, for the purpose of this study, was defined as 100 m wide buffer along the perimeter of each patch. This width represents a somewhat arbitrary decision based, in part, on avian studies by Temple (1986), McGarigal and McComb (1995), and studies by Laurance and Yensen (1991) and Laurance (1994). Edge related metrics were not calculated for this study because of confounding using the arbitrary grid cell and geopolitical magisterial district as sampling units. The use of the equal area grid cell, however, did reduce the effects of area in the metric calculations for the analysis, eliminating the need for regression area correction suggested in other landscape pattern metric studies (e.g., McGarigal and McComb, 1995). However, this technique was used in Chapter 5 to remove the area effects confounding the magisterial district metrics.

1.3.2.6 Road Effects Database

In addition to LCLU threats, one of the most widespread forms of alteration of habitats and landscapes over the last century has been the construction and maintenance of roads (Trombulak and 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 behavior modification; (4) alteration of the physical environment; (6) alteration of the chemical environment; and (7) increased alteration and use of habitats by humans (from Trombulak and Frissell, 2000). These networks cover 0.9% of Britain and 1.0% of the USA (Forman and 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. Thus, while the LCLU database provides a reasonable estimate of areas with high current vulnerability to biodiversity loss due to existing anthropogenic land transformation; road-effect zones can be used to provide another estimate of the threat to avian biodiversity.

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 KwaZulu-Natal 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 published studies (Milton and MacDonald, 1988), and unpublished data, which demonstrated that more than 80% of the transformed area of KwaZulu-Natal Province occurs within 2 km of a road, with approximately 61% of the untransformed areas occurring within the same distance (Pers. Com. Grant Benn, 1999). Therefore, national routes and freeways were assumed to affect biodiversity for a greater distance from the roadway (1 km on each side) than dirt roads (50 m; Table 1.7).

Road segments from the South African Surveyor General (1993) 1:500 000 map series files (Figure 1.9) were buffered to the distance related to its class. The roads in protected areas were excluded from this analysis as the road-effect in nature reserves is of little concern in this study. A road disturbance index was calculated within each grid cell by summing the total area of the buffered roads and converting to a percentage of that grid cell.

Table 1.7: 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 district roads)	100
Other (rural road)	50
Vehicular trail (4 wheel drive route)	25

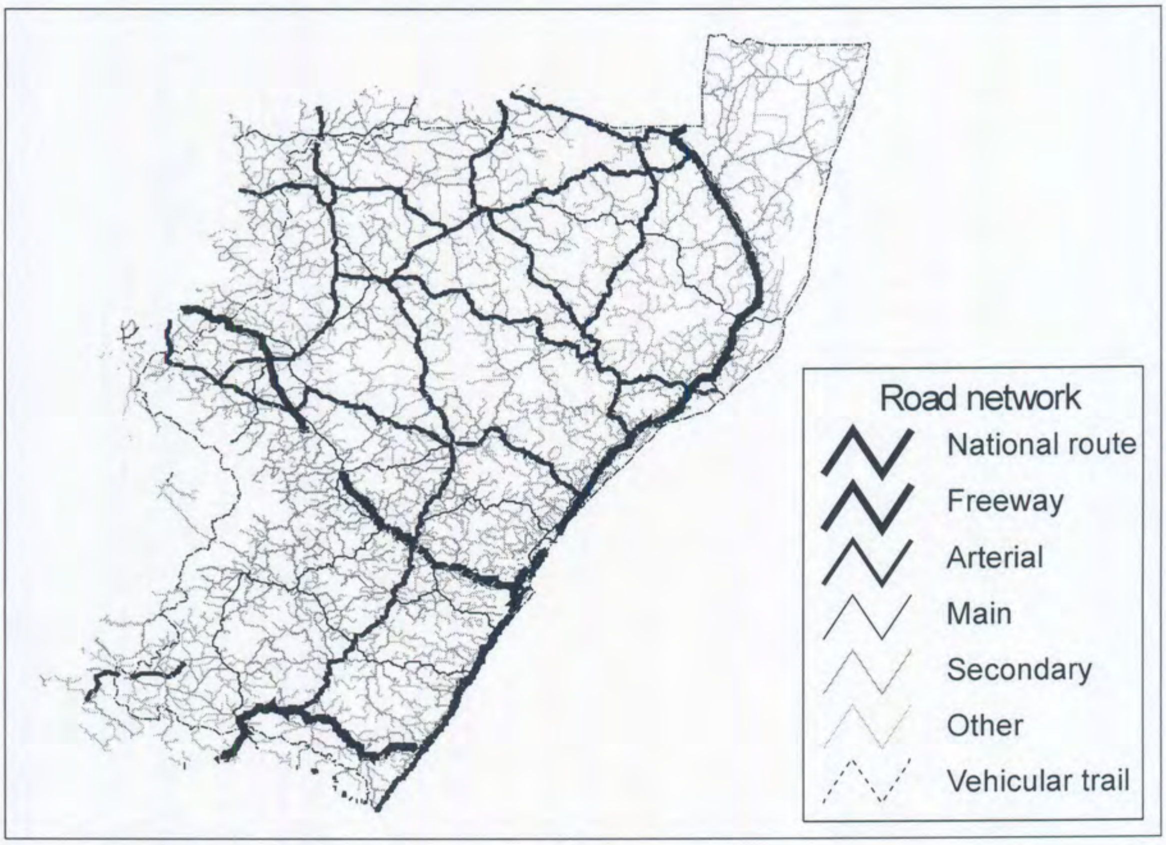

Figure 1.9: The 1:500 000 KwaZulu-Natal road distribution network.

1.3.2.7 Socio-economic Indicators

Three databases of available social and economic indicators were examined for variables that would cover the entire province using the latest magisterial district definition (Table 1.8) and distributions from the 1996 Census (Figure 1.10). By limiting the data to the 1996 boundaries used in the 1996 South African Census (Stats SA, 1998) a whole host of historical census and economic data was made unacceptable for this study. This is rather unfortunate, however, the radical changes in districting that have accompanied the disbanding of the apartheid state have seen the magisterial districts and boundaries change five times since the 1991 census. The 1996 census ushered in the first reliable geographic results of the countries demography. Boundary

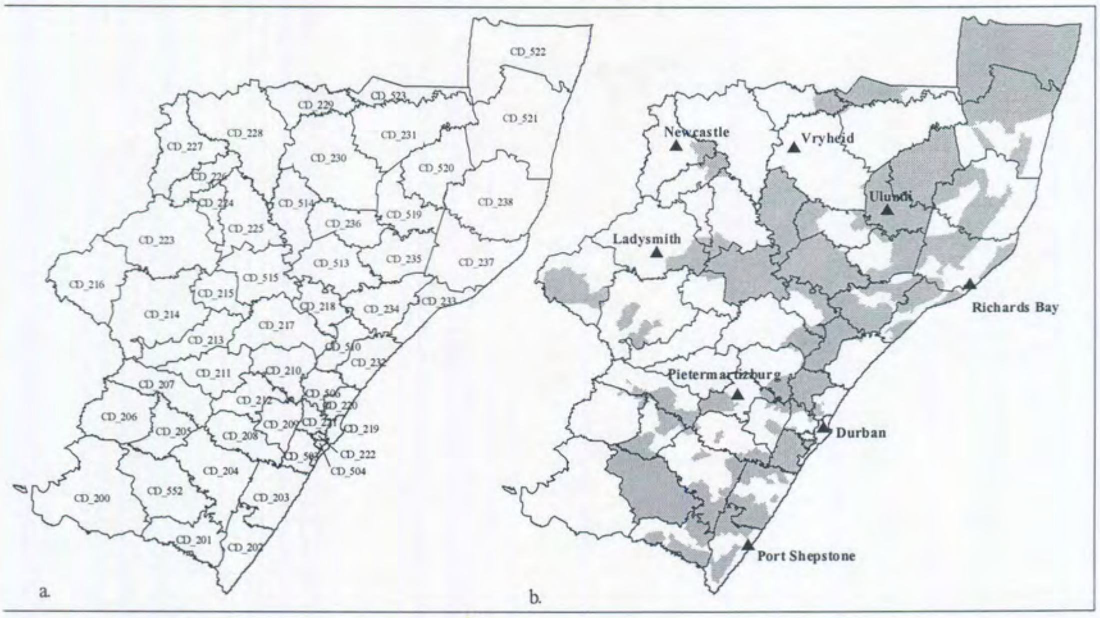

Figure 1.10: (a) Magisterial districts used for the 1996 Census; and (b) magisterial districts in relation to the former KwaZulu and Transkei homeland boundaries (pre 1994; shaded gray).

Table 1.8: Codes and names of magisterial districts in KwaZulu-Natal Province.

HSRC code	Magisterial district	HSRC code	Magisterial district
CD_200	Mount Currie	CD_226	Dannhauser
CD_201	Alfred	CD_227	Newcastle
CD_202	Port Shepstone	CD_228	Utrecht
CD_203	Umzinto	CD_229	Paulpietersburg
CD_204	Ixopo	CD_230	Vryheid
CD_205	Polela	CD_231	Ngotshe
CD_206	Underberg	CD_232	Lower Tugela
CD_207	Impendle	CD_233	Mtunzini
CD_208	Richmond	CD_234	Eshowe
CD_209	Camperdown	CD_235	Mthonjaneni
CD_210	New Hanover	CD_236	Babanango
CD_211	Lions River	CD_237	Lower Umfolozi
CD_212	Pietermaritzburg	CD_238	Hlabisa
CD_213	Mooi River	CD_503	Umbumbulu
CD_214	Estcourt	CD_504	Umlazi
CD_215	Weenen	CD_506	Ndwendwe
CD_216	Bergville	CD_510	Mapumulo
CD_217	Umvoti	CD_513	Nkandla
CD_218	Kranskop	CD_514	Nqutu
CD_219	Durban	CD_515	Msinga
CD_220	Inanda	CD_519	Mahlabathini
CD_221	Pinetown	CD_520	Nongoma
CD_222	Chatsworth	CD_521	Ubombo
CD_223	Kliprivier	CD_522	Ingwavuma
CD_224	Glencoe	CD_523	Simdlangentsha
CD_225	Dundee	CD_552	Umzimkulu [†]

[†] This district is managed by the Eastern Cape Province but has been included as part of KwaZulu-Natal for this study.

problems with the ex-homelands, especially in KwaZulu-Natal, were finally removed, yet the spatial landscape characteristics of their former presence was not.

The socio-economic data was drawn from the *1996 census* (Stats SA, 1998), 1996 *KwaZulu-Natal Service Needs and Provision* (Human Sciences Research Council, HSRC; Schwabe et al., 1996), and the *1997 KwaZulu-Natal Development Indicators* (Human Sciences Research Council, HSRC; Kok et al., 1997) databases. The last two databases are unique in South Africa, as KwaZulu-Natal province is the only region to have rather recent social surveys conducted for each magisterial district based on development indicators (i.e., need for water, sewer, etc.) that provide information on basic needs and tensions. Appendix A provides the descriptive breakdown of the eighty-four socio-economic and environmental indicators used in Chapters 5 and 6.

1.3.2.8 Provincial Protected Areas Database

KwaZulu-Natal Nature Conservation Service provided a spatial database of their provincial protected areas (Figure 1.11). The protected areas database describes the boundaries of provincial reserves, digitized from 1:50 000 maps. Table 1.9 provides the names and basic descriptions of the protected areas. The spatial distributions of private conservation areas and game farms were not available for the analyses.

1.4 Differing Aspects of This Study

The compilation of a series of studies described in this thesis is unique from most traditional landscape ecological and conservation biology studies in at least three major respects. The first is the coarse-size of the geographical sampling unit from which the species distribution information is derived; the second is the quantification of coarse-scale avian turnover related to environmental and landscape pattern gradients; and the third is the pattern analysis of socio-cultural and economic data in relation to evolved landscape pattern.

Typically, most quantitative bird analyses have used plots or transect as sampling units. The aim of such studies is to characterize local avian-vegetation relationships (e.g., Wilson, 1974, Forman et al., 1976; Cody, 1985; Opdam et al., 1985; Opdam et al., 1984). Small plot based samples have been used in coarse-scale avian analysis for many years (e.g., Wiens, 1973; Rottenberry and Wiens, 1981; Wiens, 1989a; McGarigal and McComb, 1995). The sampling schemes rely on subjective choices to find representative "homogeneous" vegetation plots in a much larger vegetation community type or landscape within which a birds presences and relative abundances are recorded.

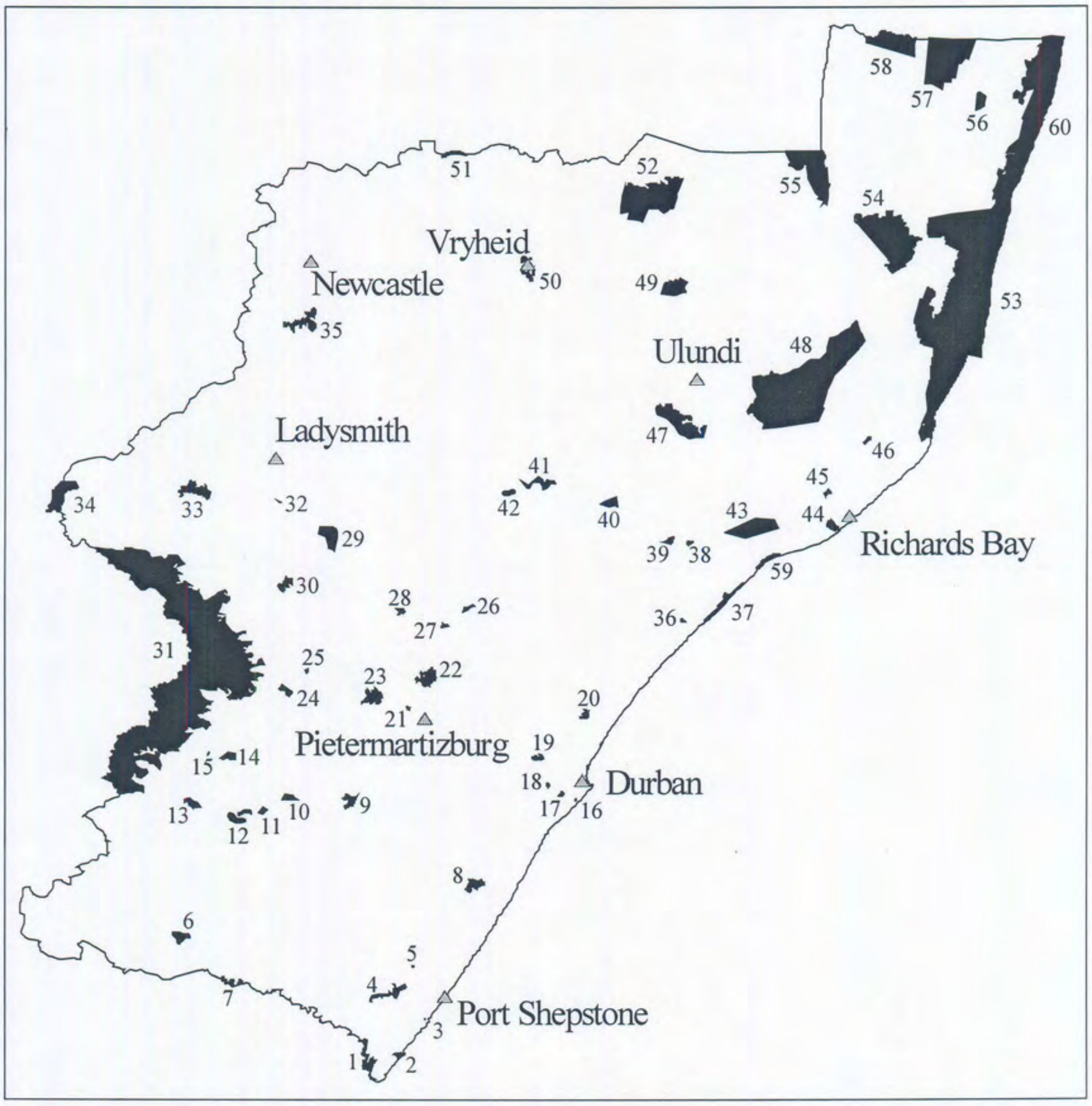

Figure 1.11: Protected areas of KwaZulu-Natal Province managed by KwaZulu-Natal Nature Conservation Services.

When approached from the regional scale, the plot sampling strategy leads to scale problems (Wiens, 1981) and to substantial under representation of less common species due to the shorter survey periods (Preston, 1948). The plots can usually provide ecologists with an idea of how species grade with the environment on a fine scale, but comprehensive bird species information for a vegetation type or landscape is always limited by time and sampling effort. The effort described in this thesis is a trade-off of spatial precision for more comprehensive community inventory in coarse mapsheet units. This study also has the added advantage of not having to worry about high frequency spatial and temporal effects (Preston, 1960).

Table 1.9: Names and descriptions of the protected areas managed by KwaZulu-Natal Nature Conservation Services.

Map Code	Name Description	Map Code	Name Description
1	Umtamvuna Nature Reserve	31	Natal Drakensberg Park
2	Mpenjati Nature Reserve	32	Tugela Drift Nature Reserve
3	Skyline Nature Reserve	33	Spoienkop Dam Nature Reserve
4	Oribi Gorge Nature Reserve	34	Royal Natal National Park
5	The Valleys Widlife Sanctuary	35	Chelmsford Dam Nature Reserve
6	Mount Currie Nature Reserve	36	Harold Johnson Nature Reserve
7	Bruce's Valley Natural Heritage Site	37	Amatikulu Nature Reserve
8	Vernon Crookes Nature Reserve	38	Dlinza Forest Nature Reserve
9	Soada Forest Nature Reserve	39	Entumeni Nature Reserve
10	Greater Ingwangwana River	40	Nkandla Nature Reserve
11	Greater Ingwangwana River	41	Qudeni Forest reserve
12	Greater Ingwangwana River	42	Tugela Gorge
13	Coleford Nature Reserve	43	Ngoye Forest Reserve
14	The Swamp Nature Reserve	44	Richards Bay Game Reserve
15	Himeville Nature Reserve	45	Enseleni Nature Reserve
16	Bluff Nature Reserve	46	Lake Eteza Nature Reserve
17	Stainbank Nature Reserve	47	Opathe Nature Reserve
18	Paradiase Valley Nature Reserve	48	Umfolozi-Hluhluwe Game Reserve
19	Krantzkloof Nature Reserve	49	Ngomi Forest Reserve
20	Hazelmere Public Resort Nature Reserve	50	Vryheid Mountain Nature Reserve
21	Doreen Clark Nature Reserve	51	Pongola Bush Nature Reserve
22	Albert Falls Nature Reserve (dam)	52	Itala Game Reserve
23	Midmar Dam Nature Reserve	53	Greater St. Lucia Wetland Park/Marine Reserve
24	Umgeni Vlei Nature Reserve	54	Mkuzi-Pumulanga Game Reserve
25	Fort Nottingham Heritage Site	55	Pongolwane Biosphere Reserve
26	Umvoti Vlei Nature Reserve	56	Sileza Forest Reserve
27	Karkloof Nature Reserve	57	Tembe Elephant Park
28	Blinkwater Nature Reserve	58	Ndumo Game Reserve
29	Weenen Nature Reserve (dam)	59	Umlalazi Nature Reserve
30	Wagendrift Nature Reserve (dam)	60	Maputaland Biosphere Reserve

1.5 Format

This thesis is presented as chapters that document a set of studies that are stand-alone papers. Several of the chapters have been published or are in press (Chapters 3, 4, and 5) and the remaining Chapters (2, 5, and 6) are prepared for submittal. The chapters, however, are designed around the central theme of conservation within human dominated systems, and thus the whole is much greater than the parts. Chapter 2 provides the reader with a background and justification to the theory of co-evolution and its integration within landscape ecology. The argument sets up the analytical framework to be used in the subsequent chapters to show the need for this type of approach for biodiversity conservation in developing nations. Chapter 3 details the creation and critiques the use of a landscape model for conservation area identification. Chapter 4 defines a methodology and procedures to use environmental gradient analysis in conjunction with complimentary-based reserve selection algorithms to analyze and prioritize avian conservation areas. The effort in Chapter 5 looks at multi-scaled spatial effects on avian diversity and community structure. The study determines how changes in landscape structure (both composition and configuration) affect bird populations in the spatially and temporally dynamic landscapes at the extents of South Africa and of KwaZulu-Natal Province. Chapter 6 provides pattern analysis of human dominated landscapes evolved in association with socio-economic variables. The emphasis is on the co-evolutionary model outlined in Chapter 2 and aimed at assessing the ideal reserve system for birds developed in Chapter 4. Thus, Chapter 6 brings together lessons and results developed in all the previous chapters to lend support to a revision of biodiversity threat models and analysis. The thesis work is then rounded off with conclusions providing a broader message on the impact of the results and delivering final thoughts on the stated effort.

2. Developing a Co-evolutionary Landscape Ecology Framework to Address Sustainable Biodiversity Conservation

To understand the crisis with respect to the destruction of biodiversity we urgently require an analytical framework, which takes into account socio-cultural values, economic systems, and the biophysical theater in which this tragedy takes place. The growing rates of this destructive process further urge the development of a conceptual framework aimed at understanding the responses of ecosystems to habitat destruction, with associated landscape change. Such information will be available by the integration of both field and theoretical studies. What needs to be articulated for defined regions of the world are the principles upon which the actual biodiversity threats have evolved. By developing an appropriate framework based on co-evolutionary thought and landscape ecology principles, the likelihood of potential landscape changes across a variety of systems may be assessed to guide conservation planning efforts.

Understanding the form, behavior, and historical context of landscape dynamics is crucial to understanding ecosystems and subsequent biological diversity at several temporal and spatial scales (O'Neill et al., 1986; Noss, 1990; Forman, 1995). This understanding and analysis should not be limited to the physical or natural history of landscapes, but must include landscapes within an anthropogenic context first noted by Sauer (1925). In essence, sustainability research with respect to biodiversity conservation could be better addressed by way of a co-evolutionary landscape ecology framework.

There have been numerous calls for the study of landscape or ecosystem diversity and function for conservation purposes (e.g., Noss, 1983; Forman, 1989; Franklin, 1993; Forman, 1995; Walker, 1995; Risser, 1995; Folke et al., 1996). Because conservation of species diversity depends on conservation of the habitats and landscape ecosystems in which species live (Noss 1990; Franklin 1993), a greater attention should be given to understanding and examining the economic, social, and cultural diversity of human groups in landscapes within regions. Fundamentally, landscapes can be viewed as the critical spatial scale at which biodiversity is minimized, as it is the scale where macro and microeconomic policies converge.

This chapter argues that problems related to biodiversity loss, landscape resilience and ecosystem integrity have at their root a co-evolutionary response. A conceptual development and proposed research agenda to enhance the theoretical and application framework for biodiversity conservation planning within developing country landscapes is expressed.

2.1 Sustainability and Resilience

As the scale of the world's socio-economic situation continues to grow there is increasing demand for land and its resources. A firmer knowledge of changes in the diverse landscapes of developing countries must aid the urgent need to join environmental management that is sound with economic development that is viable in the long-term. The imperative for conservation-with-development has been labeled "sustainable development" (Goodland, 1995). Much publicized mandates for sustainable development echo forth as a *sine qua non* of conservation in the developing countries of the world, a seeming panacea for the world's environmental problems. Nonetheless, sustainable development has remained a general concept and one that is subject to unending debate (Redclift, 1987; Dovers and Handmer, 1993; Meffe and Carroll, 1997). Indeed the more exact meanings of sustainability are typically lacking. The most widely used definition of sustainability states: 'A sustainable condition is one in which there is *resilience* for both social and physical systems, achieved through meeting the needs of the present without compromising the ability of future generations to meet their own needs' (WCED, 1987).

Stability is substituted in the original statement for the operative term, resilience (Holling, 1973; 1986), which is required of a system to return to a "stable" state. For sustainability, the concept of ecosystem resilience becomes crucial for biodiversity conservation. Resilience represents the ability of ecosystems to recover from or adjust easily to disturbance, and the speed with which they return to an attractor state (Pimm, 1984), which can be deemed "stability." Following the work of Holling (1973; 1986), resilience can be used to identify the existence of functions within systems that, at any given moment, are offset from any one of a number of locally stable attractor states. Resilience in this sense is a measure of the perturbation that can be absorbed before an ecosystem in the domain of one attactor state is dislodged into that of another attactor state (Folke et al., 1996). It is essentially the capacity of the system to buffer disturbance. The essential condition for the resilience of a system in order to persist is determined by spatial heterogeneity and the associated biotic diversity, based on Elton's (1958) original hypothesis that ecological stability should depend on biological diversity. There have been many conceptual and empirical advances, and debates (e.g., Woodwell and Smith, 1969; Pimm, 1984; Holling 1986; Tilman, 1996; Tilman et al., 1996) on the importance of diversity within systems.

At the landscape scale, biotic processes, interacting with abiotic ones, can control structure and variability. This is also the scale range where human land-use transformations occur, so that the area where plant and animal controlling interactions unfold is the same area where human activities and population interact with the landscape. The landscape concept is appropriate for sustainable planning because it is sufficiently large to contain a heterogeneous matrix of LCLU elements that provide a context for mosaic stability (Forman 1990; 1995).

2.2 Biodiversity Protection Strategies

Efforts to conserve biodiversity remain largely rooted in the concept of species, a most ephemeral part of an ecosystem. Species-based approaches address only a small part of biological diversity because they ignore different levels of organization and the functional linkages among these levels (Noss, 1983; Pimm, 1991; Maddock and du Plessis, 1999). Broadening our view of biodiversity into one of ecosystem hierarchy and diversity highlights that the species diversity of an ecological system is a systems-related attribute (Noss, 1990; Jizhong et al., 1991). A focus on ecosystem diversity underscores the inherent value of the systems, apart from which the myriad of species cannot survive.

To be sure, the most important considerations, which are typically directly ignored, for any of the conservation methodologies outlined in Chapter 1 are the role human societies, values and economies play as threats and protectors of biodiversity. Conservation based public agencies and academic conservation biology tends to disassociate themselves from the human-side of the analysis and only focus on their biological domain science. Humans' are a part of natural systems and by their evolutionary nature disturb “natural” habitat (e.g., through habitat loss, fragmentation) and altercate key resources (e.g., water, soil, climate), which in turn affects the species, community assemblages and food webs in the hierarchy (Figure 2.1). A logical framework for understanding the interactions of human threats has not been considered in species or broad model approaches of conservation planning, although they are the dominant causes of biodiversity loss (Ehrlich and Wilson, 1991).

2.3 Critique and Reconstruction of Problems

The multi-dimensional and multi-disciplinary field of sustainability encompasses the traditional academic disciplines of ecology, economics, sociology, developmental studies, and philosophy (Norgaard, 1988; van Jaarsveld, 1996). It strives to integrate social, economic and environmental goals into a single manageable framework capable of directing regional and global development towards a more just and equitable future (Munasinghe, 1993).

Several problems continue to hamper the scientific communities ability to address sustainability and the integration of the environment, society and economics. The following problems currently challenge sustainability and biodiversity conservation:

- The fallacy of "natural" nature. There is little point in regretting the history that has made humans or exotic species part of the ecosystem they now inhabit (e.g., Cronon, 2000).
- The view that there is an achievable end state.

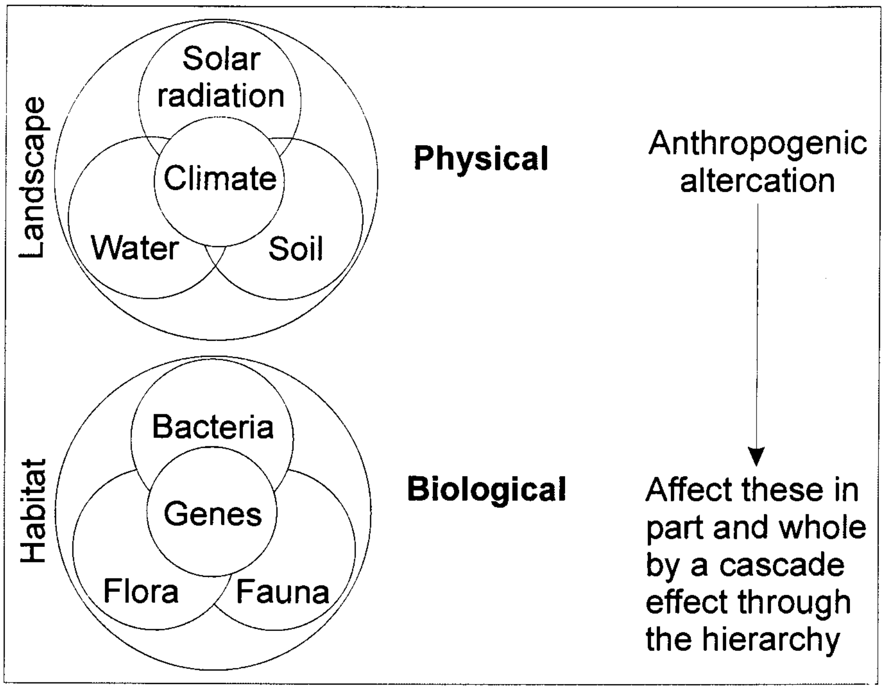

Figure 2.1: Key resources appropriated through human action and the biota that are affected through a hierarchical cascade.

- The role of isolation, i.e., one discipline or segmented disciplines driving development and conservation. Problems tend to be isolated, rather than acknowledging their true connective nature.
- The drive toward one correct analytical framework, when there are more than one way of looking at solutions.

A continuation of previous ideas and opening new ways of thinking and viewing our current crisis with biodiversity loss needs to be explored. The following proposed profile of reconstruction should continue the debate:

- The development of shared learning.
- A co-evolutionary understanding of development and the biodiversity crisis in especially developing countries.
- The continued acknowledgement and support of the role of resilience with the adoption of adaptive environmental management (e.g., Holling, 1996). This follows on the realization that most ecosystems are in various levels of dis-equilibirium and that policy must remain flexible and evolutionary.
- The need to develop models of macro/micro scale interaction in order to build realistic conservation impact scenarios for planning and policy assessment (e.g., Dale et al., 1994).

- The continued acknowledgement of spatial variation and scale as important factors in understanding environmental systems (e.g., Wiens, 1989b)

One of the principle aims of a co-evolutionary dynamics model is to establish human-ecosystem interaction within an interpretative/interrogative framework. We must develop a critical, evaluative methodology, which stresses a multiple interpretative framework and is consistent with the need for a multiple modelling strategy. This is an acknowledgement of the impossibility of any single model adequately encompassing the diversity of social and environmental phenomena, which comprise co-evolutionary systems.

Essentially all model characterizations of human-ecosystem processes are of necessity both incomplete and proximate; thus we need a variety of model scenarios not only at different temporal and spatial scales, but also at different levels of social and natural aggregation. We need a research framework, not only capable of encompassing qualitative and quantitative observational sets, but moreover, one in which empirical data can be situated within an interpretive frame of reference. By proposing a co-evolutionary landscape ecology framework we are looking for systematic ways of linking disparate bodies of knowledge, currently resident in discrete academic boxes. The conceptual structure must be able to facilitate and allow interrogative dialogue between qualitative and quantitative data sets. To truly understand what is needed for sustainable biodiversity conservation, a scheme should encompass three distinct areas of knowledge acquisition interlinked and focussed on supplying information and knowledge for shared learning (Figure 2.2). This framework avoids reductionist methods, which stress the importance of arriving at a single unambiguous model as the basis of prediction. In contrast the goal is directed at the representation of human-ecological systems with a view to a more complete understanding of biodiversity threat and uniquely tailored regional action. Therefore, we need more, rather than fewer representations so as to create a more effective dialog.

Monitoring indicators should be able to provide information on long-term LCLU patterns of the locale, along with attendant social and political constraints within which resource management strategies were implemented. The relationship between power structures and the land provides new information on the rates of resource exploitation, human demography, and the differential resilience of specific landscape units to support biodiversity. The nature of this framework should be able to generate a series of scenarios arriving, not at any single predictive

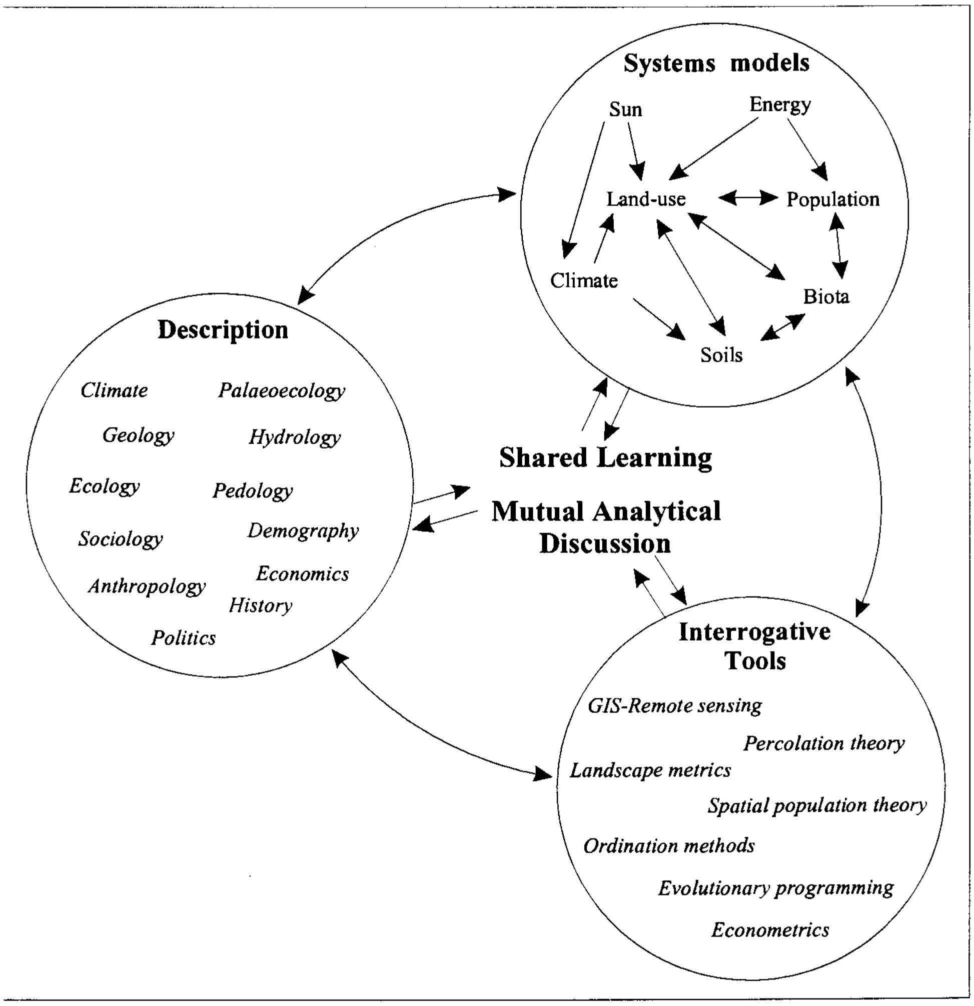

Figure 2.2: A shared learning framework for assessing human-ecosystem sustainability dynamics.

model of unsustainability, but at a series of potential evolutionary pathways to which the landscape or region is prone. In a sense, it is a mapping of the 'possibility spaces' within which human settlement and ecosystem functioning can persist, and within which is nested a probability space of human action.

Limited resources for the protection of the environment and the rising competition between land-use developments in developing countries call for appropriate conceptual frameworks and relevant methods for facilitating and analysing trade-offs and compromises. The methodology must encompass economics, socio-cultural and environmental attributes in a disaggregated fashion to understand a regions overall vulnerability with respect to sustainability. Van Jaarsveld (1996) offered one way of looking at the highly disaggregated data that are typically acquired from each of these sectors. It was suggested that the development of highly aggregated indexes may have significant political advantages in communicating with the public and policy-makers, but they do not provide an ideal or adequate framework within which political action should be prioritized. Instead a framework should be developed that would require an evaluation of disaggregated data, and leaving the researcher with the problem of dealing with, and interpreting, complex environmental, social and economic data matrixes in the absence of a simplistic 'cause-effect' understanding of interactions between these variables or their social values. In biodiversity conservation planning in developing nations, there is a need for analyses that are able to answer questions of viability or security of conservation practices in the face of anthropogenic land-use changes driven by global economic policy. An integration of complex environmental and socio-economic indicators should provide the information needed to answer questions pertinent for sustainable biodiversity conservation.

2.4 Evolutionary Pathways

2.4.1 Co-evolutionary Framework

There need be little doubt that the landscapes we have today (homogeneous and heterogeneous, 'wild' and humanized, fine-grained and coarse-grained), and hence the ways in which cultures interact with nature, have been strongly influenced by historic economic instruments. Increasingly aspects of social organization as well as the paths of knowledge and technology advance affect the pathway landscapes assume (i.e., pattern and process). Norgaard (1988; 1994) presents this aspect of viewing these interactions between economics and other factors by borrowing from evolutionary, and in particular from co-evolutionary, explanations of change, portraying development as a process of co-evolution between knowledge, values, organizational, technological, and environmental systems (Figure 2.3). In Norgaard's (1994a; 1994b) portrayal, each of these systems is related to each of the others, yet each is also changing and affecting change in the others. Deliberate innovations, chance discoveries, random changes, and chance introductions from other societies occur in each system which affect the fitness and hence the distribution and qualities of components in each of the other systems. With each system putting selective pressure on each of the others, they co-evolve in a manner whereby each reflects the other. This type of thinking is consistent with landscape ecological theories which incorporate the interaction of humans and species immigrations, emigrations, and populations effecting pattern and process leading to state changes (Forman, 1995). Co-evolution explains how everything is tightly locked together, yet everything is also changing. This approach could be used as a conceptual underpinning to understand current and future biodiversity threats and to assess the sustainability of protected areas.

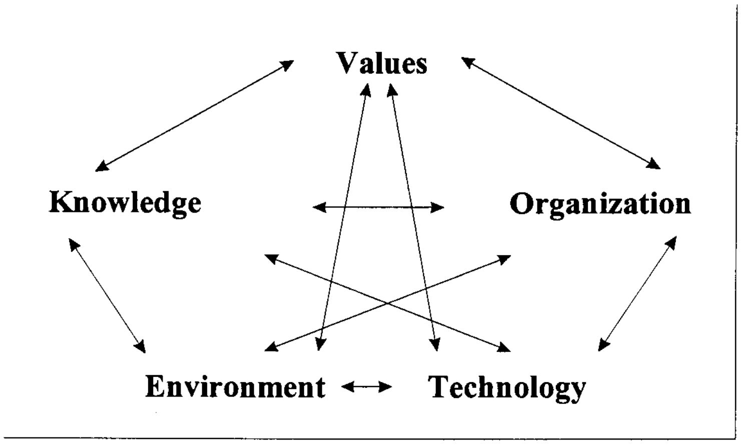

Figure 2.3: A co-evolutionary view of development (Norgaard, 1994).

2.4.2 Non-linear Dynamics

Discoveries in the natural and physical sciences have demonstrated the evolutionary pathways traced by non-linear systems, and their convergence towards a variety of stable, quasi-stable and unstable states. These trajectories are reached through a sequence of bifurcations, during which the system undergoes qualitative change (Laszlo, 1987). A fundamental aspect of human-environment relationships is the opposition or tension between temporal rhythms, which are embedded in natural processes and those resident in societal structures; the asymmetries between them provide the context for abrupt discontinuous transition through bifurcation (Figure 2.4). In this presented case the bifurcation is symmetric and represents the pathways of spatial landscape change. Since humans are an intimate part of landscapes the process of landscape pattern evolution begins with habitat perforation or dissection leading to fragmentation, shrinkage of fragments and finally a lengthy process of attrition of the remaining fragments (Forman, 1995). The land-use types that replace the natural habitat add to the diversity of the landscape till at some point the attrition of the natural remnants is so great that the homogenizing forces of human development at some defined analytical scale renders the landscapes simple again.

Human-environment systems are a prime example of the operation of non-linear dynamical processes. They are governed by interlinked sets of non-linear processes, which resist obvious disaggregation into systemic subsets- something which conventional reductionist methodologies force upon them. An important property of such complex systems is the role played by feedback mechanisms, which amplify or reinforce human physical and social processes. For example, the development of economic core areas and a poor periphery appears to be the process of cumulative and circular causation.

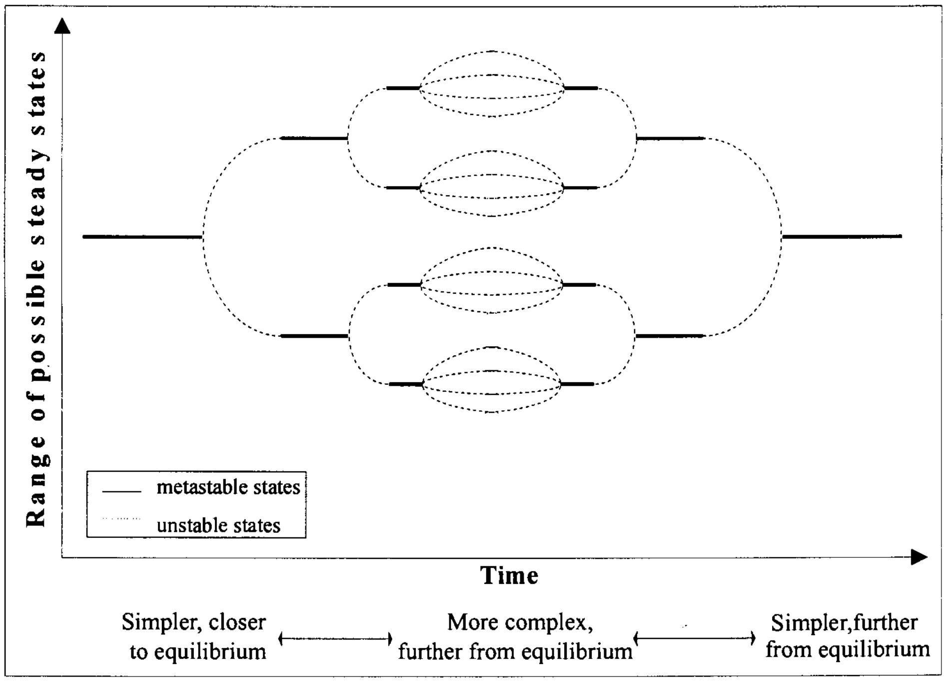

Figure 2.4: Bifurcation diagram of the probable development of landscape pattern.

The existence of external economies, economics of scale, and agglomeration in core areas, compounded by the provision of transportation networks, serve to enhance and capitalise upon existing advantages of relative locations.

In the language of dynamical systems, two elementary concepts are important: the notion of phase space and the other is concerned with the concept of attractors or basins of attraction (for more detail see Waldrop, 1994). First, phase space can be thought of as a geometric representation of the universe of possibilities possessed by a system- in a sense, the allowable territory within which it operates- an arena in which a phase portrait of the evolutionary history of the system can be constructed. Second, is their long-run behavior, which is manifest by a particular attractor; a region of the phase space to which all points ultimately converge. It is effectively the 'signature' of the system.

With respect to human-modified landscapes under discussion here, what we are faced with is an empirical situation in which a number of different attractors are co-present. In a sense they inhabit an operational space constrained by non-linear causality on account of the multiple periodicities represented by the wide variety of temporal rhythms, which define natural ecological phenomena and their constant modification by human social groups who themselves are defined by alternative periodicities (i.e., economics). Research in a number of fields has shown that non-linear feedbacks can amplify these rhythms causing either catastrophic collapse (Holling, 1986) or the emergence of spontaneous structure (Allen, 1993), with the system evolving to a new qualitative state.

2.4.3 Landscape Socio-ecodynamics

To elaborate the process within the context of landscapes, imagine that the systems of Figure 2.3 - values, knowledge, social organization, and technology - are made up of different ways of valuing, knowing, organizing, and doing things. Similarly the landscape (environmental) system consists of different types of species and other particular ecological factors which it starts with before human contact (Figure 2.5). From a starting pre-human landscape geography (T_0) a perturbation (unstable state) occurs whereby a particular human social organization arrives randomly, allowing that landscape to co-evolve (T_1) to a new characteristic look (pattern, process, use) with relative stability. Sauer (1925) originally referred to this process as landscape morphology, where a landscape environment could take a multitude of pathways making prediction difficult. In effect changes within any one of the components from Figure 2.3 acts to evolve the landscape development process conceptualized in Figure 2.4 and simplified in Figure 2.5. The process of experiments, discoveries, chance mutations, and introductions within each of the systems (Figure 2.3) drives co-evolution across all of the systems simultaneously and thus creating bifurcation on the landscapes. The landscape bifurcations described in Figures 2.3, 2.4, and 2.5 helps us to understand how policy overriding economic, social and environmental systems (Figure 2.6) can cause critical instabilities (bifurcation) and thus instigate a new co-evolutionary pathway within a landscape. Policy is a fundamental determinant of the way natural resources are exploited and/or conserved and how human systems are organized. In South Africa the separate development policies of the Ex-Apartheid State created spatial separation and development pathways for local indigenous African versus colonial Europeans. The landscape character of the created African tribal homeland system versus the Western industrial development model of White South Africa are still clearly evident today (Fairbanks et al., 2000). The commonly held implications of this can be the asynchronous rhythms between the natural world, societal reproduction and consumption patterns which challenges the sustainability of landscape biodiversity conservation. Munasinghe and Cruz (1995) note that linking specific causes with particular effects is especially difficult where many conditions are changing simultaneously. However, it is usually possible to identify a small number of linkages affecting high priority environmental concerns.

Through the process of co-evolution, the world's landscapes can be thought of as having become a patchwork quilt along a gradient of loosely to strongly interconnected, co-evolving social and ecological systems. Within each landscape the ecological system evolved in response to cultural pressures and tended to reflect the values, worldview, and social organization of local peoples. At the same time, the cultural system in each landscape evolved within the constraints imposed by the ecosystem and hence tended to mirror the fertility, species composition, stability, and management options presented by the ecosystem.

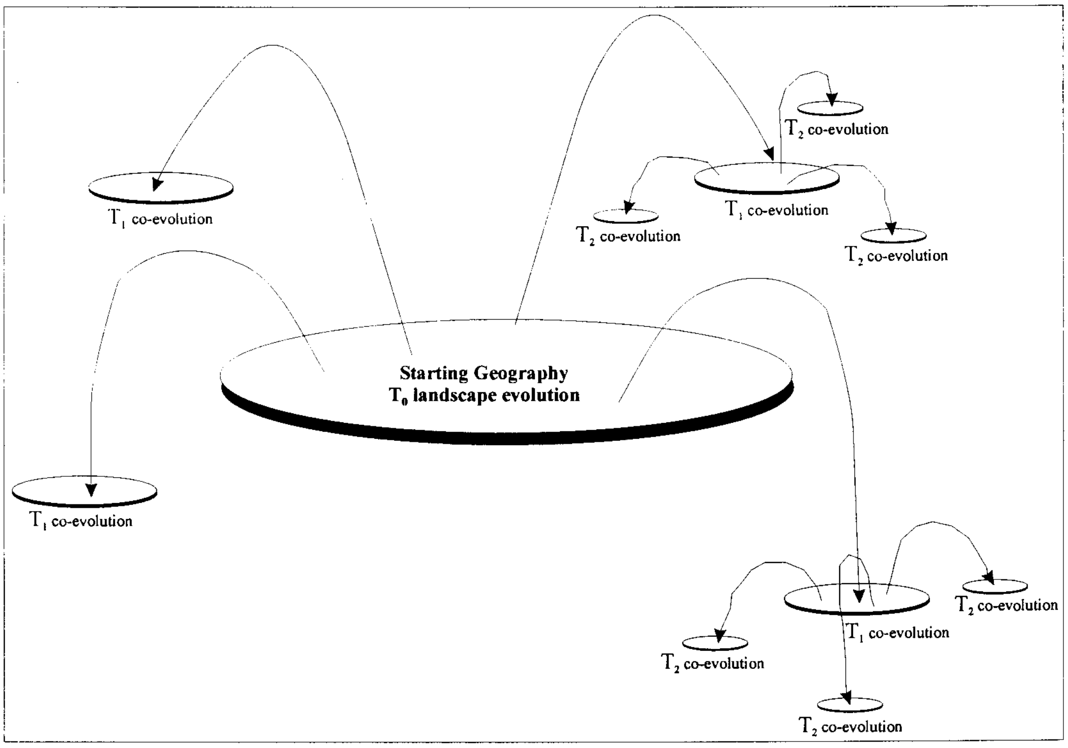

Figure 2.5: Conceptual diagram describing the process of co-evolution within landscapes.

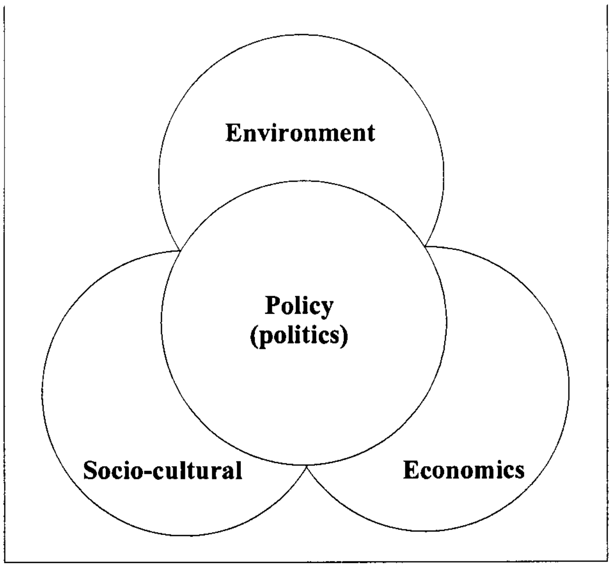

Figure 2.6: The interaction among the major sectors affecting sustainable development. Policy-political action oversees and drives decisions and actions taken in the other sectors.

Therefore, each landscape takes on unique characteristics particular to the non-random biological and cultural structuring occurring within the landscape mosaic. This reading of a landscape can provide us with a valuable framework for examining developing countries. Developing nations area able to illustrate co-evolution more clearly than technologically advanced nations (Norgaard, 1994). Information about the path a landscape or region has co-evolved along may let us interpret future actions. Future landscape paths could be assessed in terms of objectives such as sustaining biodiversity both in the unprotected landscape matrix and formally protected areas.

2.5 Landscape Ecology Principles to Ensure Sustainability

The real world is represented by finely fragmented habitats interwoven with human-altered environments. This is especially true in southern African landscapes where nomadism, colonialism and the ever rising human population have affected every part of the region in some way, shape or form (Puzo, 1978). The vast majority of biotic inhabitants that occur across the remnant pockets of the original environment are important. The species that can survive in the habitat fragments come together to determine the integrity and resilience of ecosystems to a range of environmental perturbations. In essence biodiversity loss has a direct impact on the ability of interdependent ecological-economic systems to maintain functionality, and thus in a policy sense, sustainability. In South Africa, for example, the vast majority of the natural landscape is fragmented by land-uses (Fairbanks et al., 2000), which presents logistical problems for conservation planners using species-based reserve selection designs (Lombard et al., 1997; Wessels et al., 2000). African conservation analysis frequently still maintains the false expectation that large pristine tracts of 'natural' habitat to support irreplaceable species will be available in seas of poverty (Western, 1989; Adams and McShane, 1996).

Landscape ecology has been broadly defined as the study of the effect of landscape pattern on ecological processes (Turner, 1989). In a clearer sense landscape ecology is the study of how landscape structure affects (the processes that determine) the abundance and distribution of organisms. The object of landscape ecology is not to describe landscapes, but to explain and understand the processes that occur within them. Certainly, the most challenging aspect is to extend this discipline to the analysis of pattern in a socio-economic context, given the need to find more sustainable forms of landscape management.

The application of the principles of landscape ecology in the formulation and solving of problems is of interest here. Human influences in landscapes tend to eliminate gradual changes and to produce abrupt boundaries, however the diversity of human cultural groups and their subsequent economic development levels based on a combination of policy, historical, and environmental factors effect landscapes and biotic diversity in a variant of ways. Landscape metrics employed to quantitatively measure the spatial patterns of boundaries and patches within a natural landscape (Turner, 1989) could be linked to socio-economic and cultural systems to assess the health of ecological systems (O'Neill, 1999; O'Neill et al., 1999) for biodiversity conservation.

The ecological structure, function, and potential change of landscape mosaics need to be understood within the socio-cultural and economic structures of a region to adequately address sustainable conservation action. The spatial arrangement of local ecosystem level components and land-uses within a landscape within a region will have an affect on the areas ecological integrity. To understand an area's conservation potential one must understand an areas current and future landscape function, but within human economic and social systems. Thus, landscapes should be perceived as the tangible matrix of the total human ecosystem (sensu Naveh, 1997), and therefore as concrete systems in their own right and not just as ecosystems on km-wide stretches.

2.5.1 Hierarchy, Scale, and Landscape Metrics

This argument to consider the evolution of human-ecosystem interactions within a complex, co-evolutionary context governed by metastable states, means that the resulting ecodynamics of pattern and process can be viewed from a hierarchical perspective (O'Neill et al., 1986). A key concept is that ecosystem processes operate over a wide spectrum of rates, and these can be assembled into discrete classes. The structure imposed by these differential rates allows the system to be decomposed into organizational levels, with each level being segregated on the basis of response times (i.e., higher levels associated with slower rates, and lower ones by more rapid rates). Within such a scheme, ecosystem structure is viewed as a series of weakly coupled sets within a hierarchy of process rates involving biotic interaction and abiotic factors. The non-linear couplings in these processes are further complicated by human action, whether as the result of un-coordinated stochastic events or by a series of policy-directed interventions (Giampietro, 1994).

Scale is critical, for as spatially heterogeneous areas, landscapes may exhibit stability at one spatial scale, but not at another. Thus, the scale at which observations are made profoundly influences the research and analytical interpretation process (Turner, 1989; Wiens, 1989b). In this case a variety of local and regional studies would be ultimately required to confidently provide conservation planning and management strategies.

Analysis of landscape pattern makes use of measurements of the connectedness, diversity, shape complexity, and size of land-cover patches to study ecological condition at local to regional scales (Turner and Gardner, 1991). These metrics (O'Neill et al., 1988; Ritters et al., 1995) have been used to assess landscape condition (Krummel et al., 1987; Wickham et al., 1999), infer ecological process from pattern (Milne, 1992; Fahrig, 1997), and show how landscape configuration can impose constraints on biological populations (Pearson et al., 1993; Flather, 1996; Flather and Sauer, 1996). From a regional perspective, land-cover patterns may be considered as either forcing or constraint functions for sub-regional dynamics, or as integral parts of strictly regional models (Allen and Starr, 1982). Information about land-cover patterns has proven useful for both local and regional assessments of ecological condition (Vos and Opdam, 1993).

Landscape metrics are a set of tools that can be used to measure pattern, which can be correlated to ecological processes, biodiversity persistence, and define 'spatial signatures' which describe the co-evolutionary response of landscapes (O'Neill et al., 1996; Wickham et al., 1996). Therefore, by using a monitoring framework to quantify spatial patterns and their changes (O'Neill et al., 1999) we can quantify their effect on ecological processes and then combine these indicators with biodiversity elements, socio-economic, and cultural information to provide a integrated conservation solution.

2.5.2. Measuring the Ecological Effects of Landscape Pattern

Physical location, transportation costs, social climate and policy often determine the profitability of an economic activity. In turn, economic activity is the primary determinant of landscape pattern and change, and therefore the resiliency of ecosystem function. Co-evolution of human-ecosystem dynamics develop positive feedback loops which enforces landscape pattern 'signatures.' This allows remotely sensed imagery, GIS, and landscape ecological metrics to be combined into a powerful approach for interrogation and interpretation of the pattern, which can then be back related to social, economic, and environmental indicators. For example, let us assume that we wish to evaluate the status of the landscape pattern for several defined co-evolutionary landscape regions. We could ask how far the present landscapes deviates from an ideal landscape for sustaining all hierarchical levels of species diversity with complete habitat cover (high dominance) in large (un-fragmented) and complex patches. We might also ask how far the landscape deviates from a total state of ecosystem decay with many human land-use and natural land-cover types (low dominance), in dissected (fragmented) and simple patches.

In statistical parlance, the 'response' variables in landscape ecology are abundance/distribution/local process variables, and the 'predictors' are variables that describe landscape structure. However, in order to understand present co-evolution from past interactions the 'responses' are variables that describe landscape structure, and the 'predictors' are the economic, socio-cultural, and environmental indicators. Gradient analysis may provide a promising analytical approach to understanding the effects of multiple stressors on ecosystem functioning (Whittaker, 1967; McDonnell and Pickett, 1993) by integrating the complexity of multiple stress effects across the landscape (McDonnell et al., 1995). The gradient approach relies on the assumption that graduated spatial environmental patterns govern the structure and functioning of ecological systems. Changes in population, community, or ecosystem variables along the gradient can then be related to the corresponding spatial variation in the environmental and socio-economic variables, with specific statistical techniques dependent upon whether or not environmental variation is ordered sequentially in time or space, and whether single or multiple variables are being monitored. In the case of system responses to multiple stressors, complex, nonlinear gradients are apt to be present and ordination techniques may provide insight into the

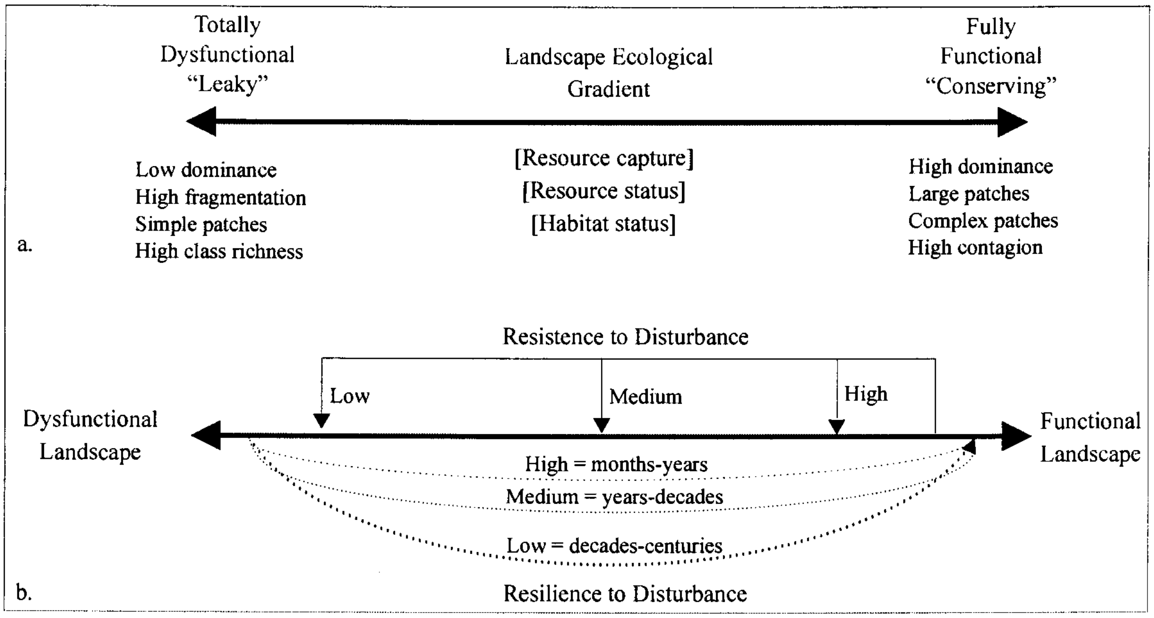

Figure 2.7: Landscape functionality as: (a) a continuum from functional to dysfunctional, and in relation to (b) resistance and resilience to disturbances (modified from Ludwig, 1999).

biotic responses to these gradients (ter Braak and Prentice, 1988; Jongman et al., 1995). Therefore, how well a landscape functions to conserve resources and maintain biodiversity could be viewed as a continuum (Figure 2.7a). Ludwig (1999) proposed a conceptual model that deemed landscapes as "fully functional" when they conserve resources to maintain rich and diverse environments that provide many habitats suitable for a high species richness. At the other end of the spectrum, a landscape may be very dysfunctional where all resources 'leak' from the system, resulting in a landscape with poor resources and no habitats suitable for species. The concept of stability (resistance and resilience) can then be applied to how disturbances affect landscape functionality. Resistance refers to the ability of the system to remain unchanged when disturbed, while resilience refers to the ability of the system to rapidly return to an assumed equilibrium state. Using these definitions (Figure 2.7b), a landscape has low resistance if a disturbance causes a highly functional system to become dysfunctional. A landscape with high resistance will only slightly shift down the continuum under the impact of the same disturbance. Highly resilient landscapes will rapidly recover, for example, in a matter of months or a few years, to a displacement down the continuum caused by a disturbance. Landscapes with low resilience may take centuries to recover from this same disturbance. This conceptual model could show promise in being able to assess various landscape environments and the drivers that have 'pushed' them into different 'states' or pathways (McIntyre and Hobbs, 1999).

2.6 Socio-Ecosystem Interaction

Following on the argument developed so far, this chapter proposes an enhancement of the theoretical framework for biodiversity conservation planning by integrating both anthropogenic and ecosystem integrity goals into a decision framework guided by co-evolutionary theory and landscape ecology methods. The basic principle encompasses a larger approach to biodiversity protection, by protecting levels of biodiversity linked by process and spatial organization. This is the underlying concept for integrated approaches to the management of land resources (e.g., Noss, 1990). The implementation of landscape level plans in routine environmental policy and planning is complex, but if we understand that environmental change is a co-evolutionary process that acknowledges pluralistic systems then suitable frameworks can be developed for protecting biodiversity based on each regions particular issues rather than on a general model.

In studies of the causes and consequences of tropical deforestation in Rondonia, Brazil, Southworth et al. (1991) and Dale et al. (1993; 1994) indirectly developed a co-evolutionary model. The authors acknowledged land-use change as one of the major factors affecting global environmental conditions and that to address the problem, spatially combined explicit ecological information and socio-economic factors. This aspect is particularly needed within developing countries. In Figure 2.8, a framework is presented for developing a methodology that integrates the idea of co-evolution by addressing the state of human social and economic welfare, the biodiversity profile and the landscape ecological attributes of a defined region. Ethical stewardship of the environment requires that society monitor and assess environmental change at the national scale with a view toward the conservation and wise management at the local scale (O'Neill et al., 1997; O'Neill et al., 1999). Most social and economic indicators are measured at regional levels, while some of the most important environmental and social changes occur at a landscape scale (e.g., Forman, 1995). The landscape scale is important because political decisions to manage natural resources are made at broad scales, such as catchments. Decisions about how to change land cover may be made by individual landowners, but their impacts are seen cumulatively, as a change in spatial pattern on the landscape. These decisions are usually also a reflection of global, national and regional policy, economic or social situations that draw attention to a hierarchical reading of these co-evolutionary systems. Resulting data from 'representative' reporting zones (e.g., political districts, catchments, etc.) of economic, socio-cultural and environment- reflecting the true state of society and nature- are recorded and analyzed hierarchically (Figure 2.8) within some defined multidimensional data reduction method.

For example, in sub-Saharan Africa women and children invest enormous energy in obtaining domestic energy from fuelwood and herding cattle. Dasgupta (1993) has described the complexities of interactions among population growth, poverty, and environmental deterioration. Men are typically part of a migratory labor system whereby they leave the rural tribal areas for temporary work on the mines and in industry. Monies are sent back to their wives for food and cattle purchase, which is equated as wealth accumulation (Hall, 1987). As the human and cattle population grows in these areas grazing range is placed under greater pressure leading to land degradation. An examination of KwaZulu-Natal, South Africa illustrates this pattern noted by Dasgupta (1993) and Ehrlich et al., (1995) whereas areas of low male to female population ratios in developing countries have a higher percentage of degraded land (Figure 2.9). In KwaZulu-Natal this can be depicted as a systems model (Figure 2.10), which has been documented historically (Cole, 1960) and linked anthropologically (Hall, 1987). Therefore, along with economic geography models, culture should also be assigned a central role in any theory

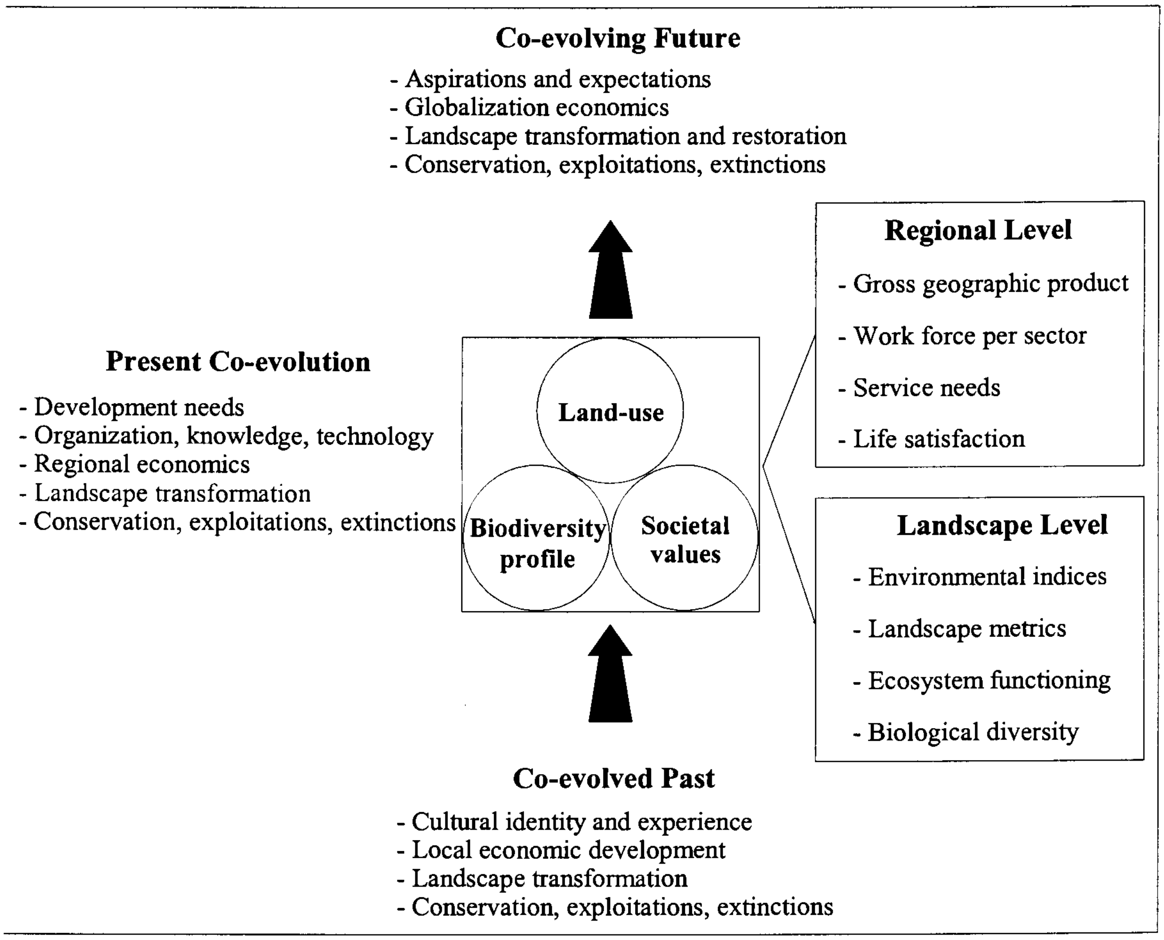

Figure 2.8: An overview of the hierarchical indicator reading framework for analysing co-evolutionary dynamics.

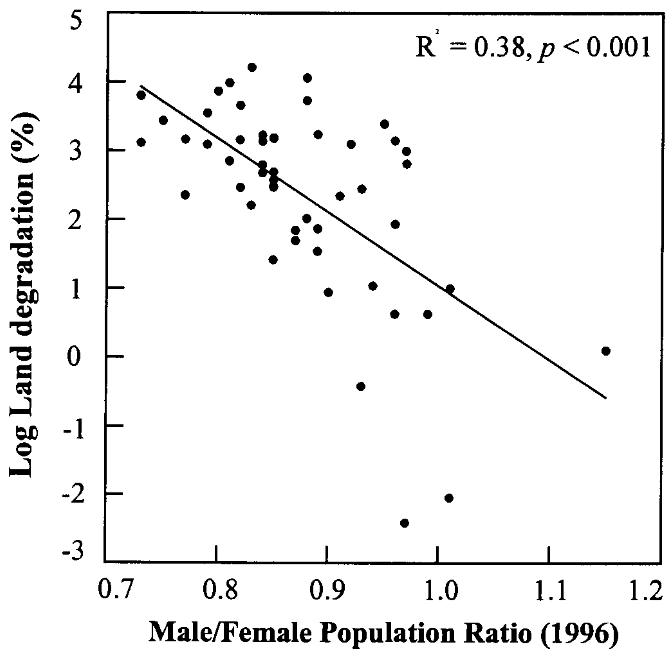

Figure 2.9: Linear regression relationship of male/female population ratio to percentage degraded land per magisterial district in KwaZulu-Natal (N=52). Human population data from 1996 census and land degradation assessment from the South African National Land-cover Database (Fairbanks et al., 2000).

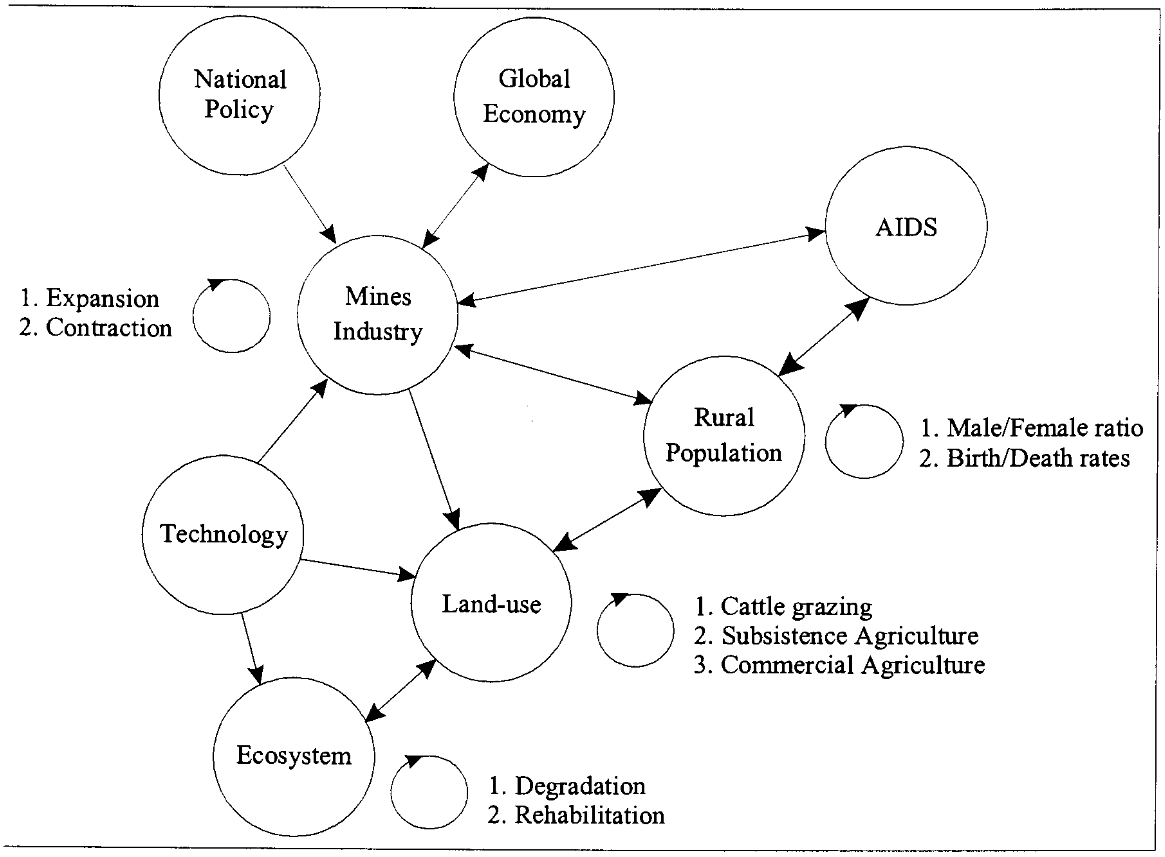

Figure 2.10: Economic core and poor rural periphery systems model of landscape development within rural African communities in South Africa.

purporting to characterize the process of land-use intensification and landscape pattern development among rural African communities.

2.7 Co-evolutionary Implications for Sustainable Biodiversity Conservation

The primary implication of the foregoing discussion is the need for a conceptual retooling and use of multiple analytical methods if we are to come to a more complete understanding of the future development of human-ecosystem interactions on biodiversity conservation. The proposed framework fundamentally changes our ideas with respect to evolution, human-ecosystem interactions and long-term predictability. This argument also draws attention to how much deeper an understanding can be made of developing nations through transdisciplinary research and shared learning.

The implications of the role of non-linear phenomena in generating long-term dynamics is a pre-requisite for understanding the evolutionary processes which structures landscapes and subsequent biodiversity loss. This type of thinking effectively renders evolutionary models which support linear, simple trajectories redundant (see Turner et al., 1996; Wear et al., 1996), stressing the fact that human-ecosystem dynamics within landscapes seen as long-term history can more usefully be conceptualized as a series of transformations of structuring and restructuring over time. Essentially, if human-ecological systems are prone to complex co-evolutionary pathways and the kind of 'structured disorder' associated with chaos, then this has significant consequences for biodiversity conservation and general land management policy decisions (e.g., Holling, 1986).

In developing countries simple systematic conservation planning may fall short in informing conservation planners and policy makers as to the future persistence of ecosystems, landscapes, and species populations. A new model of co-evolutionary landscapes incorporating social, cultural, economic, as well as environmental indicators (species, habitats, landscapes, landscape metrics) is needed to understand and develop conservation management plans which incorporate the goal of persistence (sustainable biodiversity). Although preserving biodiversity through formal protected areas is an important short-term step, it will not be sufficient to solve the problem of biodiversity loss (Western, 1989; Shafer, 1994). Reserves are embedded within the larger environment, and most reserves alone cannot deal with ecological attributes that cover larger scales (e.g., broad climate, global climate change). Thus, conservation efforts should firstly be planned at the scale of the regional landscape to assess the available landscape matrix of 'natural' fragments. Small reserves will lose their distinctive species if they are surrounded by a hostile landscape (Askins, 1995; Baillie et al., 2000). Reserves, as islands in a sea of change driven by interconnected economic and social systems, may not be a basis for sustainable biodiversity conservation.

Moving toward a model of a co-evolving patchwork quilt of discursive communities conceptually presents social systems as systems against a responsive environmental backdrop. These landscapes will change over time through mergers and divisions as the social and environmental systems co-evolve. The strategy is to use the available social, economic and environmental data in an analytical framework that helps promote sustainable landscape and regional social, economic and environmental systems.

Conservation International (1998) revealed that just seventeen nations collectively claim more than two-thirds of all known species worldwide, making conservation efforts in these 'megadiversity' countries essential for the survival of Earth's natural heritage. Not surprisingly, fifteen of the countries singled out are considered developing. These countries are also home to a major portion of the planet's cultural diversity, perhaps even a larger percentage than for biodiversity. Positive human welfare is directly related to sustainability of the environment and is the critical link in the chain towards a comprehensive conservation (persistence) goal. It should be apparent, that human welfare has to be met at the same time as biodiversity conservation, for they are not mutually exclusive.

3. Identifying Regional Landscapes for Conservation Planning

Landscape ecology has made a significant contribution to conservation biology (Noss, 1983; Noss, 1990; Hansson and Angelstam, 1991; Forman, 1995). However, much of the landscape ecological research that investigates biological conservation problems has not occurred within appropriately defined landscapes, rather relying on arbitrary ecoregion delimitations (as discussed Host et al., 1996; Wright et al., 1998). For planning purposes, a representative landscape approach to conservation could potentially be used as a spatial surrogate to ensure the long-term maintenance of biodiversity. The maintenance of processes that sustain ecosystem structure and functioning is essential for achieving persistence goals for systems of conservation areas (Baker, 1992; Noss, 1996). If a landscape approach to conservation biology is to be effective, the landscape units need to be properly defined. At present, the only ecologically defined system that exists within South Africa is for the Kruger National Park (Gertenbach, 1983). This is understandable considering the relatively recent international emergence of landscape ecology as a discipline (Wiens, 1992), the importance placed on species systematics and inventorying in southern Africa (Huntley, 1989), and the emphasis placed on poorly sampled species databases for reserve selection (e.g., Rebelo and Siegfried, 1990; Lombard, 1995; Freitag and van Jaarsveld, 1997). The first step in developing a successful landscape level conservation plan is identifying and locating the landscapes of a region.

The goals and objectives of environmental management frequently require the classification of regions based on measurable environmental characteristics. Delineation of ecological landscapes is useful in a variety of contexts, for example, in the assessment of the regional representation of conservation areas (Margules et al., 1988; Bedward et al., 1992; Franklin, 1993; Pressey et al., 1994), defining zones for sustainable ecological management (Forman, 1995), and as a framework for assessing the diversity of species and processes within landscapes (Lapin and Barnes, 1995).

An ecological framework that can integrate multiple environmental characteristics diminishes problems of duplication among government land resource agencies, and it can assist in the exchange of information and research results. Towards this end, the utility of ecoregional classifications, developed for the conterminous United States (Omernik, 1987; Gallant et al., 1995; Omernik, 1995) and Canada (Wiken, 1986), have been successfully demonstrated (e.g., U.S. Environmental Protection Agency: Environmental Monitoring and Assessment Program).

There are two broad approaches to classifying landscapes: human landscape-based classification approaches mainly applied in European countries (Blankson and Green, 1991;

Green et al., 1996), and biophysical approaches (Christian and Stewart, 1953; De Agar et al., 1995; Bailey, 1996; Bernert et al., 1997) which combine climate, soils, vegetation and landform into observable and definable land units (e.g., Omernik, 1987). Methods vary from visual assessments using elements like scenery, to quantitative procedures, which group areas with similar values for a set of mapped variables (Benefield and Bunce, 1982; Blankson and Green, 1991; Host et al., 1996; Bernert et al., 1997). These methods are not completely objective, as variables for consideration have to be chosen, but are less judgmental than visual methods.

We used the biophysical approach, because the aim was to identify natural landscapes and then assess their conservation status by examining both the degree of protection and the amount of human-induced transformation that has occurred. This study presents a landscape classification system for the province of KwaZulu-Natal (South Africa) by using biophysical data and a combination of principal component analysis, clustering and spatial overlay techniques. A preliminary analysis is also undertaken to illustrate the important role that this kind of information can and should play in identifying conservation worthy areas.

3.1 Methods

3.1.1 Explanatory variables

The variables used were those commonly used in the description of ecological regions (Omernik, 1987; Omernik, 1995; Bailey, 1996). The set of variables was broad, and included those describing the physical (topography, landform, geology and climate) and biological environments (vegetation) and was integrated into a geographic information system (GIS). Only the topography, landform and climate variables were used in the classification analysis, the geologic and vegetation maps were not used directly in the demarcation of landscapes (as proposed by Omernik, 1987; Bailey, 1996). Rather, they are used to derive a typology of attributes within the landscapes that allows the landscapes to be described according to the vegetation types and geological substrates found in each unit. This adds considerably to the conservation planning objective by not subjectively combining the unit boundaries of vegetation and geology with landscapes to create arbitrary units (Host et al., 1996) and thus mask the landscape heterogeneity into a coarser ecoregional unit (Wright et al., 1998).

3.1.2 Approach

A systematic approach was developed for delineating landscapes (Figure 3.1) within the KwaZulu-Natal province that could be applied to any geographical region. To prevent landscapes

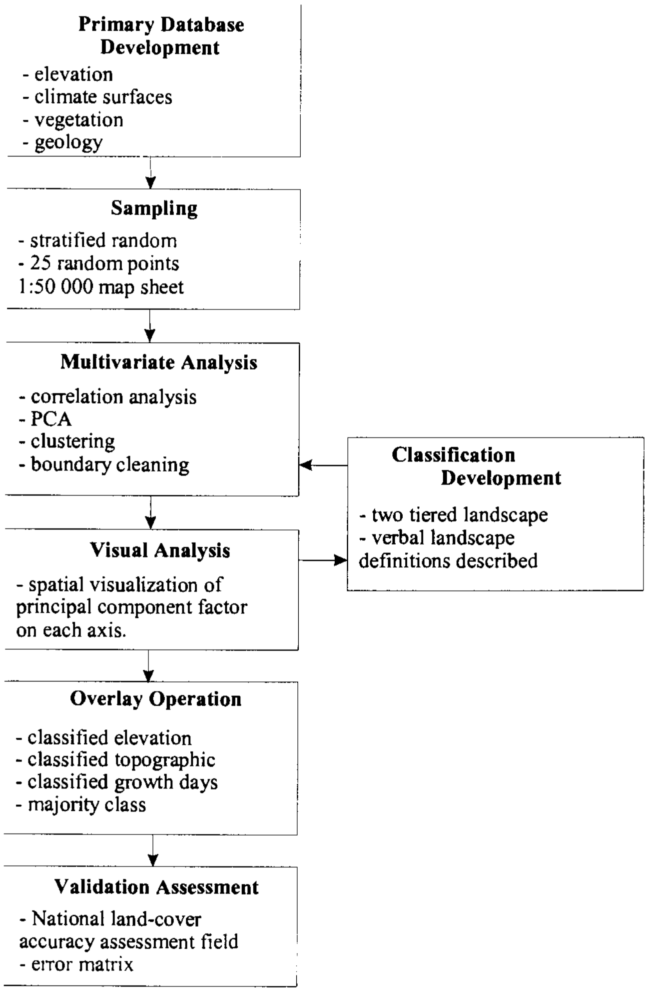

Figure 3.1: Analysis framework used to classify and identify the landscapes.

occurring along the KwaZulu-Natal border from being defined by arbitrary political boundaries, the study area was extended across the borders using catchment boundaries (DWAF, 1996). This overlap will also allow for easier edge-matching of future landscape classifications developed by neighboring provinces.

The analysis was raster grid cell based. The analysis cell size was partly determined by the largest cell size of the already rasterised data sets and a logical cell size for future integrative work, in this instance 1 km^2. All data sets were converted to Lamberts Azimuthal Equal-Area projection for analysis. To reduce the amount of data to be analysed, a stratified random sampling of data sets was conducted. The 165 South African Surveyor General 1:50 000 map sheets covering KwaZulu-Natal were used to stratify a random sample selection, with 25 cells being chosen from each sheet (i.e., a total of 4675 samples).

Pearson correlation coefficients were used to examine multicolinearity and thus minimise the duplication of variable information, and make decisions with regard to variables being recorded in the field. Principal component analysis (PCA) was performed on the resulting variables, which allows the important descriptors to be standardized against each other for interpretation into spatial objects (see Legendre and Legendre, 1998).

Pattern and cluster analysis was undertaken on the PCA results in ArcView GIS (ESRI, 1998) using bivariate map plots of the axes factor scores produced by the PCA analyses and then applying a natural breaks clustering classification technique. This method identifies breakpoints by looking for groupings and patterns inherent in the data using Jenk's optimization, which minimizes the variation within each class (Jenks, 1963). Using these techniques the data sets responsible for the greatest amount of variation, as identified by the PCA, were classified. The classified data sets were then subjected to class boundary cleaning by smoothing transitions between classes. This procedure removes class border roughness which is caused by inaccuracies in the coarse resolution data (ESRI, 1998).

Landscapes were constructed by combining the classified terrain and climatic data sets in a stepwise manner using Arc/Info GRID GIS (ESRI, 1998), and smoothing the intermediate derived data sets with a 3x3 grid cell neighborhood majority class filter. This transformation reassigned pixel values based on the most prevalent class membership within a 3x3 grid cell moving window. Scarpace et al. (1981) found that majority filtering actually increased classification accuracy by reducing 'random' noise in classification results. When applying this method over large regions the errors average out, so the landscape estimates are probably quite accurate even if the cell by cell estimates may be less accurate.

A validation exercise was performed using the South African National Land-Cover Database accuracy assessment points (Fairbanks and Thompson, 1996). The overall accuracy of the landscape classification map was tested using 530 stratified random field locations. Actual class membership for the sample locations was assigned on majority area coverage of a class within a cell. A combination of using the extra attributes collected in the field (e.g., topography, position, and vegetation) per point and inspection of the fixed ground photography of the area around a point was used to determine actual landscape class membership. This helped to ensure that the derived landscape types were recognisable ecological units for conservation analysis and planning.

3.1.2.1 Landscape Conservation Analysis

A crucial consideration in maximizing the protection of biodiversity is the assignment of priorities for protection in the face of real-world constraints (Pressey et al., 1996). The concepts of irreplaceability (Pressey et al., 1994) and vulnerability (Pressey et al., 1996) were developed to explicitly define conservation value and priority for representative areas. In its simplest form, irreplaceability is a measure of the likelihood that an area will be needed to achieve a conservation goal; vulnerability is a measure of the imminence or likelihood of the biodiversity in an area being lost to current or impending threatening processes. Thus, irreplaceability is a measure of conservation value whereas conservation priority is the value of an area combined with some assessment of the urgency with which it should be conserved (Pressey, 1997). Areas of high irreplaceability and high vulnerability are highest priorities for conservation action (Pressey et al., 1996). Focusing conservation resources on such areas will maximize the extent to which representation goals will be achieved on the ground.

To demonstrate the value the landscapes add to the analysis of conservation goals, by helping identification of conservation worthy regions, we conducted an analysis of the derived landscapes with the South African National Land-Cover database (Fairbanks and Thompson, 1996; Fairbanks et al., 2000) and a protected area database for KwaZulu-Natal. The land-cover database contains spatial information on natural land-cover and identifiable human land-use mapped from Landsat TM imagery at 1:250 000 scale (Fairbanks et al., 2000). The land-use classes are essentially a measure of transformation status in the context of threats to biodiversity. The protected area database described the boundaries of provincial reserves, digitized from 1:50 000 maps.

The land-cover data was used to assess the vulnerability of the landscapes to future human transformation based on the diversity of land-uses in each landscape. The rationale being that landscape types with several land uses are more vulnerable to future transformation than areas of single land uses because of their unique and favorable environment (e.g. available positive water balance and heat units) to a variety of human development potential (this will, however, depend on the available land cover classes being transformed). The level of irreplaceability was determined using a linear weighted combination of the extent of transformation, representation in protected areas, and rarity (measured as the relative areal contribution of each class):

$$\text{Irreplaceability} = \textstyle\sum_3 (\text{Rarity*weight}) + (\text{Transformation*weight}) + (\text{Representation*weight})$$

The classification of the measures was derived using the natural breaks classification technique (Jenks, 1963). The vulnerability and irreplaceability scores were scaled from 0-100% as calculated from classifications and weights (Table 3.1) as defined by KwaZulu-Natal Nature Conservation Services (KZNNCS).

Table 3.1: Landscape rarity, transformation, and protection classification rules based on frequency classification with accompanying importance ratings.

% of Total (Rarity)	Weights	% Transformed	Weights	% Protected	Weights
< 1.7%	1	> 50%	1	< 10%	1
1.7 - 5%	0.75	34 - 50%	0.75	10 - 25%	0.66
5 - 7.6%	0.5	18 - 34%	0.50	> 25%	0.33
> 7.6%	0.25	< 18%	0.25		

3.2 Results

3.2.1 Landscape Classification

Median minimum rainfall for driest and wettest quarters, growth temperature, mean annual temperature, mean maximum temperature for January, and mean minimum temperature for July were highly correlated ($r > 0.50$; $p < 0.05$) with elevation (Table 3.2) and were dropped from further analysis. Elevation alone is a good predictor of orographic precipitation and temperature gradients. Similarly, median annual precipitation was highly correlated with growth days ($r > 0.50$; $p < 0.05$) and was dropped from further analysis (Table 3.2). Growth days have been found to be a better predictor of water balance for determining the effectiveness of rainfall for biomass production in southern Africa (Ellery et al., 1992; Fairbanks, 2000).

The PCA results (Table 3.3) showed that the elevation model accounted for most of the variation, and therefore the primary gradient for the region, on axis one (0.84), similarly for the topographical landform index on axis two (0.975) and growth days on axis three (0.966). These three variables were therefore used for construction of the landscapes and the topographic heterogeneity variable was dropped from any further analysis. By using local a priori knowledge, visual interpretation and examination of the ordering of the factor scores on each axis with the clustering technique we determined elevation could be meaningfully classified into two hierarchical levels of ten detailed and four coarse classes (Table 3.4). The topographic landform index was retained at seven classes and lumped to two classes at a coarser level (Table 3.4). The growth days index was reclassified into 30 and 60 day ranges to produce a six level and three level hierarchical classification (Table 3.4).

Table 3.2: Pearson correlation matrix for environmental variables used in landscape classification (n = 4675). Correlations highlighted in bold violate the $r > 0.50$ multicolinearity limit defined for this study. †

	demsd	dem	tli	dm	wm	mdp	gd	gt	mat	maxj	minj
demsd	1.0	0.37	0.03	-0.13	**0.50**	0.35	0.36	-0.43	-0.39	-0.43	-0.26
dem		1.0	0.19	**-0.52**	**0.70**	0.22	0.31	**-0.94**	**-0.98**	**-0.84**	**-0.92**
tli			1.0	0.01	0.05	0.06	0.05	-0.08	-0.05	-0.10	0.05
dm				1.0	-0.04	**0.53**	0.49	0.28	0.43	0.17	**0.63**
wm					1.0	**0.79**	**0.78**	**-0.74**	**-0.72**	**-0.73**	**-0.55**
mdp						1.0	**0.91**	-0.38	-0.27	-0.45	-0.02
gd							1.0	**-0.56**	-0.43	**-0.67**	-0.12
gt								1.0	**0.98**	**0.97**	**0.82**
mat									1.0	**0.91**	**0.91**
maxj										1.0	**0.67**
minj											1.0

†Variable names: topographic heterogeneity (demsd); elevation (dem); topographic landform index (tli); driest quarter precipitation (dm); wettest quarter precipiation (wm); median annual precipitation (mdp); growth days (gd); growth temperature (gt); mean annual temperature (mat); mean maximum temperature January (maxj); mean minimum temperature July (minj).

Table 3.3: Factor weights, eigenvalues, and total variance explained derived by the PCA analysis on the chosen topographic and climatic variables. Values in bold denote the significant variable identified for each axis.

Variables†	Axis 1	Axis 2	Axis 3
DEMSD	0.77	-0.15	0.30
DEM	**0.84**	0.25	0.06
GD	0.21	0.04	**0.97**
TLI	0.06	**0.97**	0.03
Eigenvalue	1.34	1.03	1.02
Total Variance Explained (%)	43.46	25.28	16.63

†Variable names: topographic heterogeneity (demsd); elevation (dem); topographic landform index (tli); growth days (gd).

The first data combination involved the overlaying of the detailed level I elevation classification with the level I topographical landform index classification producing 20 unique combinatorial classes from the input data. All combinations of classes potentially could have yielded 70 unique classes, but in this case, only 20 unique elevation-landform types were derived. This combination was then overlaid with the level I growth days index. The combined data set derived 104 classes out of a potential 120, but several classes were shown to be small and spurious in nature (≤ 3 grid cells). The majority class filter was processed over the data surface and a final 97 class landscape map was produced. These 97 classes represent the landscapes of KwaZulu-Natal at the highest level of detail by being derived from the level I classification hierarchies of the input data. The 97 classes were then hierarchically collapsed to the coarser 24 class landscape level II classification for ease of use and illustration (Figure 3.2).

Table 3.4: Elevation, topographic landform index and growth days index classification hierarchies.

Elevation range (m) from PCA axis 1	Level I	Level II
0 - 162	Coastal plain	Coastal
162 - 352	Coastal hinterland	Coastal
352 - 558	Lowlands	Lowlands
558 - 754	Mid-lowlands	Lowlands
754 - 948	Upper lowlands	Lowlands
948 - 1138	Low highlands	Highlands
1138 - 1353	Mid-highlands	Highlands
1353 - 1610	Upper highlands	Highlands
1610 - 1986	Low Afromontane/Escarpment plateau	Afromontane
1986 - 3484	Upper Afromontane/Lesotho Alpine	Afromontane
Topographic landform index		
	Level/flat	Undulating/flat
	Valley	Undulating/flat
	Foot slope	Mountainous/hilly
	Mid-slope	Mountainous/hilly
	Upper slope	Mountainous/hilly
	Scarp	Mountainous/hilly
	Ridge/crest	Mountainous/hilly
Growth Days ranges (days)		
60 - 90	Dry	Dry
90 - 120	Moderately dry	Dry
120 - 150	Moderately moist	Moist
150 - 180	Moist	Moist
180 - 210	Wet	Wet
210 - 247	Very wet	Wet

3.2.2 Validation

The coarser Level II landscape classification was analysed using conventional error matrices for predicted versus actual class membership at field checked locations. Three summary statistics, percent correctly classified (PCC), 95% confidence limits and the Kappa statistic, were generated from the matrix for comparing the performance of the landscape model. PCC provides an intuitive measure of classification accuracy. The Kappa statistic is a measure of overall agreement based on discrete multivariate analysis described by Bishop et al. (1975), which has been promoted for use in the remote sensing community (Congalton et al., 1983; Foody, 1992).

Overall the level II landscape classification accuracy is good at 86.8% PCC (83.8 - 89.7% at 95% confidence), considering the coarse data resolution, with predictable confusions along landscape borders and within areas where the coarse data were not able to describe local structural anomalies. The Kappa statistic implies that our classification is 85.3% better than the accuracy that would result from a random class assignment. This means that a high repeatability of the same classification results could be acquired by another knowledgeable analyst using

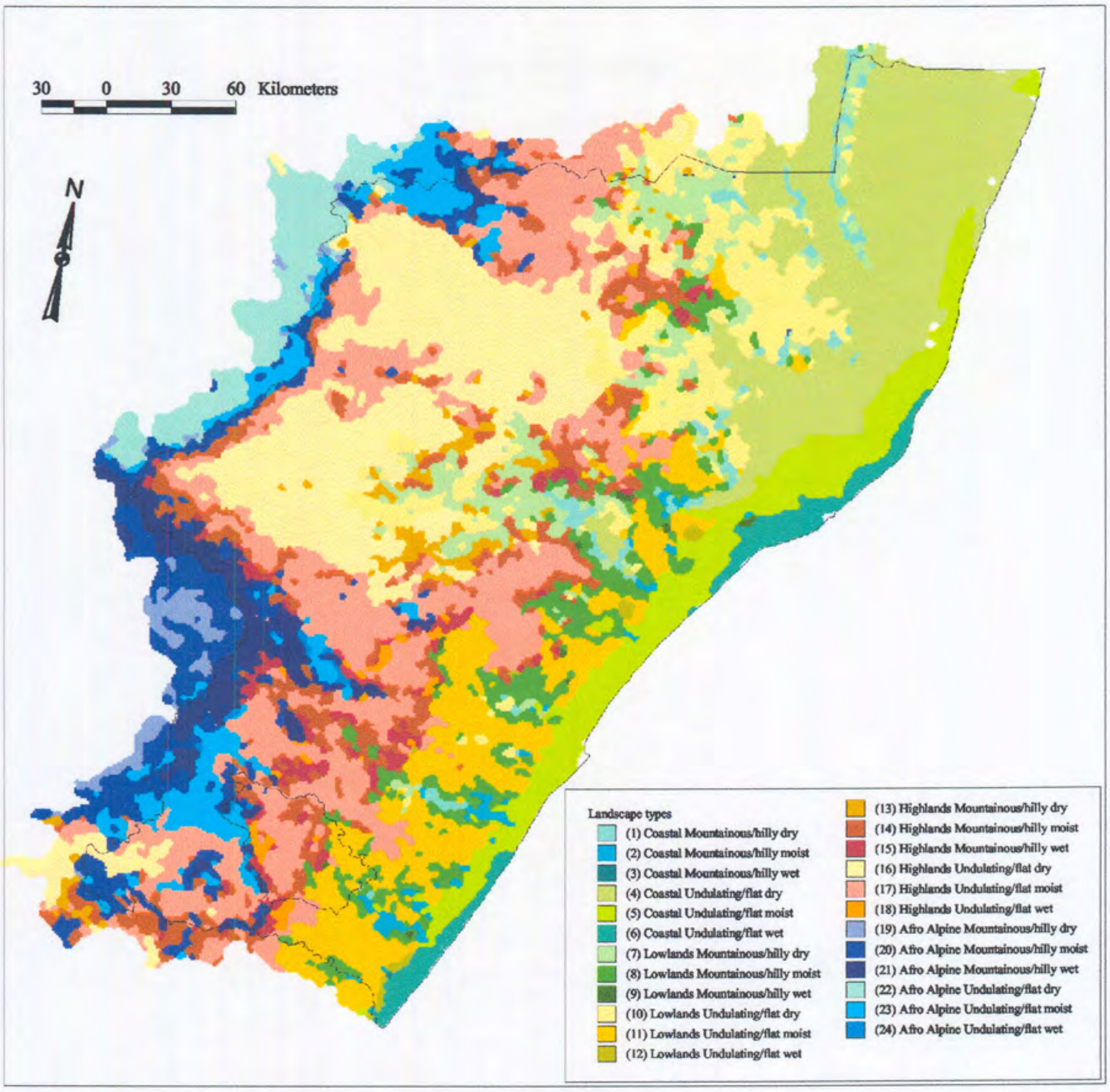

Figure 3.2: Landscape classification (Level II; 24 classes) of KwaZulu-Natal Province, South Africa.

our methodology and having local *a priori* knowledge.

3.2.3 Landscape Conservation Analysis

Landscape rarity, current transformation status, and current protection provided by conservation authorities are presented in Table 3.5. Figure 3.3 illustrates the current human-induced transformation status on the level II landscapes. The majority of the transformation has taken place in the coastal and highland regions. Figure 3.4 demonstrates the bias the provincial protected area network managed by KZNNCS has in its protection of landscapes versus the landscape vulnerability status. In this case, the Maputaland coastal region and the Drakensberg

Table 3.5: Calculations of percent rarity, current transformation percentage and percent protected in managed nature reserves. The legend for the landscape numbers is given in Figure 3.2.

Level II	% of Total	% Transformed	% Protected
1	1.2	24.2	4.2
2	0.6	0.2	1.0
3	0.01	25.2	0.0
4	12.7	29.9	13.3
5	5.9	62.5	13.9
6	1.7	50.0	5.8
7	4.1	21.2	6.3
8	4.0	30.0	0.5
9	0.1	39.3	1.4
10	6.2	34.2	1.5
11	7.6	52.9	1.5
12	0.2	66.1	0.0
13	1.4	18.6	0.7
14	6.7	25.1	2.0
15	1.6	33.1	10.9
16	13.9	30.8	0.8
17	15.0	40.3	0.9
18	0.4	56.2	1.9
19	1.6	34.6	14.8
20	5.1	12.5	20.2
21	3.0	2.5	51.7
22	3.3	11.9	2.6
23	3.7	12.5	4.1
24	0.2	8.2	7.8

Escarpment are well conserved (areas with Malaria and high rocky areas), but the landscapes denoting the lowlands and highlands (highly valued agricultural lands) are severely under protected. This illustrates a much noted paradox in conservation's history: pieces of land have been put aside in an *ad hoc* manner, often on economically marginal land or to conserve a few charismatic species (Pressey, 1994).

Irreplaceability and vulnerability (Figure 3.5) reveal the landscapes with high values for both as areas of high priority for conservation action. The majority of these areas have undulating/flat terrain with moist-wet climates in the coastal, lowland, and highland regions (e.g. 5, 6, 12, 17, and 18). These priority landscapes are dominated by mixed woodland and upland grassland ecosystems (Table 3.6), which are habitats considered in serious threat to development throughout South Africa (Fairbanks et al., 2000). By using the modest IUCN protection rule of 10% minimum area and a hypothetical division of vulnerability status at 50% (see Figure 3.4), only three landscape types (4, 5, and 15) are minimally protected with greater than 50% vulnerability (Figure 3.6). In the case of landscape type five, which lies along a north-south coastal gradient, only the far northern section receives adequate protection. By using a combination of analytical graphs and spatially plotting these results, landscapes like type five can be identified by their skew

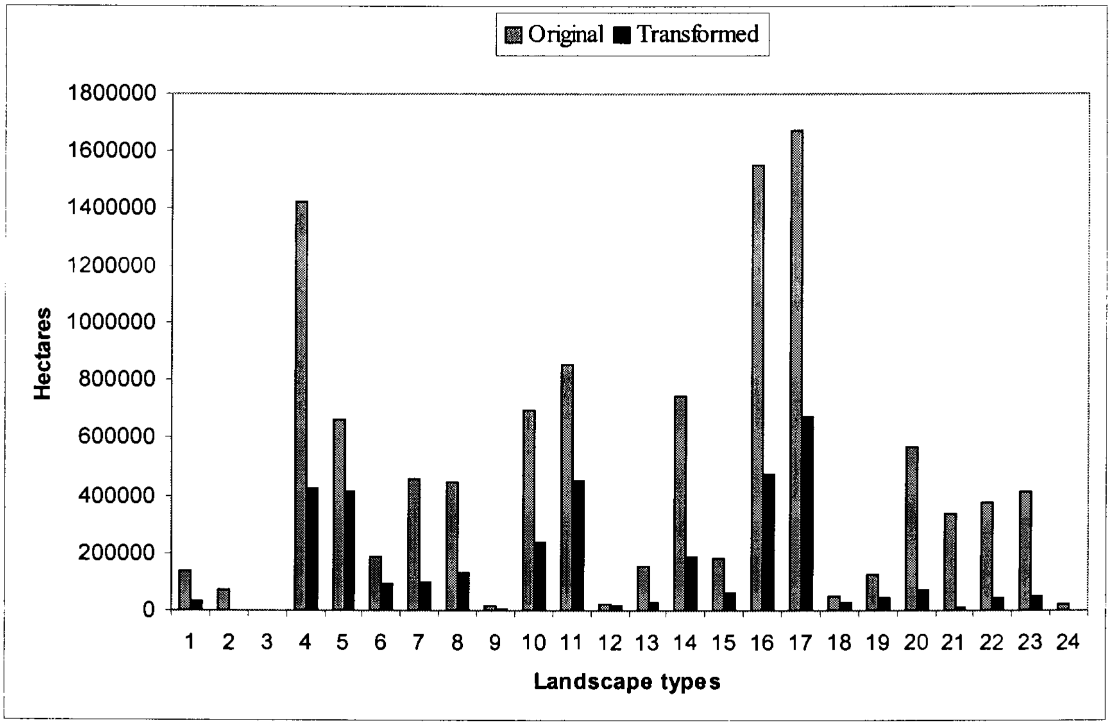

Figure 3.3: Preliminary assessment of the level of transformation within the second level landscapes relative to their areal coverage (see Figure 3.2 for number code descriptions).

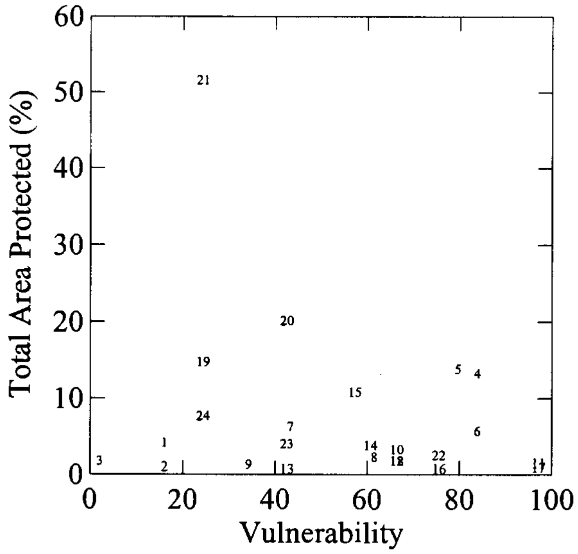

Figure 3.4: Scatter plot of current protection status vs. vulnerability for each landscape type (see Figure 3.2 for number code descriptions).

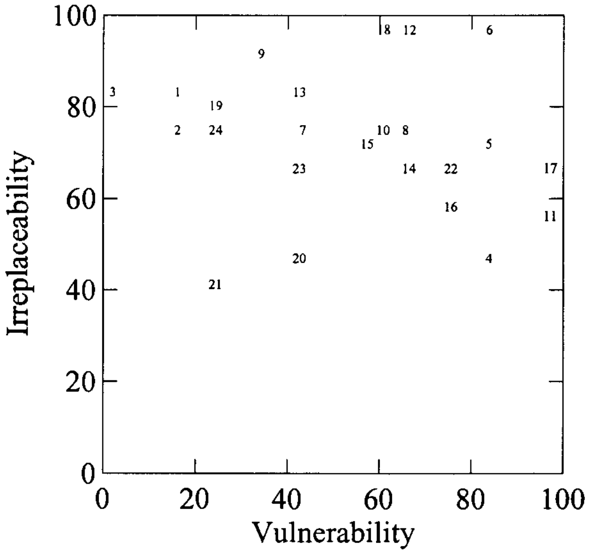

Figure 3.5: Preliminary scores for irreplaceability (conservation value) and vulnerability to threatening processes for the landscapes. Landscape types in the upper right-hand corner are conservation priorities (see Figure 3.2 for number code descriptions).

Table 3.6: The values represent the percentage of each level II landscape type that is comprised of each functional vegetation type. Values in bold represent vegetation types with >10% affiliated area with level II landscape types.

Level II	Forest†	Arid Woodland	Moist Woodland	Mixed Woodland	Thicket	Upland Grassland	Highland Grassland
1	0.5	**47.3**	0.3	**26.9**	**24.2**	0.0	0.8
2	1.7	0.0	**31.7**	**37.0**	**25.6**	3.9	0.0
3	**12.5**	0.0	0.0	0.00	0.0	**87.5**	0.0
4	0.9	**62.7**	**26.2**	7.2	2.8	0.0	0.1
5	1.9	0.0	**76.9**	**10.3**	**10.6**	0.2	0.0
6	3.6	0.0	**88.0**	1.0	2.7	4.7	0.0
7	0.2	**32.0**	0.0	**26.9**	**23.5**	4.6	**12.8**
8	1.2	5.5	5.4	**43.6**	**28.9**	**12.0**	3.4
9	**27.6**	0.0	5.3	**37.6**	8.8	**20.6**	0.0
10	0.0	**33.3**	0.0	**38.4**	**11.2**	2.7	**14.3**
11	0.7	1.7	5.3	**44.6**	**20.6**	**22.5**	4.5
12	3.3	0.0	9.5	**49.2**	4.1	**33.9**	0.0
13	0.0	2.1	0.0	**41.7**	**21.7**	**17.6**	**16.8**
14	1.1	2.2	0.0	**22.4**	4.6	**36.4**	**33.4**
15	8.0	1.3	0.0	7.9	2.8	**61.1**	**18.9**
16	0.1	1.3	0.0	**66.1**	4.9	8.5	**19.1**
17	0.4	1.2	0.0	**13.9**	1.1	**46.2**	**37.2**
18	2.4	2.6	0.0	1.0	1.8	**86.9**	5.4
19	0.1	0.0	0.0	0.0	0.0	0.8	**99.1**
20	0.4	0.1	0.0	1.5	0.0	**28.2**	**69.7**
21	2.2	0.7	0.0	0.0	0.0	**34.6**	**62.5**
22	0.1	0.0	0.0	0.0	0.0	0.1	**99.8**
23	0.8	0.0	0.0	0.9	0.0	**45.0**	**53.3**
24	1.8	0.0	0.0	0.0	0.0	**79.3**	**18.9**

†Note: Forest is a combination of *Montane* and *Coastal Forest*.

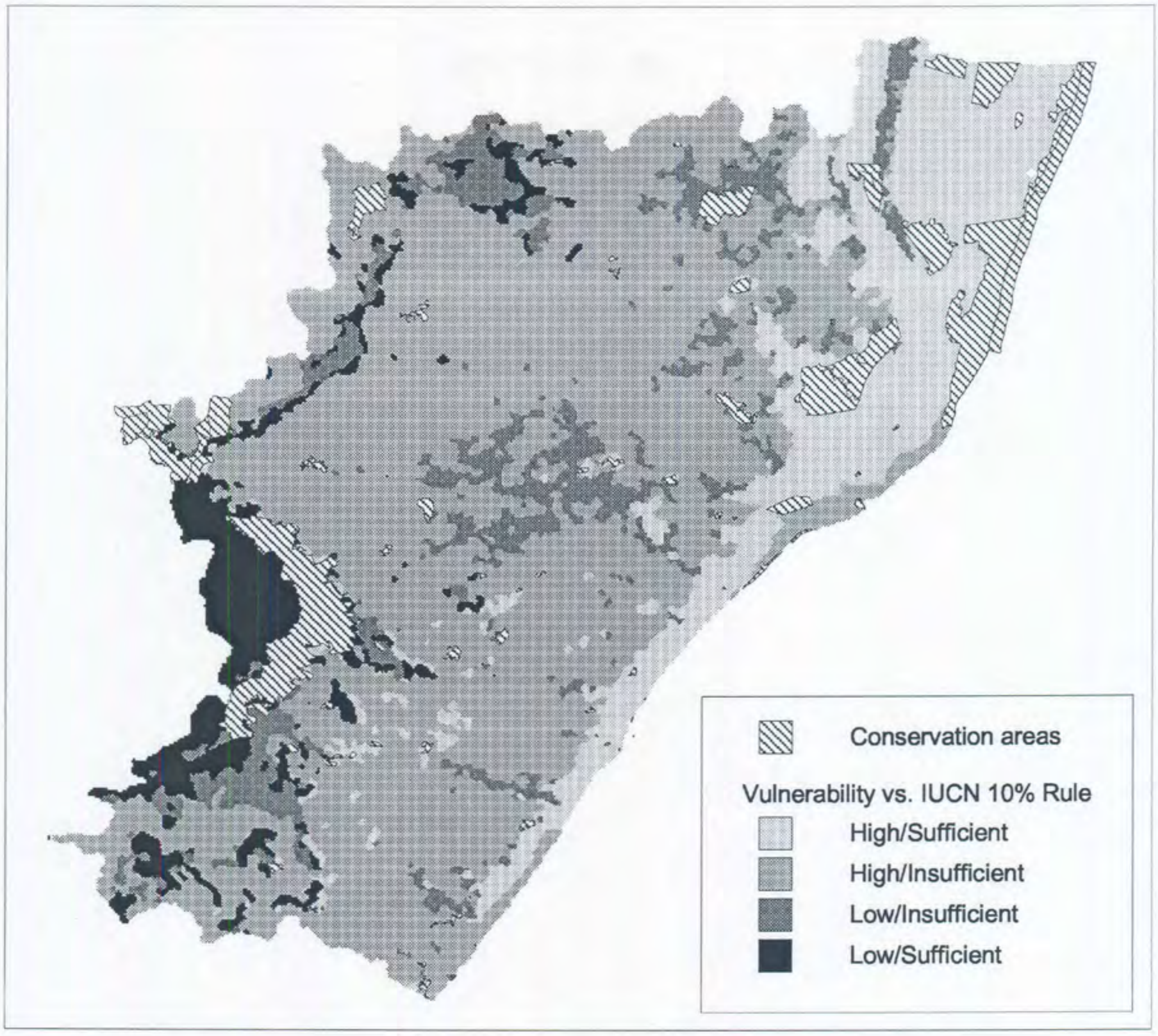

Figure 3.6: Landscape types classified by a 50% vulnerability status boundary and using the proposed IUCN 10% target for minimum protection of habitats.

representation and critical contribution to a provincial conservation goal.

Landscape types (6, 8, 10, 11, 12, 14, 16, 17, 18, and 22) represent the bulk of the province and have been historically ignored by the conservation authorities and targeted for development. They primarily contain fertile habitats of mixed woodland and upland and highland grasslands (Table 3.6). The almost total transfer of land in the formerly white areas 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, Canada or the USA were retained by the authorities because of their unsuitability for agriculture (Christopher, 1982). The strong tradition of land ownership rather than leasehold in South Africa and the absence of state interest in land through a leasehold system has developed a strong demand for land and an attempt to make a living in areas often highly unsuitable for the purposes of farming (Christopher, 1982; Schoeman and Scotney, 1987). Demand for land has further driven land prices to levels far in excess of its value as an agricultural commodity, and thus confounded past and present conservation efforts.

In practice, conservation managers rely on species distribution data as an aid to developing conservation plans. However, it would seem more reasonable to adopt the Noss (1990) hierarchy framework for identifying important areas for conservation based on a combination of landscape priority-species or vegetation priority-species. An example using the landscape priority assessment (from Figure 3.5) and a vegetation priority assessment (see Appendix B for Reyers et al., in review) were conducted with the bird atlas database (Harrison et al., 1997). Landscapes are ranked in order of importance based on dividing the graph (Figure 3.5) into four quadrants based on the 50% boundaries on each axis and then defining the following ranked values for the landscapes (Cartesian quadrants read clockwise; based on suggestions from the C-Plan website, http://www.ozemail.com.au/~cplan/background_1.html):

I. Very high priority for conservation in formal or secure reserves. (Rank 1)

II. High conservation values but not threatened, maybe consider off reserve management. (Rank 3)

III. Low priority for conservation. (Rank 4)

IV. These areas may contain features that are already represented in reserves, but which are still at risk. (Rank 2)

The priority vegetation type ranks were conducted in a similar manner (Appendix B), with the KwaZulu-Natal province containing four ranked vegetation types based on a national level assessment (Appendix B). The spatial distributions of the landscape and vegetation priority ranks are contained in Figure 3.7. Each ranked class on each map is used sequentially in turn to define the search areas for rarity and richness-based reserve selection algorithms (Rebelo and Siegfried, 1992; Howard et al., 1998; Reyers et al., 2000). The results of using the hierarchy of ranked landscapes and vegetation to determine complementary sets of bird species for conservation are provided in Figure 3.8.

Clearly, from the examples given, the goal of conservation is not only to ensure minimum landscape, habitat and species protection, but also to represent geographic gradients and to enable longer-term ecological and evolutionary processes to persist. This is not in conflict with the

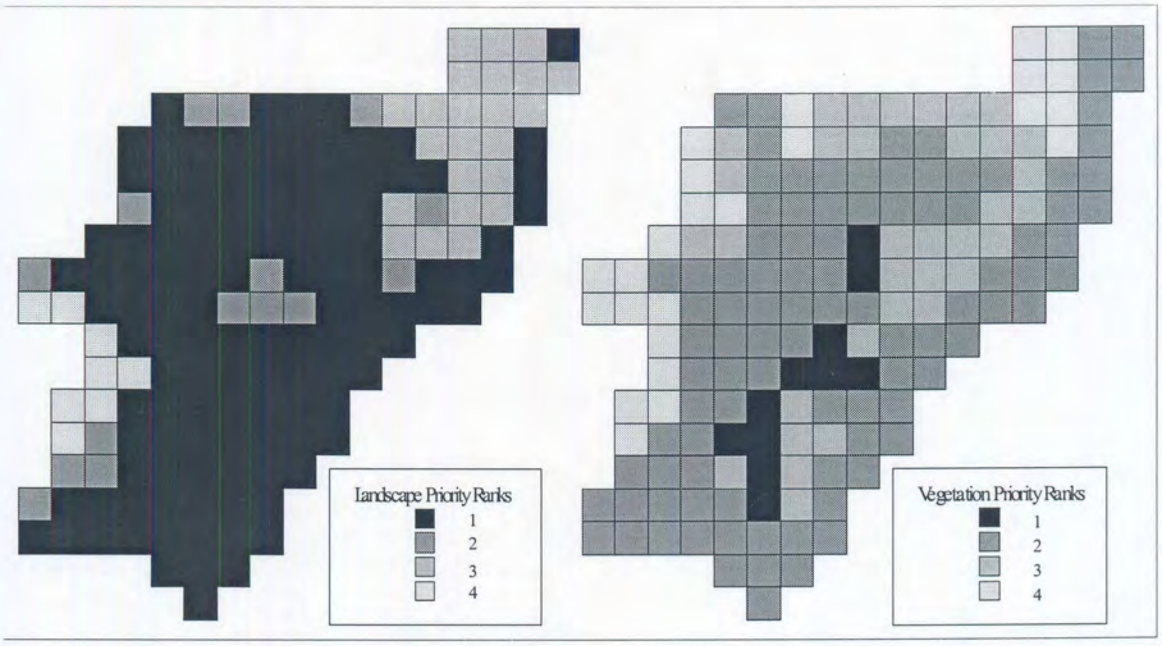

Figure 3.7: Priority ranks for landscapes and vegetation types as inclusion to rarity and richness-based reserve selection algorithms.

importance of habitat loss for the immediate persistence of biodiversity, but long-term persistence goals also need to be considered in designing and implementing reserve systems, especially in response to global change.

3.3 Discussion

This analysis represents one of the few times that a landscape or ecoregion classification has been properly assessed for accuracy and fitness for use in the field, and thus evaluated for use in systematic conservation planning. Using indirect methods, Wright et al. (1994) and Host et al. (1996) also assessed the value of larger ecoregional units (e.g., Omernik, 1987) and a machine driven ecosystem classification with mixed success. The use of ecoregion classifications for conservation planning is questionable given the very coarse scale of the units, the mixing of 'potential' and actual data sets (e.g., potential vegetation, climate zones, land-use pattern, soils, etc.), and the reliance on boundaries drawn by a consensus of experts, which may not provide a repeatable methodology. Rather, a data driven and parsimonious approach based on ecologically important structural and climatic variables derived at a larger landscape scale may allow for a better understanding of the pattern and processes required for biodiversity preservation. This type of landscape model can then be independently assessed with potential vegetation and edaphic

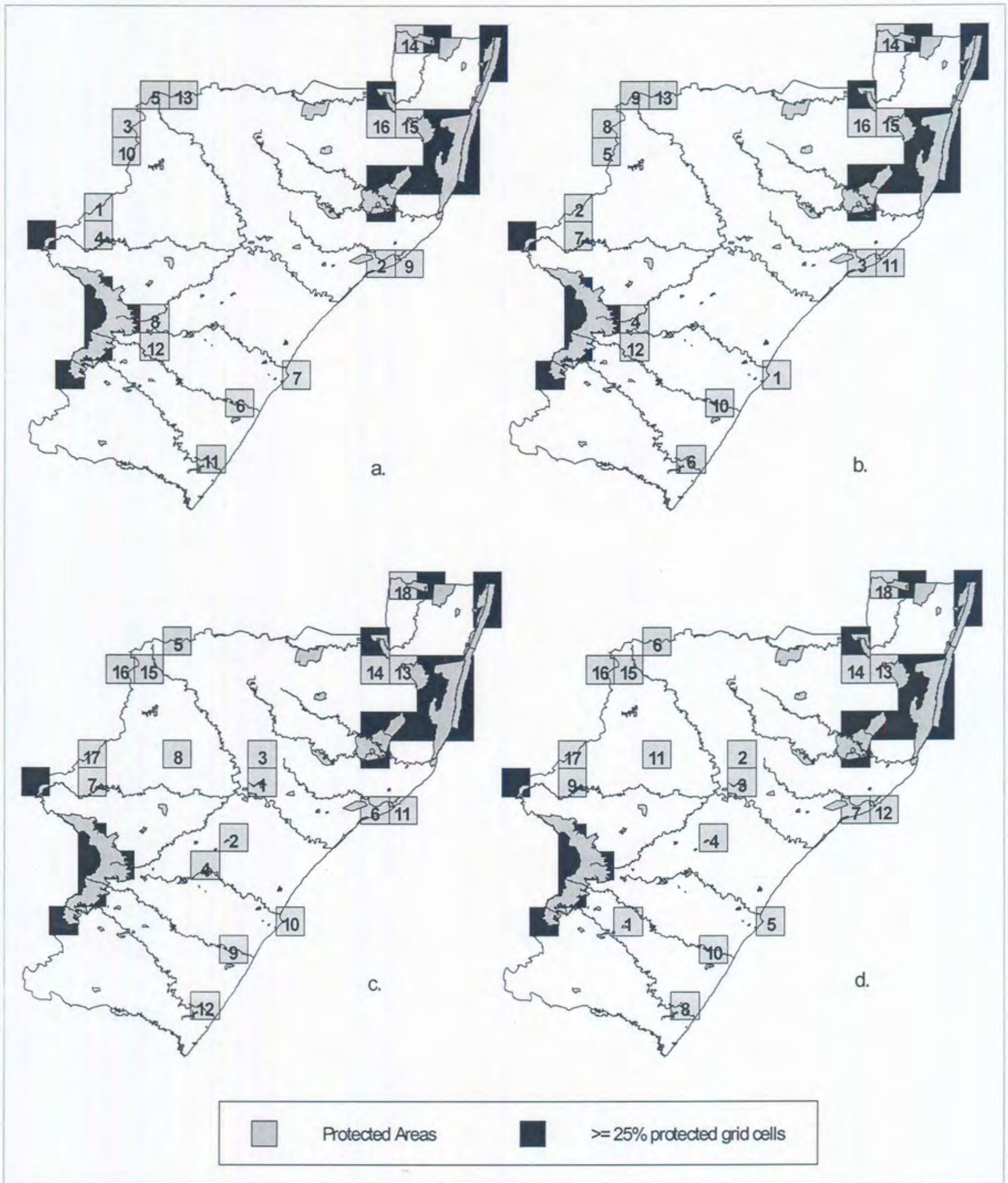

Figure 3.8: Selection order results for potential reserve networks based on either rarity or richness procedures for birds. (a) and (b) Results are based on a hierarchical mask of ranked landscape values based on four quadrants derived from 50% cutoff points in Figure 3.8; and (c) and (d) results are based on a hierarchical mask of ranked priority vegetation types based on current versus potential transformation (see Appendix B).

factors as the landscape attributes.

While chosen data layers and analytical methods are relatively objective, there are a number of decisions that require some *a priori* understanding of the landscapes under study. There are also data processing questions, such as determining, a statistically appropriate number of classification levels, selecting important variables or generalizing boundaries that require subjective, yet defendable decisions. It is unrealistic to expect that the process of landscape classification can be accomplished entirely by spatial and numeric analysis; human understanding is also an important component (Host et al., 1996). However, by defining a computationally repeatable methodology the knowledge of experts may be captured for future refinements within a data driven model.

3.3.1 Landscape Scale and Structure

Terrain analysis is the quantitative analysis of topographic surfaces with the aim of studying surface and near-surface processes. In short, terrain analysis provides the basis for a wide range of landscape-scale environmental models, which are used to address both research and management issues and objectives. It is widely recognised that landscape pattern analysis is sensitive to the resolution (spatial scale) of the source data (Turner et al., 1989). As the distance between neighbouring elevation samples increases, fine-scale features are lost and the surface becomes more generalised. However, when identifying landscapes there is a tendency to focus on specific finer detailed terrain or ecosystem elements *within a landscape* rather than the broad scale structures that truly define a landscape. For this study, a landscape was not defined traditionally as a mosaic where the mix of local ecosystems is repeated in similar pattern over a kilometers-wide area (Forman, 1995), but rather where the physical systems integrate together to define identifiable patterns over a kilometers-wide area. Therefore, the database of environmental layers defined at a resolution of 1km^2 was considered appropriate for striking a balance between regional and local ecosystem heterogeneity.

3.5.2 Landscapes as an Element of Biodiversity for Use in Prioritisation Procedures

This study has shown that it is possible to produce an ecologically inclusive inventory of regional landscapes, notwithstanding the extensive areas they occupy and their inherent spatial complexity. Noss (1990) described landscapes as the upper level in a hierarchical framework that extends upwards from genes-species-ecosystems to describe the range of biological diversity. The analytical framework presented here is an appropriate model for elucidating the landscape level biodiversity dilemmas faced by conservation practitioners. By proposing a top-down, constraint based modelling and conservation assessment an approximation of the main processes and structure maintaining long-term biodiversity pattern can be used in more specific species protection and recovery plans. Biophysically defined landscapes containing elements of vegetation types with edaphic drivers determine and drive co-evolution with other species of mammal, reptile, bird and insect. The products of interacting organisms in a hierarchically defined landscape environment are ecosystems.

The majority of the work on preserving biodiversity and selecting priority areas for conservation has concentrated on the lower level of the biodiversity hierarchy: species (Pressey and Nicholls, 1989; Rebelo and Siegfried, 1990; Lombard, 1995; Pressey et al., 1996), populations (Lamberson et al., 1992; Breininger et al., 1995; Doak, 1995), and community (especially vegetation assemblages; Scott et al., 1993; Strittholt and Boerner, 1995; Barbult, 1995) patterns. Recently, criticism has been levelled at especially the species based approaches to identifying priority conservation areas (Noss, 1983; Franklin, 1993; Scott et al., 1993; Barbault, 1995; Maddock and du Plessis, 1999; Maddock and Benn, 2000). However, due to the hierarchical nature of biodiversity any approach, which only concentrates on one of the levels, is flawed. There has been virtually no research on designing reserve systems intended for long-term persistence of biodiversity in the face of global change. Such a strategy must embody the representation and retention of both biodiversity patterns as well as the processes that maintain and generate these patterns. Thus, more comprehensive and inclusive biodiversity protection can be obtained by focussing on as many levels as possible. Landscape areas representing high irreplaceability and vulnerability are focus areas for follow-up species and ecosystem representation analysis, and identification of key processes that are responsible for the maintenance and genesis of biodiversity. If the information is available, important constituent ecosystems within these priority landscapes can be identified using the classification procedure developed here. The dominance of mixed woodland and upland grassland vegetation functional types within the priority landscapes identified in the preliminary analysis suggests the ecosystems needing consideration, and gives significant insight into what conservation actions are needed on the ground.

Hierarchy theory (O'Neill et al., 1986) suggests that constraints operate downward in complex hierarchies such as ecosystems (i.e., from the more aggregated levels to the less aggregated levels). In recognising this, it has been suggested that using higher levels of biodiversity alone to select priority areas for conservation is preferable, especially in areas with inadequate region-wide biological data (Margules and Redhead, 1995). This is based on the assumption that diversity and spatial heterogeneity are intrinsically linked (Diamond, 1988;

Hunter et al., 1988; Samways, 1990; Forman, 1995). If for instance landscapes were to be used in this manner, it assumes that a predictable relationship (surrogacy) between diversity at the landscape level and lower levels exist. Unfortunately, little research has tested these assumptions, but some do suggest (see Harner and Harper, 1976; Burnett et al., 1998; Nichols et al., 1998) that the upper levels of biodiversity (e.g., Noss, 1990) may act as effective surrogates for biodiversity as a whole. However, this will vary between ecosystems and depend on levels of disturbance. Until such relationships are adequately explained, the best practice for selecting priority areas and preserving biodiversity will involve multiple levels of biodiversity (i.e., broader classification such as landscapes, vegetation, geology in conjunction with species data and human development induced threats) guided by the principles of retention of pattern and process.

A final issue that must be addressed is the robustness of the derived landscape classification system over time and space. The landscape classification system developed was based on both structural and climatic components. The structural data layers are expected to be robust over time and space due to their slow geological evolution, but climate may present resiliency problems for the current classification. Under a predicted climate change scenario for precipitation in southern Africa (Joubert and Hewitson, 1997) the growth days index can be expected to change over space and in magnitude. Re-defining the classification when newer climatic data sets become available can therefore retain the relevance of the landscape classification system. This is not in conflict with the objective of providing a classification system for a *functional landscape*, which is also expected to undergo evolutionary change over time. However, there is a trade-off between too much data resolution versus the expected resilience of the classification system, which can be tested through sensitivity analysis.

3.4 Summary

The use of regional ecological classification systems is increasing (Bailey, 1996; Host et al., 1996; Pressey, 1997). This is a result of efforts by resource and nature conservation managers to replace political boundaries with ecologically based management units that better reflect the spatial distributions of natural features. This is particularly true in water resource and nature conservation planning sectors, where landscape and regional ecology can be used to spatially combine natural processes and human activities to promote sustainable land management (Davis and Stoms, 1996). Developing a landscape classification allows for this often ignored level of biodiversity to be inventoried and considered in conjunction with species-based conservation prioritisation exercises.

The classification methodology proposed here is not totally objective in that data themes were chosen, and requires some *a priori* knowledge of the focus region's landscapes. However, the method is systematic and extensible to other areas. Furthermore, the method provides approaches for quantitatively classifying data, allows for quantitative understanding of the data heterogeneity among the themes, and can be updated as better data becomes available or environmental changes are documented.

By developing data layers for all the levels of biodiversity we can then provide a protocol for developing a reserve system that will enable biodiversity to persist into the next millennium. Rather than maximizing conservation of contemporary biodiversity patterns, a system should conserve ecological and evolutionary processes essential for sustaining biodiversity. The use of the landscapes-species hierarchy and the identification and role of processes in maintaining biodiversity patterns will help conservation planners to formulate clear representation goals in balance with human induced threat.

4. Species and Environment Representation: Selecting Reserves for the Retention of Avian Diversity

Considerable progress has been made in developing and testing practical protocols for designing representative conservation area systems (for review see Margules and Pressey, 2000). Historically, opportunistic methods have been used for assigning land with low potential for economic and political conflict; or high potential for recreation and tourism to biodiversity conservation, which has resulted in an inefficient and ultimately more costly means of conservation area allocation (see Pressey, 1994; Rodrigues et al., 1999). This has lead to the 'minimum set' approach to conservation planning to identify whole systems of complementary areas that collectively achieve some overall conservation goal in a more efficient manner (Pressey et al., 1993). Its prevailing conservation focus is to identify potential conservation areas that represent the greatest number of features (e.g., species, vegetation types) at least once. However, the extent to which conservation areas fulfill the role of securing a region's biodiversity depends only partly on the goal of sampling biodiversity pattern. The long-term retention of biodiversity also requires the representation of the processes that contribute to shaping and maintaining biodiversity patterns.

Several authors have emphasized that current biodiversity representation within conservation areas is not equivalent to the ultimate goal of maintaining biodiversity over the long-term (Cowling et al., 1999; Fairbanks and Benn, 2000; Margules and Pressey, 2000; Rodrigues et al., 2000). The representativeness concept implies that a reserve, or system of reserves, should contain biota that ideally represents the entire range of biological and environmental variation within a given geographical area (Margules and Usher, 1981; Kirkpatrick, 1983; Austin and Margules, 1986; Mckenzie et al., 1989). Fairbanks and Benn (2000), along with Margules and Pressey (2000), agree, but also emphasize the maintenance of natural processes as an important component of conservation area selection. Rodrigues et al. (2000) argue that as species distribution patterns change over time, the selection of conservation areas that are robust to turnover in species or environmental diversity is a critical component of conservation area selection for ensuring the long-term maintenance of biodiversity. Thus, in selecting nature reserves, one should attempt to identify the major gradients of biotic and environmental variation within habitat types of interest in the study area and, if possible, the environmental variables that most closely correlate with the distribution and abundance patterns of relevant taxa (DeVelice et al., 1988).

Emphasis should not only be placed on the identification and conservation of biodiversity pattern, but also the natural processes that control and maintain that pattern within the biodiversity hierarchy (Noss, 1990; Balmford et al., 1998). Conservation of ecosystem processes that sustain ecosystem structure and function (Fairbanks and Benn, 2000), and evolutionary processes that sustain lineages and generate diversity (Cowling et al., 1999), are essential for achieving the long-term maintenance of biodiversity in conservation areas (Nicholls, 1998). However, as Margules and Pressey (2000) point out, because conservation area selection is often a spatial exercise, protection of these natural processes is often based on their spatial surrogates rather then on the processes themselves. Nevertheless, by ensuring that conservation areas are large or span substantial environmental gradients it should be possible to accommodate, at least partially, many of these natural processes (Noss, 1996).

Ordination analyses have illustrated tremendous potential for identifying important environmental gradients responsible for biodiversity pattern (DeVelice et al., 1988; Faith and Norris, 1989; Saetersdal and Birks, 1993; Taggart, 1994). This analytical approach is used for integrating multiple environmental effects across a landscape (Bray and Curtis, 1957; Gauch, 1982; Jongman et al., 1995). Ordination, whether direct or indirect, is particularly useful when studying the relationships between species composition and environment (Jongman et al., 1995).

Beta diversity is concerned with species spatial turnover along habitat gradients (Whittaker 1977). Beta diversity is important in determining regional species richness patterns, yet little attention has been paid to this component of diversity in selecting conservation areas. If conservation areas are selected only to represent numbers of species, they may not necessarily continue to serve this purpose over a period of years (Margules et al., 1994; Virolainen et al., 1999; Rodrigues et al., 2000).

The present study addresses the issues of conserving natural processes and spatial turnover of species diversity in an investigation conducted to assist the KwaZulu-Natal Nature Conservation Service (South Africa). The goal was to identify additional potential avian conservation areas in KwaZulu-Natal Province, as an added component to their strategic plan (Armstrong et al., 2000) for the long-term maintenance of regional biodiversity. To date, no study has been carried out on the complete bird fauna of the province to assess its representativeness or relationships with environmental processes and features.

4.1 Methods

4.1.1 Ordination

The primary analytical tool used was canonical correspondence analysis (CCA; ter Braak and Prentice, 1988), a widely used direct gradient analysis method (Palmer, 1993), and detrended correspondence analysis (DCA), an indirect gradient analysis method (Gauch, 1982). The program CANOCO, version 4.0 (ter Braak and Smilauer, 1998), was used to conduct all gradient analyses. DCA and a hierarchical classifier were used to determine the avian species communities within KwaZulu-Natal (Legendre and Legendre, 1998). Environmental data (e.g., the 13 environmental parameters found under topography and climate in Table 1.1) were entered with the species data using stepwise CCA to investigate which environmental variables explained the patterns in observed avian diversity (ter Braak and Smilauer, 1998). Variables are added to the model in the order of greatest additional contribution to total variation explained, but only if they were significant ($P \leq 0.01$), where significance was determined by a Monte Carlo permutation test, and if adding the variable did not cause any variance inflation factors to exceed 20. Variables with large inflation factors are strongly multicolinear with other variables and contribute little unique information to the model (ter Braak and Smilauer, 1998). In order to combine this information on species patterns and the related environmental gradients responsible for those patterns into practical conservation planning techniques, I propose the use of spatial autocorrelation analyses.

4.1.2 Spatial Autocorrelation Analysis: Local Indicators of Spatial Association

In the analysis of spatial association among many spatial observations, the tendency is to assess spatial autocorrelation based on global statistics such as Moran's *I* or Geary's *c* (Cliff and Ord, 1981). A focus on local patterns of association (local spatial clusters) prompted the development of local indicators of spatial association (Anselin, 1995). This form of analysis was used to identify areas with high levels of species and associated environmental gradient turnover. The software packages Spacestat (Anselin, 1999) and S-plus with the spatial statistics component (Mathsoft, 1999) were used to conduct this part of the analysis.

Using Moran's *I* analysis, based on the information gained from the previous CCAs, local spatial clusters of integrated species compositions and their associated environmental gradients were identified. A grid cell with a high positive Moran's *I* value is highly autocorrelated or is similar to neighbouring grid cells in terms of avian species contained and environmental parameters. A grid cell with a negative to low positive Moran's *I* value shows low levels of autocorrelation and is thus very different from surrounding grid cells in terms of species assemblage and the associated environmental variables. Thus, those grid cells with low levels of spatial autocorrelation are indicative of areas with high turnover in species composition as well as strong environmental gradients.

4.1.3 Conservation Area Selection

An algorithm based on species rarity or richness (Rebelo and Siegfried, 1992; Howard et al., 1998; Reyers et al., 2000) for selecting a set of complementary reserves was initially run on the birds species distribution data. However, such selection procedures do not successfully select areas for the representation of natural processes responsible for generating biodiversity patterns. Furthermore, they do not target areas of high beta diversity, i.e. areas with a high turnover in feature diversity. I attempted to include steps in these algorithms that selected areas high in beta species diversity and with associated environmental gradients by ranking the grid cells from lowest spatial autocorrelation to highest and iteratively incorporating the required species for representation using either species rarity and richness approaches. Moran's *I* values were used as indicators of the importance of grid cells in terms of species and environmental turnover. This then made it possible to represent not only alpha diversity patterns (numbers of species within a community), but also beta diversity patterns and sample the underlying environmental gradients during the reserve selection procedure.

First, a grid cell was considered protected if ≥ 25% of its area fell within protected areas. The species found within these grid cells were removed from the analysis. Second, Moran's *I* values of each grid cell were categorized and ranked into four groups: negative autocorrelation, weak positive autocorrelation, moderate positive autocorrelation, and strong positive autocorrelation. Third, two analyses were completed, one based on complementary rarity and the other on complementary richness. The algorithm starts by selecting grid cells from the first category of spatial autocorrelation (i.e. grid cells in the negative autocorrelation category) and scans them for un-represented species not removed in the first step. The algorithm then proceeded in a stepwise fashion through all spatial autocorrelation categories until all species were represented at least once. In this way two real-world reserve system outputs were developed for comparison, based either on species rarity or richness, but also incorporating areas with dissimilar species compositions and different environmental characteristics from neighbouring and previously selected grid cells (high beta diversity). This beta diversity (BD) algorithm, therefore, selects a network that not only represents all species in the area, but also bases its selection on the spatial structure of the species assemblages and environmental gradients, i.e. it samples both biodiversity pattern and process in a representative manner.

4.2 Results

4.2.1 Ordination Analysis

Geographic patterns of hierarchically classified DCA scores are indicated in Figure 4.1 illustrating the five avian communities identified within the province. The Maputaland community in the northeast, the East Coast, the Drakensberg Escarpment, Central Zululand forming a transition between the Drakensberg and Maputaland communities and the Central-southern Midlands community at the southern end of the province, each contain unique combinations of species. The most important bird species in each community, based on indicator species analysis (Dufrene and Legendre, 1997) is provided in Table 4.1. Eigenvalues and gradient lengths were moderately higher for DCA than for CCA for the first two axes (Table 4.2). This fact together with the strong and significant correlations between the DCA for axis 1 and axis 2 with the explanatory variables (Table 4.3) suggested that much of the variation in avian diversity distribution is related to the measured environmental variables. The stepwise CCA reduced the number of significant variables required to explain the variation in species turnover (Table 4.4). Most (81%) of the variation in bird species assemblages in KwaZulu-Natal was accounted for by the explanatory environmental variables of elevation heterogeneity, mean growth days, mean growth temperature, mean annual evapotranspiration, and seasonality of precipitation.

The CCA results are graphed as a biplot, in which arrow length and direction indicate the correlation between the explanatory variable and the CCA axes, and smaller angles between arrows indicate stronger correlations between variables (Figure 4.2). The dominant compositional gradient (axis 1) reflected an altitudinal gradient, which was represented by the mean growth temperature and the seasonality of precipitation, from the sub-tropical climate of the coast to the temperate-afromontane climate of the Drakensberg Escarpment. Grid cells towards the higher lying areas experienced higher seasonal variability in temperature and precipitation, whereas low lying coastal regions experienced lower seasonal variability in temperature, higher temperatures, and lower variability in precipitation. The seasonality of precipitation and elevation heterogeneity are moderately correlated with each other, but reflected low inflation factors in the CCA analysis therefore each was able to provide explanation for the turnover in species composition. This altitudinal gradient runs roughly east-west from the Maputaland coastal plain to the Drakensberg Escarpment, reflecting the strong climatic influence of the Indian Ocean and the generally north-south orientation of the Drakensberg Escarpment.

The second CCA axis was a gradient in growing season moisture stress, from the areas of warm, dry growing seasons around Maputaland and the Lebombo Mountains, which are characterized by arid woodlands to areas of warm, wet growing seasons along the southern East

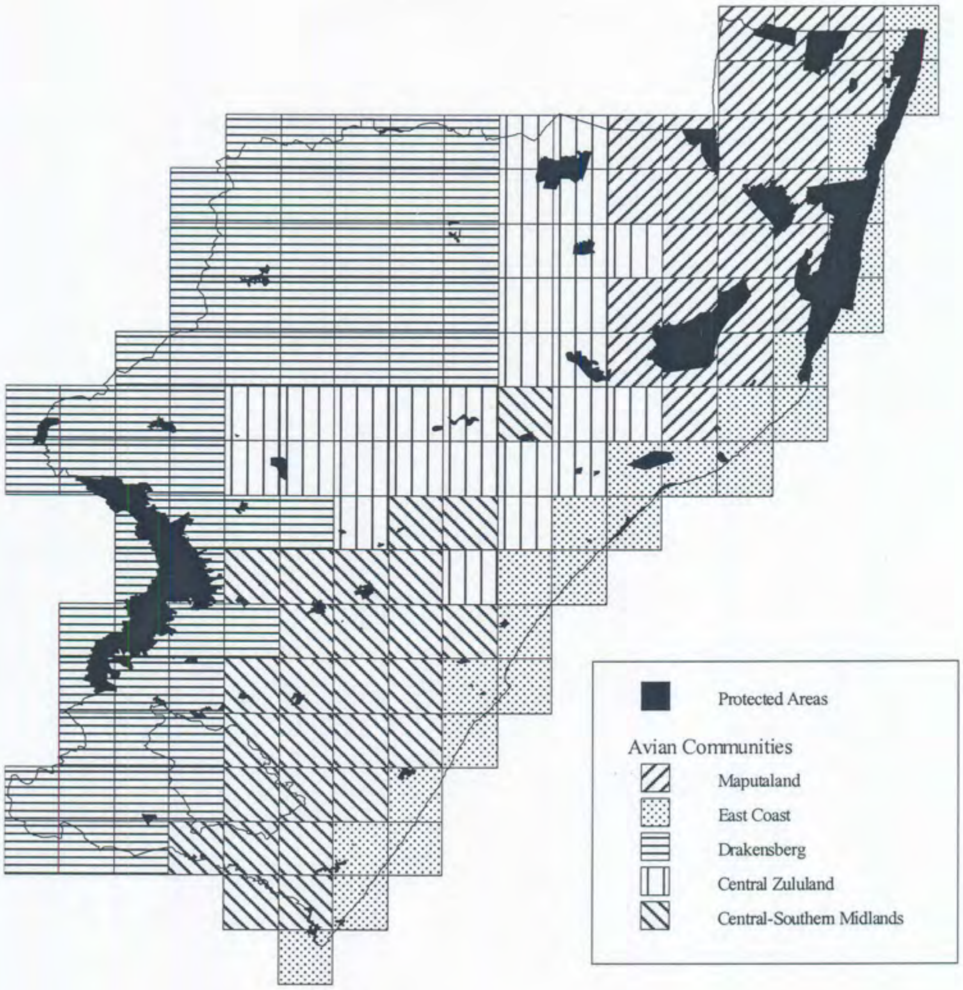

Figure 4.1: Identified avian diversity assemblages derived from hierarchical classification of first two axes of the detrended correspondence analysis results.

Coast (Figure 4.2). Areas of low summer precipitation and high annual evapotranspiration included the interior valleys to the west of the Lebombo Mountains, especially northern Zululand, and the White Mfolozi and Tugela River basins. The Central-southern Midlands represents areas of higher summer precipitation with variable elevation owing to lower annual evapotranspiration being able to support montane forests and upland grassland.

An analysis of the available vegetation habitat and human impact on the bird communities of KwaZulu-Natal illustrates the conservation conflicts and habitats to be managed. In Table 4.5 potential functional vegetation types (Fairbanks and Benn, 2000) that would have occurred today, were it not for all the major human-made transformations, were combined with currently mapped major land-use types (Fairbanks et al., 2000). The proportion of vegetation types for each avian community (Figure 1.3) provides a general description of the habitat requirements. The land-use

Table 4.1: Avian bioindicators in order of importance based on Dufrene and Legendre (1997) indicator species value measure for each identified avian community assemblage.

Community		Community	
Maputaland		**Central Zululand**	
Trigonoceps occipitalis	whiteheaded vulture	*Aquila rapax*	tawny eagle
Eupodotis ruficrista	redcrested korhaan	*Cossypha humeralis*	African whitethroated robin
Torgos tracheliotus	lappetfaced vulture	*Cisticola chiniana*	rattling cisticola
Coracias naevia	purple roller	*Merops pusillus*	little bee-eater
Eremomela usticollis	burntnecked eremomela	*Hieraaetus spilogaster*	African hawk eagle
Nectarinia neergaardi	Neergaard's sunbird	*Vidua paradisaea*	paradise whydah
Tockus erythrorhynchus	redbilled hornbill	*Aquila wahlbergi*	Wahlberg's eagle
Terathopius ecaudatus	bateleur	*Tricholaema leucomelas*	pied barbet
Cossypha heuglini	Heuglin's robin	*Turtur chalcospilos*	greenspotted dove
Eremomela icteropygialis	yellowbellied eremomela	Sylvietta rufescens	longbilled crombec
East Coast		**Central-Southern Midlands**	
Morus capensis	cape gannet	*Hirundo atrocaerulea*	blue swallow
Sterna hirundo	common tern	*Zoothera gurneyi*	orange ground thrush
Sterna bengalensis	lesser crested tern	*Serinus scotops*	forest canary
Calidris alba	sanderling	*Poicephalus robustus*	cape parrot
Sterna sandvicensis	sandwich tern	*Tauraco corythaix*	Knysna lourie
Charadrius leschenaultii	sand plover	*Ploceus bicolor*	forest weaver
Sterna albifrons	little tern	*Anthus lineiventris*	striped pipit
Sterna paradisaea	Arctic tern	*Seicercus ruficapillus*	yellowthroated warbler
Sterna bergi	swift tern	*Nectarinia chalybea*	lesser doublecollared sunbird
Larus dominicanus	kelp gull	*Anthreptes collaris*	collared sunbird
Drakensberg Escarpment			
Eupodotis caerulescens	blue korhaan		
Hirundo spilodera	SA cliff swallow		
Chaetops aurantius	orangebreasted rockjumper		
Francolinus africanus	greywing francolin		
Euplectes afer	golden bishop		
Spreo bicolor	pied starling		
Gypaetus barbatus	bearded vulture		
Chersomanes albofasciata	spikeheeled lark		
Myrmecocichla formicivora	southern anteating chat		
Amadina erythrocephala	redheaded finch		

Table 4.2: Eigenvalues and gradient lengths (1 Standard Deviation) for the first two axes from DCA and DCCA of all bird species for KwaZulu-Natal.

	Axis 1		**Axis 2**	
	DCA	DCCA	DCA	DCCA
Eigenvalue	0.21	0.19	0.09	0.08
Gradient length	1.96	2.45	1.51	1.23

Table 4.3: Spearman's rank correlation of explanatory factors with axis scores from DCA and intraset correlation coefficients from CCA that included all explanatory variables. [†]

	Axis 1		**Axis 2**	
	DCA	CCA	DCA	CCA
DEMMEAN	0.93	0.93	-0.05	-0.05
DEMSTD	0.59	0.59	-0.5	-0.023
GDMEAN	0.05	0.04	0.83	0.84
MAP	-0.03	-0.86	0.73	-0.21
GTMEAN	-0.88	-0.92	-0.21	-0.11
NGTMEAN	-0.91	-0.91	-0.11	-0.10
MAT	-0.91	-0.03	-0.09	0.74
HOTMNTHMN	-0.89	-0.89	-0.16	-0.17
MINMNTHMN	-0.93	-0.93	0.02	0.01
EVANNMN	-0.42	-0.42	-0.66	-0.69
PSEAS_MN	0.85	0.86	0.06	0.04
TSEAS_MN	0.53	0.54	-0.49	-0.52
MXSEAS_MN	0.57	0.57	-0.40	-0.42

[†] Sign reflects arbitrary selection of gradient direction by CANOCO.

Table 4.4: Summary of results from stepwise CCA. [†]

	Axis 1	**Axis 2**
DEMSTD	0.61	-0.001
GDMEAN	0.05	0.86
GTMEAN	-0.88	-0.21
EVANNMN	-0.44	-0.72
PSEAS_MN	0.87	0.04

[†] Sign reflects arbitrary selection of gradient direction by CANOCO. $P < 0.01$

information provides an indication of the current transformation processes taking place within the avian community assemblages. The heterogeneous nature of the Central Zululand and Central-southern Midlands vegetation structures and avian assemblages is apparent. The environmental heterogeneity found within the Central-southern Midlands community has also provided ample development opportunities for humans, with 43% of the landscape having been transformed, and most of the existing protected areas here are small. The small sizes of these protected areas, their scattered locations, their progressive isolation through the loss of connecting habitats are cause for concern.

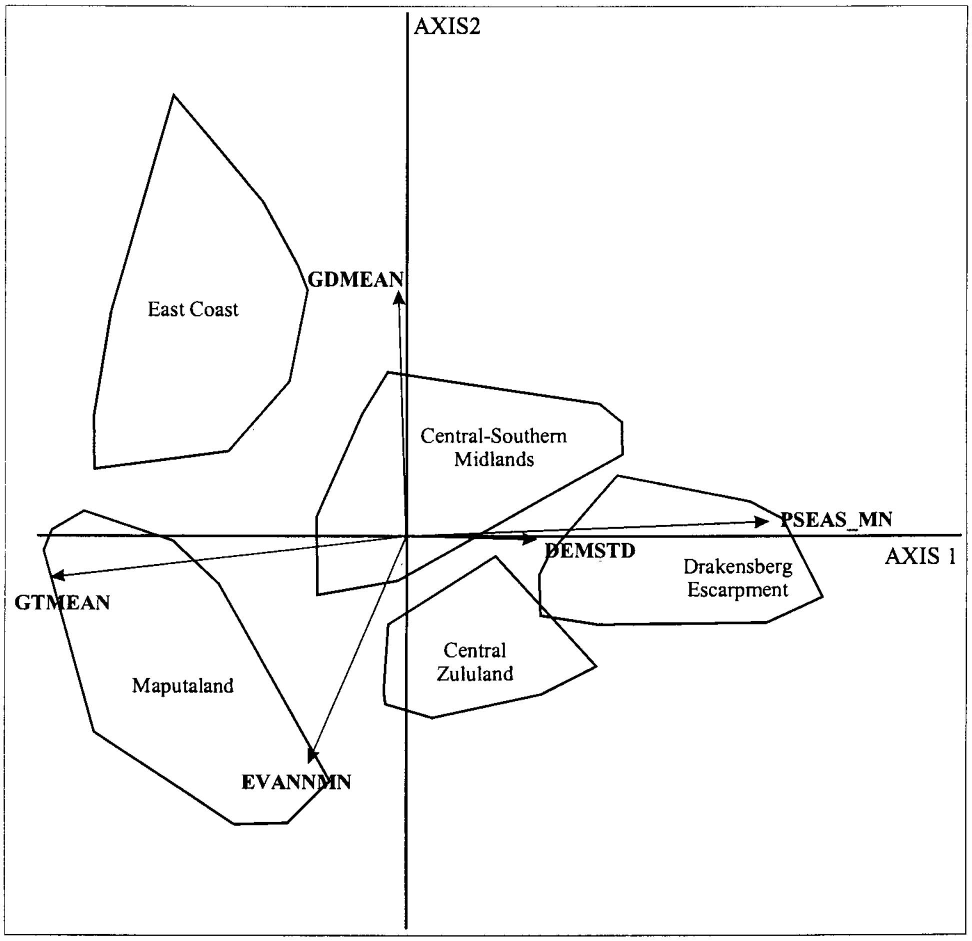

Figure 4.2: Species-environment gradients identified from stepwise canonical correspondence analysis with convex hulls of avian community biogeographic zones. GTMEAN - Annual mean of the monthly mean temperature (°C) weighted by the monthly growth days; PSEAS_MN - Precipitation seasonality from the difference between the January and July means; DEMSTD - Elevation heterogeneity; GDMEAN - Number of days per annum on which sufficient water is available for plant growth; and EVANNMN - Total annual pan evapotranspiration (mm).

4.2.2 Spatial Autocorrelation Analysis

The analysis was performed on axis 1 and 2 of the CCA results (Figure 4.3a, b). The resultant Moran's *I* axis values were then derived for each grid cell for the analysis of the species-environment spatial structure in the reserve selection procedure. On axis 1 strong positive autocorrelated clusters of similar species-environment compositions were located along the northern coast, Maputaland coastal plain, and Drakensberg Escarpment. Negative autocorrelated clusters were identified in the interior associated with the Central Zululand and Central-southern

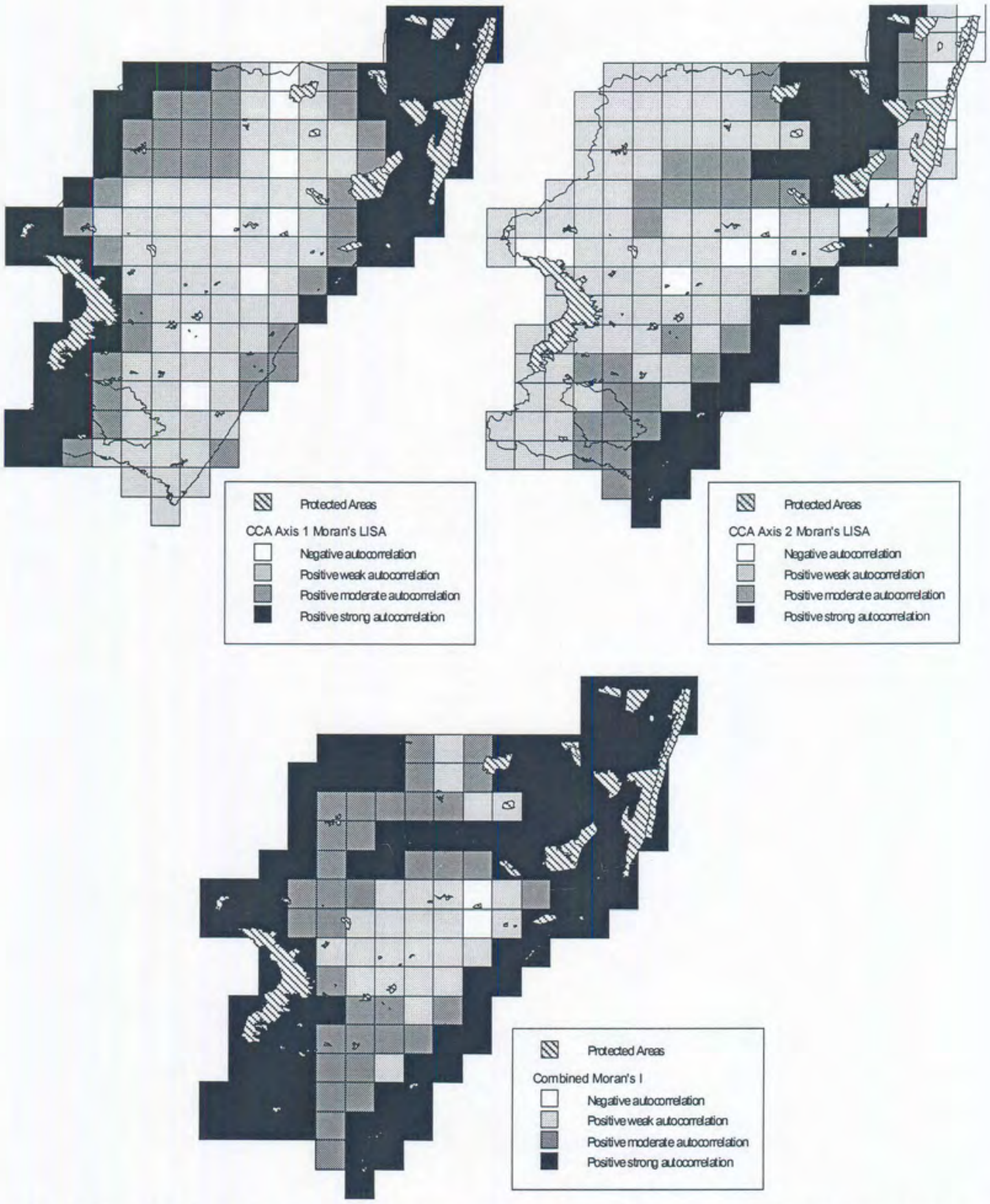

Figure 4.3: Moran's *I* spatial autocorrelation results: (a) CCA axis 1; (b) CCA axis 2; and (c) combined Moran's *I* axes 1 and 2.

Midlands avian communities. These grid cells represent dissimilar species-environment compositions from their immediate neighbours and therefore represent areas of high species turnover along the identified environmental gradients.

Moran's *I* analysis of the second axis identified strong positive autocorrelated clusters in the arid woodland region of northern Zululand, Maputaland and the Lebombo Mountains and along the southern East Coast. Negative clusters were found in the Tugela and Mhlatuze river basins, central Drakensberg Escarpment and northern East Coast.

Table 4.5: Percentage of functional vegetation and land-cover/land-use types per identified avian community assemblage.

	Maputaland†	East Coast†	Drakensberg	Central Zululand	Central-Southern Midlands
Coastal Forest	0.6	1.8	0.0	0.0	0.0
Afromontane Forest	0.1	0.7	0.7	0.5	1.2
Arid Woodland	46.6	0.1	0.7	9.8	0.0
Moist Woodland	9.6	25.2	0.0	0.0	2.0
Mixed Woodland	7.6	4.9	18.0	31.9	13.3
Thicket	0.0	3.9	0.3	16.3	9.6
Upland Grassland	0.0	2.9	19.2	4.5	20.6
Highland Grassland	0.4	0.0	36.7	6.4	3.3
Wetlands	4.4	6.2	1.0	0.1	0.5
Bare	0.1	0.5	0.5	0.5	0.0
Degraded	11.8	7.5	5.6	9.6	10.0
Exotic plantation	1.8	8.8	3.4	5.8	16.1
Agriculture Dryland	16.5	22.1	10.5	13.7	19.5
Agriculture Irrigated	0.4	0.1	2.0	0.5	2.0
Urban	0.1	7.4	1.3	0.4	2.0

† Missing area measurements from coast and Mozambique border.

Spearman's rank correlation analysis of the individual Moran's *I* axis values and combined values revealed relationships between the Moran's *I* values and definitions of land type heterogeneity (Table 4.6). A combined model of landscape types (Figure 3.2) and functional vegetation types (Figure 1.3) had the highest correlations with Moran's *I* values for axis 1 and combined Moran's *I* values. There was no meaningful relationship for the axis 2 Moran's *I* results. This relationship depicts decreasing Moran's *I* values as the variety of landscape-functional vegetation types increases, i.e. with increasing environmental heterogeneity (Figure 4.4). This implies that local bird diversity turnover is more strongly linked to landscape and vegetation structure (e.g., MacArthur, 1964; Wiens, 1989a) within the Central Zululand and Central-southern Midlands, than to broad climate. These areas appear to represent important transitionary regions for birds, between the richer and more homogenous high grassland areas of the Drakensberg Escarpment, the Maputaland arid woodlands and East Coast moist woodlands. These heterogeneous areas may also be of significance as zoogeographical barriers to avian distributions because of deeply incised river valley conditions (Figure 1.2a - also see Benson et al., 1962; Clancey, 1994). Microclimates, diverse habitat assemblages, and geomorphology all seem to play important roles in maintaining and driving the unique bird assemblages and rapid species turnovers across the province's interior regions (Figure 4.3c).

Table 4.6: Spearman's rank correlation coefficients of the Moran's *I* analysis and the diversity of landscape definition types (see Table 1.1).

	Axis 1	Axis 2	Combined
LAND	-0.52	-0.16	-0.49
LANDVEG	-0.62	-0.07	-0.54
LANDVEGF	-0.70	-0.04	-0.59
VEG	-0.37	0.11	-0.23
VEGF	-0.51	0.14	-0.32
LCLUTYPES	0.01	0.09	0.00
LCLULAND	-0.57	-0.05	-0.49

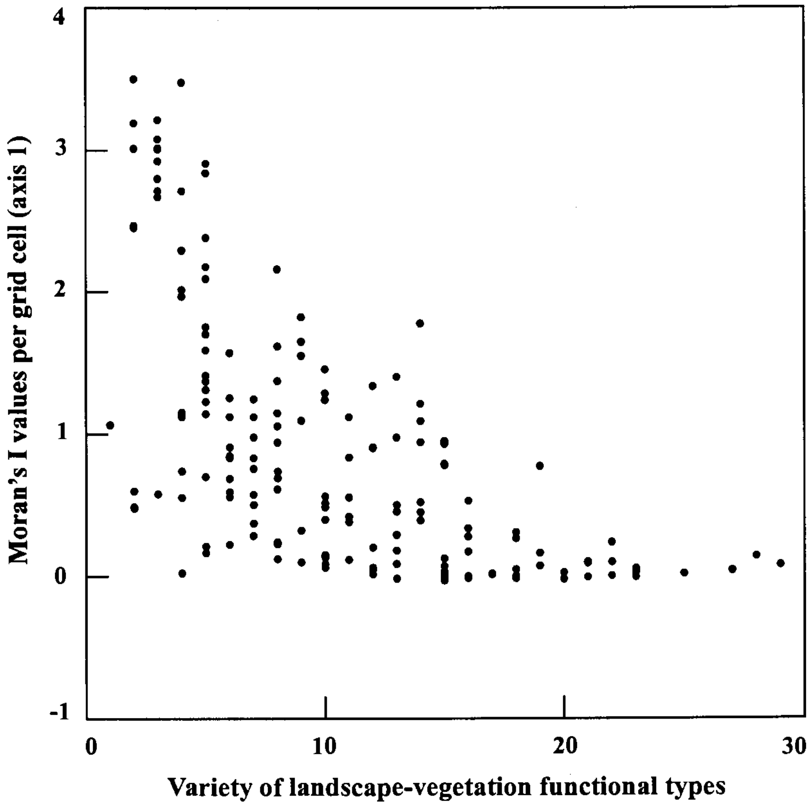

Figure 4.4: Graph of CCA axis 1 Moran's *I* values relationship to the variety of landscape-vegetation functional types found within each grid cell.

4.2.3 Priority Conservation Areas

The study area of 165 grid cells included 19 (11.4%) grid cells that were considered protected, i.e. ≥ 25% protected. These grid cells are located almost entirely within the central Drakensberg Escarpment and Maputaland areas, and represented 529 (93%) of the 566 recorded bird species. This illustrates that these larger existing reserves do contribute significantly towards the goal of conserving all avian species. The rarity and richness-based complementary algorithms selected 15 (10%) and 14 (9%) of the remaining 147 grid cells respectively to represent the remaining 37 species at least once (Figure 4.5a,c). To achieve the goal of adequately sampling all species while also representing the identified environmental gradients, the BD (beta diversity) algorithm for both the rarity and richness-based analyses needed 18 (12%) grid cells (Figure 4.5b,d).

Figure 4.6 illustrates the rates of species accumulation for the four algorithms. The richness-based algorithm rapidly represented most species (> 90%) within 7% of the remaining land area, with the rarity-based algorithm requiring only slightly more land (9%). The rarity-based algorithm also illustrates the break levels its search rules creates by looking for pockets of rare species while constrained by proximity rules to pick grid cells that are closer to the previously selected grid cells. The richness-based BD algorithm initially selected species at a slow rate but increased after the first 3.5% of the grid cells were selected and the rarity-based BD algorithm shows the same breaks but chose more land area earlier.

The results outlined above assume that the protected areas that are already proclaimed are adequate, and that the procedure used can only produce results that add to defining an all inclusive representative reserve network. Once the environmental gradients that are associated with birds species turnover are identified it may be more appropriate to ask what would an "ideal" network for total bird protection look like if the current protected areas were not assumed adequate. Figure 4.7 provides such a result, which might provide a more resilient and thus viable option for long-term retention of the provinces bird diversity. For either algorithm, the contrasts with the status quo of using straight species-based complimentary procedures versus incorporating associated environmental gradients are strikingly apparent.

The original rarity and richness-based algorithms were the most efficient representing all species in the least amount of land area possible. These algorithms obviously concentrated on the areas of high species richness and rarity. The algorithm rules for either approach (rarity or richness) select grid cells in a locally optimal manner, based on the species database and grid cell proximity, rather than selecting based on regional optima. The grid cells picked for either the rarity or richness-based algorithms are similar, except for the selection order, with most areas

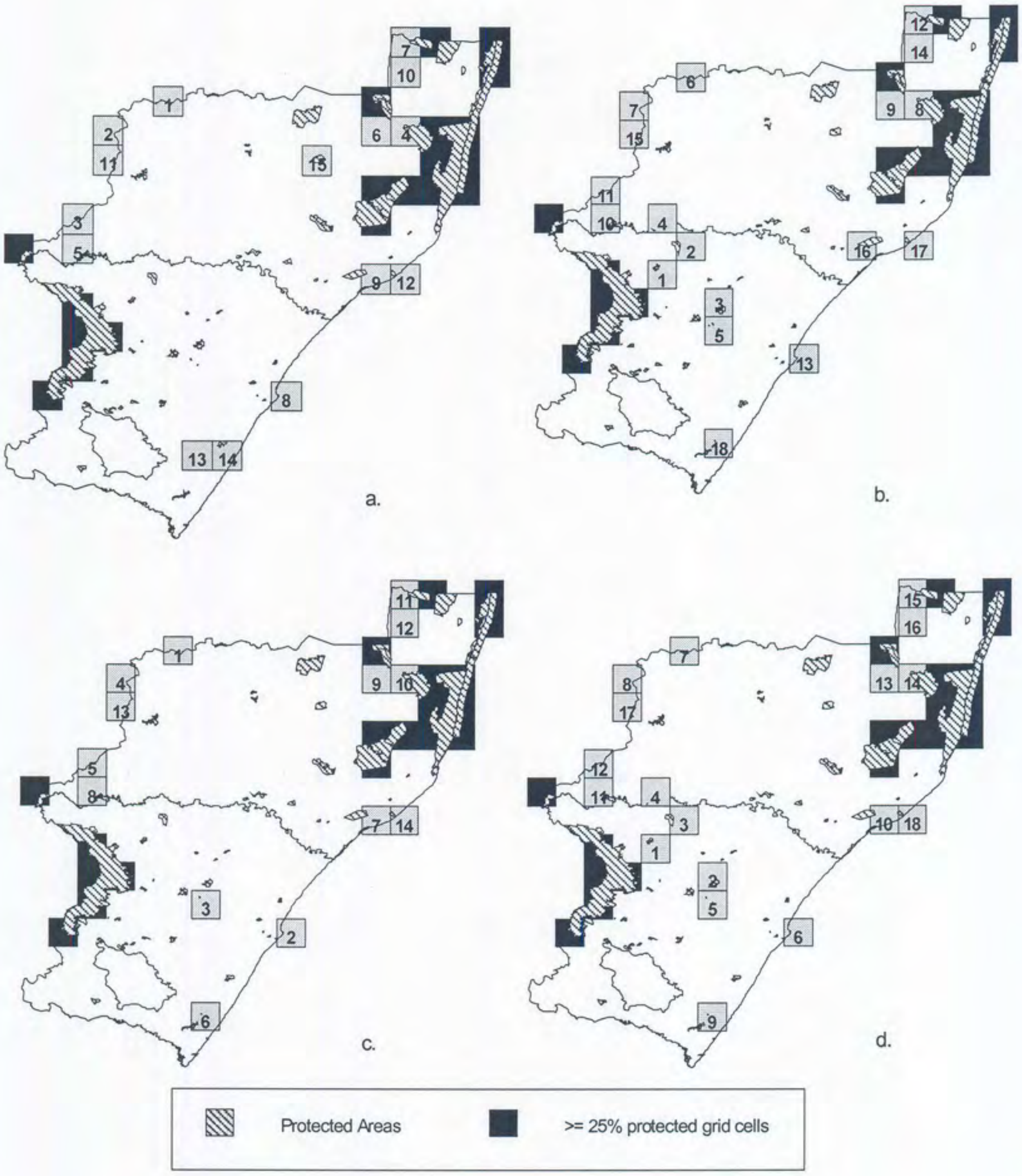

Figure 4.5: Comparison of algorithm results: (a) species rarity-based algorithm; (b) species rarity and beta diversity algorithm; (c) species richness-based algorithm; and (d) species richness and beta diversity algorithm.

selected in the Maputaland, Drakensberg Escarpment and East Coast regions. The BD algorithm attempts to provide the algorithm rules with important environmental information about the entire region using the ranked spatial autocorrelation classes. Although similar grid cells are selected for both the rarity and richness-based BD algorithms, the masking action of the ranked spatial autocorrelation categories forces the algorithms in this region to search the interior of the province (Figure 4.3c) first to locate grid cells containing the required species. Four to five grid cells are chosen from the southern areas of Central Zululand and northern areas of the Central-southern Midlands depending on the algorithm emphasis (Figure 4.5b,d). The other significant differences

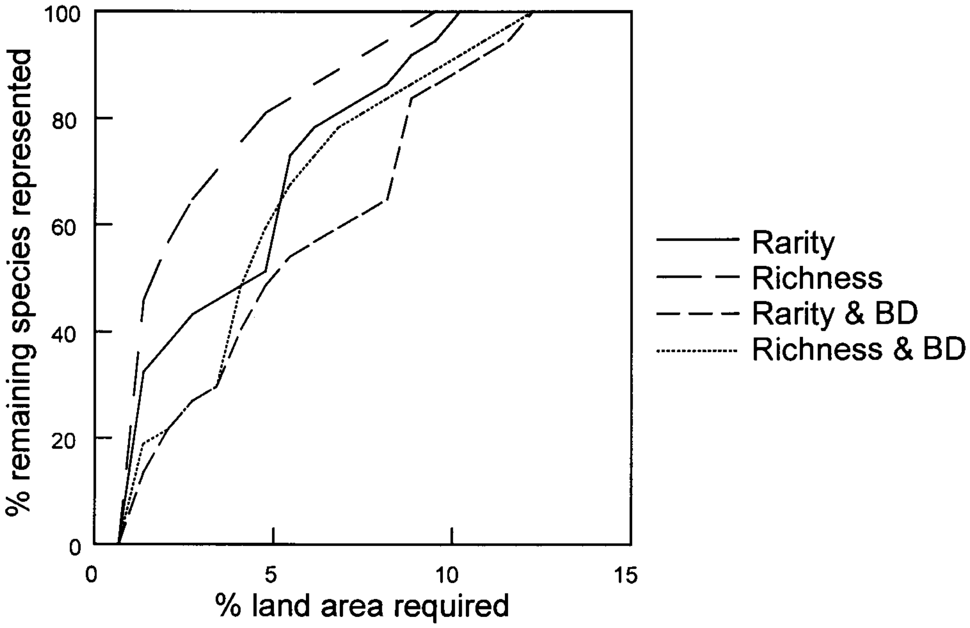

Figure 4.6: Graph of algorithm efficiencies detailing species representation versus percent land area required. (BD = beta diversity).

among algorithm outputs are the selection orders. In this case, the rarity-based BD algorithm results are the most useful for conservation as it ranks the rarest birds, landscapes and natural processes most important for immediate conservation action (Table 4.7).

4.3 Discussion

Like most other systematic conservation procedures (see review Margules and Pressey, 2000), this proposed procedure is useful for identifying conservation-worthy areas because it is flexible and multivariate. The framework of complementarity analysis can contribute to assessing the efficient selection of un-represented species for conservation. The long-term retention of those species should also be improved by extending this methodology to select by spatial changes in environmental gradients and associated species.

4.3.1 Evaluation of the Techniques

Existing protected areas within the province are concentrated mostly within the Maputaland region and the central Drakensberg Escarpment along the Lesotho border. This leaves the other avian communities identified largely un-represented or under-represented with small (< 1000 ha) ineffective reserves. The traditional complementarity-based algorithms emphasizing rarity or richness do little to correct this representation bias as they select additional grid cells in the already sufficiently conserved areas, leaving Central Zululand and the Central-

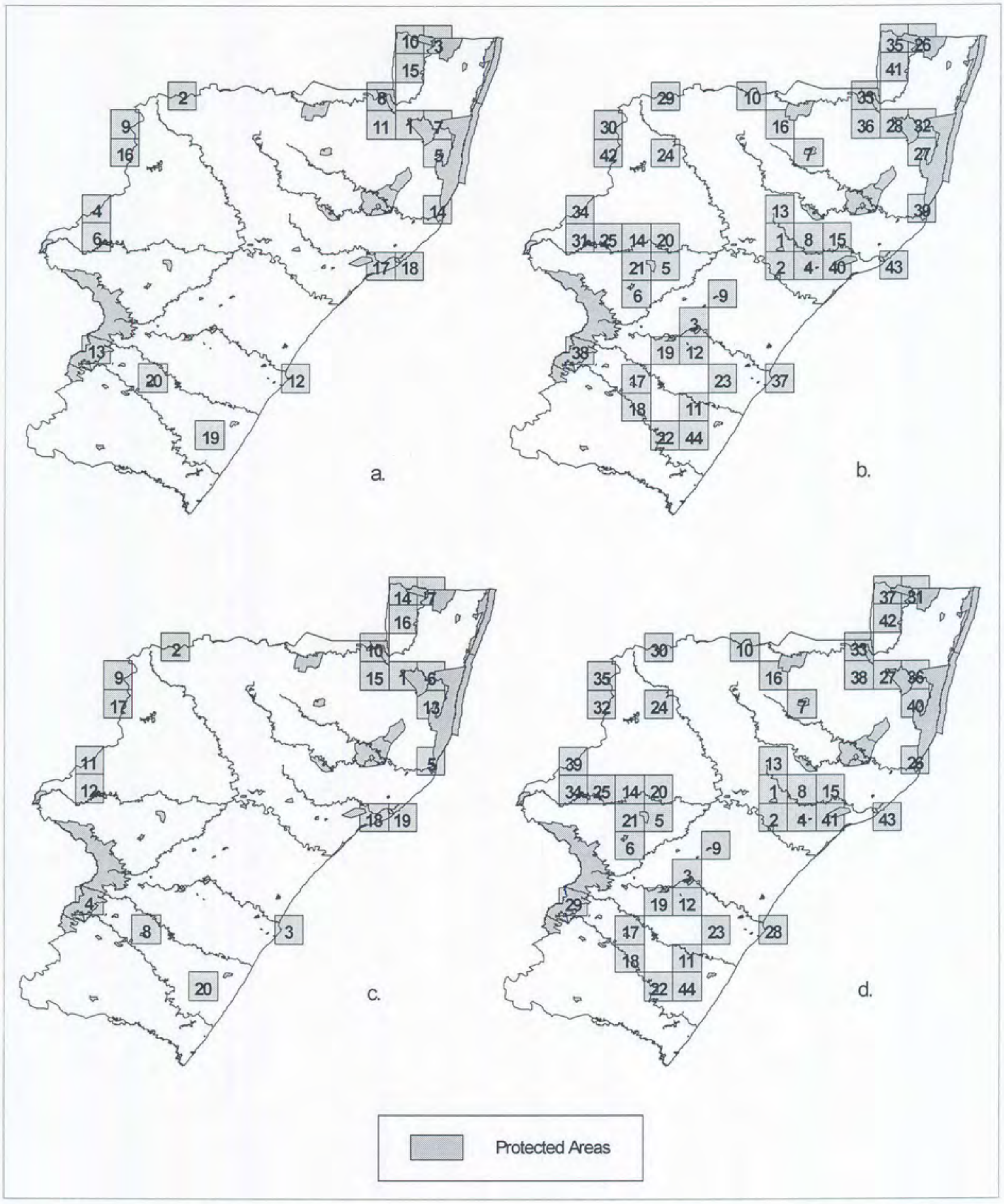

Figure 4.7: Comparison of algorithm results based on an ideal network, i.e., not taking into account current protected areas: (a) species rarity-based algorithm; (b) species rarity and beta diversity algorithm; (c) species richness-based algorithm; and (d) species richness and beta diversity algorithm.

southern Midlands avian communities largely unnoticed and under protected. This is due mostly to the fact that the Maputaland, East Coast and Drakensberg Escarpment regions are highly species rich, containing >90% of the avian species recorded for the province. Thus, once these

Table 4.7: Species conservation status and representation selection order based on algorithm type.

Species name	Common name	Conservation status	Species rarity	Species rarity and BD	Species richness	Species richness and BD
Accipiter ovampensis	Ovambo sparrowhawk	rare	10	14	12	16
Botaurus stellaris	bittern	critically endangered	12	17	14	18
Bubalornis niger	redbilled buffalo weaver	common resident	6	9	9	13
Campethera notata	Knysna woodpecker	globally near threatened	13	18	6	9
Chersomanes albofasciata	spikeheeled lark	near endemic, common	1	1	1	1
Ciconia abdimii	Abdim's stork	migrant visitor	11	15	13	17
Circus macrourus	pallid harrier	globally near threatened	5	10	8	11
Crex egregia	African crake	locally common	8	4	2	4
Cryptolybia woodwardi	Woodward's barbet	local endemic, vulnerable	9	16	7	10
Cursorius rufus	Burchell's courser	vulnerable, southern Africa	2	7	4	8
Daption capense	pintado petrel	common visitor	8	13	2	6
Diomedea melanophris	blackbrowed albatross	common visitor	8	13	2	6
Eupodotis afraoides	northern black korhaan	common resident	2	7	4	8
Falco rupicoloides	greater kestrel	common	1	1	1	1
Falco vespertinus	western redfooted kestrel	common migrant	1	1	1	1
Gallinula angulata	lesser moorhen	common	9	5	3	5
Glareola nordmanni	blackwinged pratincole	globally near threatened	3	11	5	12
Glaucidium capense	barred owl	rare	4	8	10	14
Hirundo atrocaerulea	blue swallow	rare, threatened	15	3	3	2
Larus fuscus	lesser blackbacked gull	uncommon	8	13	2	6
Macronectes giganteus	southern giant petrel	common visitor	8	13	2	6
Mirafra apiata	clapper lark	near endemic	2	7	4	8
Mirafra cheniana	melodious lark	endemic, threatened	3	2	5	3
Mirafra ruddi	Rudd's lark	local endemic, critically endangered	1	6	1	7
Numenius arquata	curlew	common, vulnerable	8	13	2	6
Oceanites oceanicus	Wilson's storm petrel	common	8	13	2	6
Pachycoccyx audeberti	thickbilled cuckoo	rare	7	12	11	15
Pinarocorys nigricans	dusky lark	uncommon	4	8	7	10
Podiceps nigricollis	blacknecked grebe	common	1	6	1	7
Poicephalus robustus	cape parrot	endemic, endangered	13	3	3	2
Prinia flavicans	blackchested prinia	near endemic, common	1	6	1	7
Procellaria aequinoctia	whitechinned petrel	common	8	13	2	6
Serinus atrogularis	blackthroated canary	common	1	1	1	1
Spermestes fringilloide	pied mannikin	rare, indeterminate conservation	14	18	6	9
Spizocorys conirostris	pinkbilled lark	near endemic, local nomad	1	4	1	4
Spizocorys fringillaris	Botha's lark	local endemic, endangered	1	6	1	7
Zoothera gurneyi	orange thrush	vulnerable, southern Africa	15	3	3	2

areas are represented, almost the entire avian diversity within the province is represented and from a species representation point of view there is no need for additional grid cells.

This makes the investigation and identification of the species community structure, as well as, the environmental gradients associated with that structure an essential component of conservation area selection procedures. By attempting to protect not only the biodiversity pattern but also the processes responsible for that pattern, conservation design may come closer to guaranteeing the representation, as well as the long-term retention of regional biodiversity. The grid cells selected by the BD algorithm, although similar to those selected by the traditional algorithm, differ in that some grid cells fall within the under-represented avian communities, particularly the highly heterogeneous areas in the Central Zululand and northern Central-southern Midlands communities. Both variants of the BD algorithm are able to begin selection in the

Central-southern Midlands and southern Central Zululand then move progressively to the higher richness areas of the East Coast, Maputaland and northern Drakensberg Escarpment.

In addition to the under-representation of the avian communities in the province's interior by the traditional reserve-selection procedures, it is obvious from the CCA analyses that these procedures succeed in representing the extremes of the CCA species-environment gradients. By focussing on species representation alone, the low lying, moist, hot Maputaland region and high, wet, cool Drakensberg Escarpment are well represented, but the climatically variable interior mid-altitude areas with their unique species assemblages are excluded.

Spatial autocorrelation analysis proved to be a valuable tool in the identification of areas of high beta diversity, as opposed to employing simple measures of alpha diversity traditionally used by reserve-selection techniques. Moran's *I* values for both the identified altitudinal-temperature environment gradient of axis 1 and the water balance environment gradient of axis 2 from the CCA analysis (Figure 4.2) enabled the identification of areas high in beta diversity. These areas highlighted by low Moran's *I* values contained very different species assemblages from their neighboring grid cells, as well as different environmental variables associated with these assemblages. By focussing on grid cells with low levels of spatial autocorrelation, the BD algorithm identified areas with highly dissimilar species, and environmental compositions from neighboring grid cells in the southern Zululand and northern Central Midlands. The Tugela River basin and Central-southern Midlands are the transition zones for flora and fauna from the Drakensberg Escarpment and coastal plains (Poynton, 1961) and these dominant river valleys may represent barriers to avian dispersal (Benson et al., 1962; Clancey, 1994). They also represent areas of high species turnover along the identified environmental gradients.

The contrasting selection orders (Figure 4.5) of the algorithms illustrate the highly dissimilar approaches and values assigned to each selected grid cell by the four procedures. The richness method favours areas of high species richness (Drakensberg Escarpment, East Coast and then Maputaland regions) and the rarity method favours the Drakensberg, Escarpment, Maputaland and then East Coast regions. The BD method using richness places emphasis on the interior regions, as it should, but must pick up the remainder of the required species from the Drakensberg Escarpment, East Coast and Maputaland regions. The BD and rarity method chooses a similar selection order for the interior but re-assigns selection order importance to grid cells in the Drakensberg Escarpment and Maputaland region. The spatial autocorrelation method employed here allows for the incorporation of measures of beta diversity into what are traditionally alpha diversity based reserve selection techniques. The results of the present study illustrate the value of the inclusion of areas with high levels of alpha and beta diversity. This investigation also highlights that the avian communities of high protection (Drakensberg

Escarpment and East Coast) are also skewed in their representation along north-south geographic gradients. The central Drakensberg Escarpment is adequately protected in the south and the East Coast protected areas lie in the north. Both the rarity and richness algorithms for all scenarios place emphasis on adequately protecting the full length of the Drakensberg Escarpment and strategic locations along the coastline.

However, as with any species-based reserve selection algorithm, problems emanating from error or particular areas in the available databases are immediately evident. The grid cell covering the city of Durban and its harbor contains eight species of Palaearctic seabirds only found there because of the fishing trawlers that they follow for food sources (Harrison et al., 1997) and the tidal mudflats. Several of these birds are near globally threatened and will require the conservation authorities to develop appropriate management plans at Durban harbor, which will not necessarily lead to the declaration of extra coastal reserves, but will require the extensive restoration of the mudflats and mangroves (Allan et al., 1999).

4.3.2 Practical Area Selection for Improved Conservation

Biological representativeness should be used as the first objective in selecting conservation worthy areas (Margules, 1986). To date complementary approaches to conservation have focussed primarily on maximising the conservation of contemporary alpha diversity patterns using measures of species, habitat richness or rarity (Margules and Pressey, 2000). The present study shows that the use of principles such as complementarity on species data alone does not always produce adequate biologically meaningful results. Although they represent the required species efficiently, they do little to address the long-term retention of species diversity through the conservation of underlying natural processes and turnover patterns that support this diversity pattern (Balmford et al., 1998; Cowling et al., 1999; Fairbanks and Benn, 2000; Rodrigues et al., 2000).

Climatic variables are generally important at coarser scales, whereas disturbance variables (e.g., management or successional stages), geology, or biotic factors tend to be important at finer scales. Of course, decisions on which environmental variables to include in direct gradient analysis will largely depend on the scale of the study (Wiens, 1989b). Nevertheless, by applying techniques such as CCA it is possible to find what the important environmental variables are, if no *a priori* knowledge exists about the possible predictor variables. In this study, the landscapes and physiographic basins contain climatic patterns, which interact to limit the species pool. By applying methods like CCA and spatial autocorrelation analysis, it is possible to consider all these environmental variables and their spatial arrangement in an integrated manner. Future studies will however, need to incorporate landscape connectivity (Forman, 1995; Wessels et al., 2000) and biological community structure (Soulé and Simberloff, 1986).

Fairbanks et al. (1996) presented evidence from Californian floral communities that the end points of species-environment gradients, where the climate is overly cold, hot, or dry, were more strongly affected by climate change and therefore more liable to species composition change. A South African climate change study conducted on invertebrate and vertebrate taxa estimated that 66% of all species found within the Kruger National Park would have a < 50% chance of being found there after a doubling of CO_2 levels (van Jaarsveld et al., 2000). It is important to raise the problem of how to preserve communities in a continually changing environment (White and Bratton, 1980), although fluctuations in natural communities over a variety of temporal scales are generally accepted (Wiens, 1984). How climate change impacts on current conservation, is an issue often discussed but rarely applied in conservation planning (Peters and Darling, 1985; Balmford et al., 1998; Huntley, 1998). Climatic change will certainly affect bird populations, though its precise effects are difficult to predict (Botkin et al., 1991; Furness and Greenwood, 1993). Therefore, although the BD algorithm is less land-use-efficient it manages to spatially represent the under-represented species, avian communities, and the identified environmental gradients in the two proposed conservation area networks. It could therefore be a surrogate for representing potential changes in temporal species assemblages (e.g., Rodriguez et al., 2000).

4.4 Summary

African conservation agencies are charged with the task of incorporating broader levels of biodiversity in an integrated manner to maintain systems and services (Maddock and du Plessis, 1999). However, the budgets of public conservation organizations fall far short of being able to fund the acquisition of all the new reserves the province will require to be truly representative of the avian biodiversity pattern identified in this study. Therefore, the development of a biologically sound logic and methods for identifying conservation areas must not be limited to identifying a reserve network. This study identified only broad conservation-worthy linkages among existing protected areas. This is the first of several steps in demarcating areas that could contribute to longer-term retention of avian diversity outside the formally protected areas (Armstrong et al., 2000). Implementation will need to ensure that landowners are amenable to conservation and that identified areas remain untransformed. In the short-term emphasis should be placed on identifying critical conservation areas for all the major taxonomic groups, which can then be included in a comprehensive regional conservation plan, integrating formal reserves and priority areas in the human-managed matrix.

5. Human-Ecosystem Co-evolution: Analysis of Bird Diversity and Structure with Human Land Transformation

> But when I consider that the nobler animals have been exterminated here - the cougar, panther, lynx, wolverine, wolf bear, moose, deer, the beaver, the turkey, etc., etc. - I cannot but feel as if I lived in a tamed, and as it were emasculated country ... I listen to a concert in which so many parts are wanting ... for instance, thinking that I have here the entire poem, and then to my chagrin, I hear that it is but an imperfect copy that I possess and have read, that my ancestors have torn out many of the first leaves and grandest passages ...
>
> -HENRY DAVID THOREAU, *Journal*, 1861

Biodiversity is suffering losses at an accelerated rate due to human action and biologists are increasing their efforts to understand this decline and develop appropriate conservation responses (Wilson, 1988; Lubchenco et al., 1991; Soulé, 1991; Dale et al., 1994; Pimm et al., 1995; Margules and Pressey, 2000). Although there is little consensus about the most appropriate response strategy (Mace et al., 2000), systematic approaches such as complementary networks, species richness "hotspots" and gap analysis (Pressey et al., 1993; Scott et al., 1993; Williams et al., 1996; Mittermeier et al., 1998; Reid, 1998; Schwartz, 1999; Myers et al., 2000) all employ species or community assemblage patterns derived from biological surveys. These data are systematically interpreted in a spatially explicit manner to identify "ideal" or "real world" conservation land-use plans.

An understanding of the structure of human modification dynamics across a landscape and its co-relation with species presence and abundance is required. In contrast to the degree of human influence on ecosystems, ecologists have concentrated their research on relatively pristine areas (Cairns, 1988; Lubchenco et al., 1991; O'Neill and Kahn, 2000) and have failed to incorporate human beings and their institutions as explicit agents in the functioning of ecosystems (McDonnell and Pickett, 1990; McDonnell et al, 1993; McDonnell et al., 1995, Breitburg et al., 1998; O'Neill and Kahn, 2000). This focus of research has led to a lack of information on how land-use affects biological diversity in general and in particular within developing regions of the world. Landscape ecology, however, and its methods have advanced the farthest in attempting to understand landscape pattern shaped by humans as explanatory variables to biological pattern and processes (Turner, 1989; Nevah and Lieberman, 1993; Forman, 1995; Brooker et al., 1999). Several studies have looked at the results of human induced changes through pattern development (i.e., fragmentation) and linked the pattern to biodiversity dynamics (e.g., Lynch et al., 1984; Quinn and Harrison, 1988; Burkey, 1989; Opdam, 1991; Farina, 1997; White et al., 1997).

5.1 Factors Associated with Regional Variation in Species Composition

Identifying the factors controlling the distribution, abundance, and diversity of species in ecological communities continues to be a central problem in ecology, with increasing emphasis on human dimensions of change to explain the patterns, at least partially (Forman, 1995; Lubchenco et al., 1991; Turner, 1989; McDonnell and Pickett, 1993). Community structure is considered not only a product of local physical condition and interactions among species, but also of regional constraints such as climate, and of historical processes such as dispersal and speciation, migration, and extinction (Menge and Olson, 1990; Latham and Ricklefs, 1993; Ricklefs and Schulter, 1993). Plant community ecologists have long devoted considerable effort to quantifying local to landscape-scale variation in vegetation with recent efforts to quantify broad scale determinants (Denton and Barnes, 1987; Ohmann and Spies, 1998; Fairbanks and McGwire, 2000). In contrast, animal community ecologists have spent much effort in understanding local and increasingly more landscape-scale variation in species and communities (Wiens and Rottenberry, 1981; Opdam et al., 1984; Cody, 1985; Maurer and Heywood, 1993; McGarigal and McComb, 1995; Villard and Maurer, 1996; Flather, 1996). Still there are few systematic, quantitative, regional-scale descriptions to provide contexts for interpreting landscape differences (but see Wiens, 1973; Wiens, 1974; Rotenberry 1978; Rotenberry and Wiens, 1980; McGarigal and McComb, 1995; Flather, 1996). Yet, the collation, examination, and synthesis of species-community data in regional analysis has been cited as a major research need for conservation (Soulé and Simberloff, 1986; Balmford and Gaston, 1999).

In an effort to understand avian community temporal dynamics, pattern and scale, this chapter undertakes a quantitative, systematic analysis of avian species data at the South African extent followed by a more detailed analysis for the KwaZulu-Natal province. It is instructive to consider these in a hierarchical fashion, from the broadest to the most localized. Broad and landscape-scale factors are examined as contributions to regional variation in community composition, and the influences of physical environment, biotic factors, and human disturbance processes are explored. The study objectives were to identify and quantify environmental and landscape pattern factors associated with regional gradients in avian species diversity between the two survey periods outlined in Chapter 1. This chapter addresses questions about factors controlling avian species assemblages by considering a broader region and a large data set from two periods, and uses contemporary multivariate statistical and spatial analytical tools to accomplish its task.

5.2 Influence of Geographical Extent and Location

Within a local area, the range of climatic conditions is usually small, and most sites fall within an animal species' physiological tolerances. Thus, shifts in species' relative abundances are thought to be associated with local variation in topography, microclimate, vegetation, biotic interactions, and human impact, as well as with stochastic disturbances that are highly variable over time and space. Therefore, one can hypothesize that species variation explained by regional climate decreases, and variation explained by local factors increases, with decreasing geographic extent.

Different environmental factors probably assume varying degrees of importance among localities within a region, and landscape pattern or land cover proportion are likely to dominant in importance in a similar manner. In KwaZulu-Natal, the hypothesis that topographic, temperature and moisture factors assume the greatest importance for explaining variation in bird diversity at coarser scales, and landscape pattern and land cover proportion explains the remaining variation in diversity in a hierarchically scaled manner is explored. In Chapter 4 this concept was explored on a reduced data set of species targeted for conservation (Table 1.3), with results showing that the climatic factors and the landscape-vegetation complex are interacting to define communities by limiting species ranges. This chapter continues the examination in more detail to study community changes and how they might affect the use of systematic conservation procedures conducted in chapter four.

5.3 Biological Indicators and Monitoring

Biological atlases routinely strive to incorporate appropriate sampling designs, data collation and interpolation procedures (Prendergast et al., 1993) to minimize sampling errors caused by differences in sampling effort, sampling duration, the degree of ecological specialization and patchy habitat occupancies flowing from metapopulation characteristics of species (Brown, 1984; McArdle, 1990; Hanski et al., 1993). Therefore, in practice, species richness and community assemblage data derived from contemporary biological atlases are considered adequate (Donald and Fuller, 1998), or at least, the best available basis from which to conduct conservation planning.

The relationship between distribution and abundance has important implications for species richness and conservation planning. The term distribution here is referred to as a species' geographical range, though recognizing that, given a set of observations with geographical coordinates, a range boundary may be drawn in different ways (Gaston, 1990). Abundance refers to the size of a "local" population found in an arbitrarily defined study area. Species richness is a problematic indicator (Stoms, 1994). Sampling effort, sampling period, size of sampling area, and human influence can hugely effect the final species distribution and abundance for a taxon (e.g., birds) found in a particular area. Where effort is recorded for species, however, for inventorying exercises over a short time frame, richness correction techniques have been suggested (e.g., Soberon and Llorente, 1993; Fagan and Karivera, 1997).

Since distribution and abundance may change over time, they should both be estimated within a sufficiently short period. This is a potentially serious problem for faunal atlasing studies and national biological surveys, on which estimates of distribution are often based, because such studies typically accumulate observations over a long period. The results from these larger longer-term studies of distribution are used to develop simple indices of species richness or diversity that gets used in reserve selection analyses to derive strategic decisions. The unique characteristics of atlas studies, however, may allow for the study of species assemblage responses to degrees of human disturbance (disturbance hypothesis; sensu Connell, 1978; Burel, 1998). This could allow for a more informed approach to conservation planning.

In addition to viewing human land transformation as a threat to conservation, this chapter explores the phenomena as a shaping force of species richness or community assemblage patterns, which can be derived from biological atlases. This chapter examines the interactions between bird species richness, assemblage characteristics, and the degree of land transformation at the South African (including Lesotho) spatial extent and then a more detailed analysis is conducted for KwaZulu-Natal.

5.4 Methods

5.4.1 Diversity-evenness and Human Transformation Patterns

Three ecological measures were used to characterize bird species assemblages (e.g., Burel, 1998) per quarter-degree grid cell: Species richness, Shannon diversity, and an adjusted evenness measure to reduce sampling effort bias. Species richness (*S*) is simply the total number of bird species recorded in a grid cell. Evenness (*E*) is a relative measure to quantify unequal species representation against a hypothetical assemblage in which all which species are equally common (Krebs, 1989). Evenness was calculated using:

$$E = \frac{H' - H'_{\min}}{H'_{\max} - H'_{\min}}$$

where H' is the observed Shannon index of species diversity as given by the following formula:

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

where S is the total number of birds species with proportional abundances $p_1, p_2, \ldots, p_S$ (Ludwig and Reynolds, 1988). In addition to providing information on presence/absence, the ADU data also provided a simple measure of abundance based on reporting rates. A reporting rate is the percentage of checklists on which a species was recorded relative to the total number of checklists for a grid cell. This form of relative abundance from the atlas data has been quantitatively evaluated previously to correspond well to other field data and deemed fit for use in general population studies (Robertson et al., 1995). As a result, the relative abundance of a species was estimated by the ratio of number of observations reported for species i over the total number of observations for all species in a grid square (Harrison and Martinez, 1995). The variables $H'_{\min}$ and $H'_{\max}$ are the minimum and maximum values of the index respectively. The maximum value of the index is simply $H'_{\max} = \log(S)$ and the minimum is given by the following formula (Krebs, 1989):

$$H'_{\min} = \log(N) - \left(\frac{N - S + 1}{N}\right)\log(N - S + 1)$$

where N is the total number of species presences observed in a grid square (Harrison et al., 1997). The evenness index (E) varies from 0, when a few species are dominant, to 1, when all species are equally abundant. In general, the total number of species in the sample and sampling effort (Magurran, 1988) can largely influence the Shannon diversity index and the evenness index. However, since evenness is measured as a ratio with the number of species in both the numerator and the denominator, it may effectively cancel the impact of the number of species in the sample, which is a product of effort (Magurran, 1988; Ludwig and Reynolds, 1988; Krebs, 1989). In this study, species richness is significantly positively correlated with the Shannon index ($r = 0.91$, $N = 1844$, $p < 0.001$) and the pre-correction relationship to evenness was significantly negatively correlated ($r = -0.62$, $N = 1844$, $p < 0.001$), but after correcting for sampling effort, the correlation was negligible ($r = 0.09$, $N = 1844$, $p < 0.1$).

Two levels of analysis, South Africa and KwaZulu-Natal, are reported to examine the influence of geographic extent on the analysis. Two datasets are reported for the South African study extent: original species richness (Figure 5.1a) and evenness (Figure 5.1b), and smoothed measures (e.g., Prendergast and Eversham, 1997; Williams and Gaston, 1998) generated by performing neighborhood averaging (Figure 5.1c, d). Smoothing of the richness and evenness maps was carried out to further remove the vagaries of sampling and to make larger scale variation more apparent. For each grid cell, species richness and evenness measure are calculated as the median for the group including the core cell and the surrounding neighborhood of eight cells (i.e., equivalent to an area approximately 75 x 75 km). Simple median filtering has the effect of reducing local differences in species richness and evenness. Given a relationship between two variables, smoothing will tend to reduce the local variance about that relationship, reducing the impact of outliers. This operation also changes the scale of analysis to provide a regional estimate of biodiversity. The original local scale human disturbance patterns of low and high intensity transformation were retained (Figure 5.2). The two data sets provide local scale and regional scale estimates of measured biodiversity co-variation with human disturbance for South Africa.

The assessment of human disturbance on species richness and evenness was conducted at the South African extent and then by biome (Figure 5.3) to control for expected variation in species richness and evenness. This is particularly the case since high intensity land-use is concentrated in only a few of the biomes (Figure 5.2b and 5.3). Not controlling for this effect assumes that all biomes have the same mean species richness and evenness, which is certainly not true. This was confirmed using analysis of covariance (ANCOVA). Spatially corrected Pearson correlation coefficients (r_s) are calculated between the data sets using the procedure developed by Dutilleul (1993), which corrects for spatial autocorrelation (using Morans *I*; Cliff and Ord, 1981) when calculating the significance (p) of the correlation coefficients. The procedure does not change the value of the coefficient but reduces the degrees of freedom and hence alters the p significance. This exploratory analysis accounts for the spatial dependence of the data and their covariance patterns. For KwaZulu-Natal, the assessment was conducted on species richness, Shannon diversity, and evenness measures for the province by life history bird assemblage (Chapter 1; Table 1.3) from the ADU database.

5.4.2 Geostatisical Analysis of Spatial Variation and Extent in Ecological Pattern

It is clear that ecologists have a great need to incorporate spatial information into their analyses. Spatial pattern reflects the underlying structure in the variation of a variable of interest, and it often provides clues as to possible cause. The development of geostatistics by Matheron (1963) provides a theoretical and methodological framework for addressing problems unique to spatial data. Variables that characterize a spatial property or process generally exhibit a localized spatial dependence (i.e., autocorrelation) within a measurement field, which satisfies some reasonable level of stationarity at a more global scale. Geostatistical techniques are based on the general regionalized variable model (Cressie, 1993). The model is a linear model of spatial process that includes both an explanatory component and a random component. Geostatistics embody a set of methods applicable throughout the Earth sciences for investigating spatial variation and extent in a continuous random variable (Cressie, 1993; Burroughs, 1986).

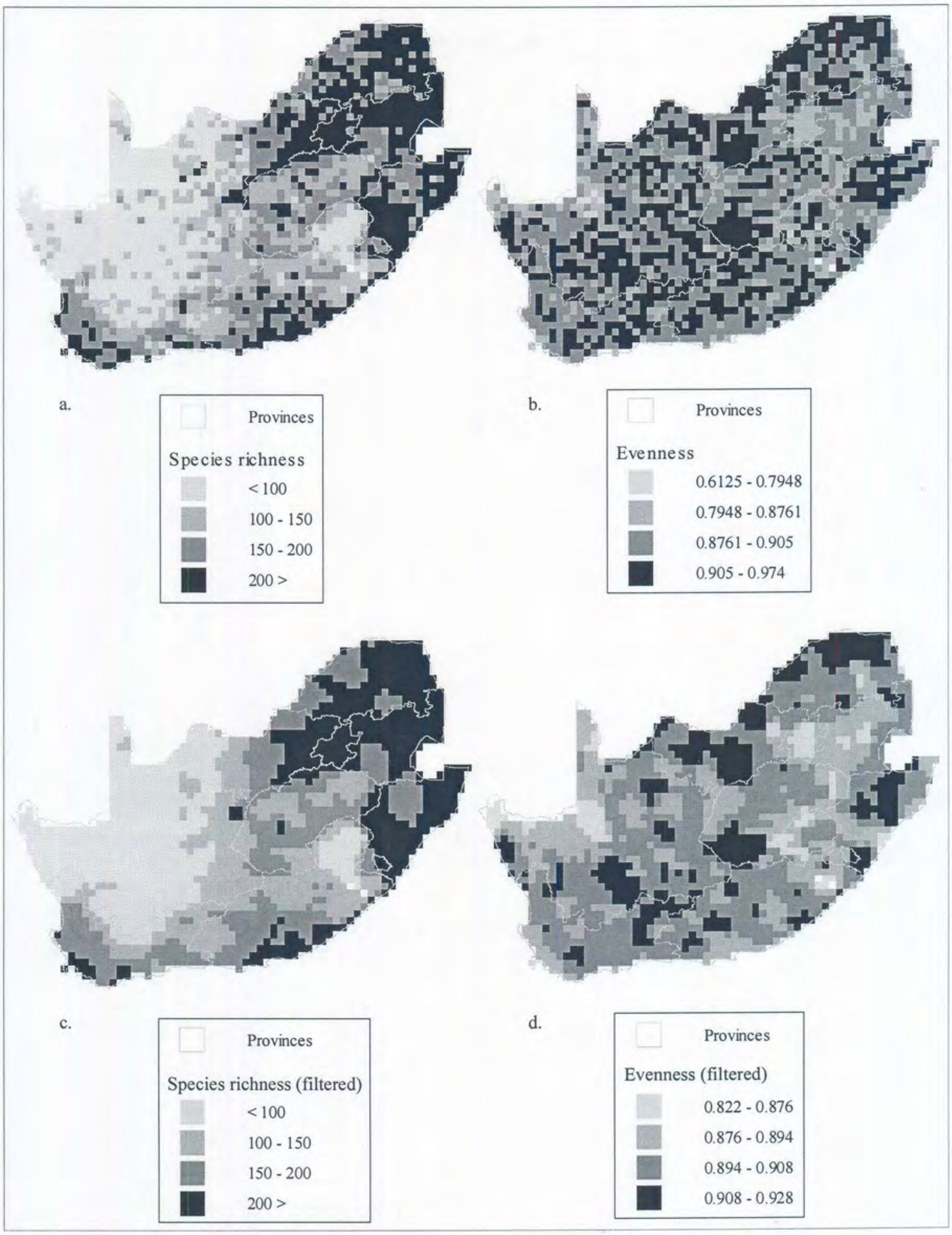

Figure 5.1: (a) Bird species richness across South Africa; (b) evenness structure of birds across South Africa; (c) Bird species richness using smoothed data; and (d) evenness structure using smoothed data.

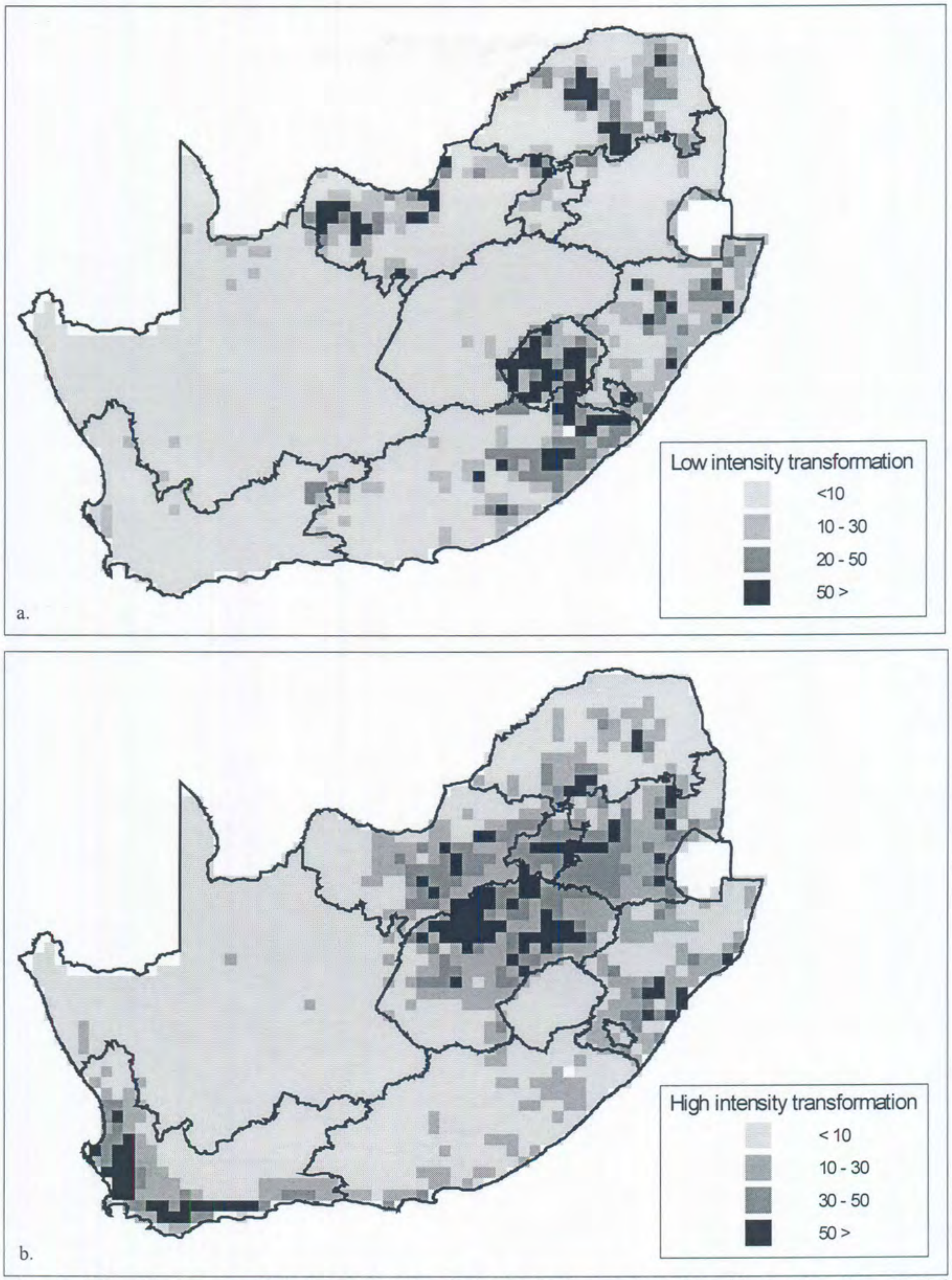

Figure 5.2: The separation between the transformation categories illustrates the spatial heterogeneity found within South Africa, particularly highlighting the development differences between: (a) low intensity transformation representing African ex-homeland areas; and (b) high intensity transformation representing "White" developed South Africa.

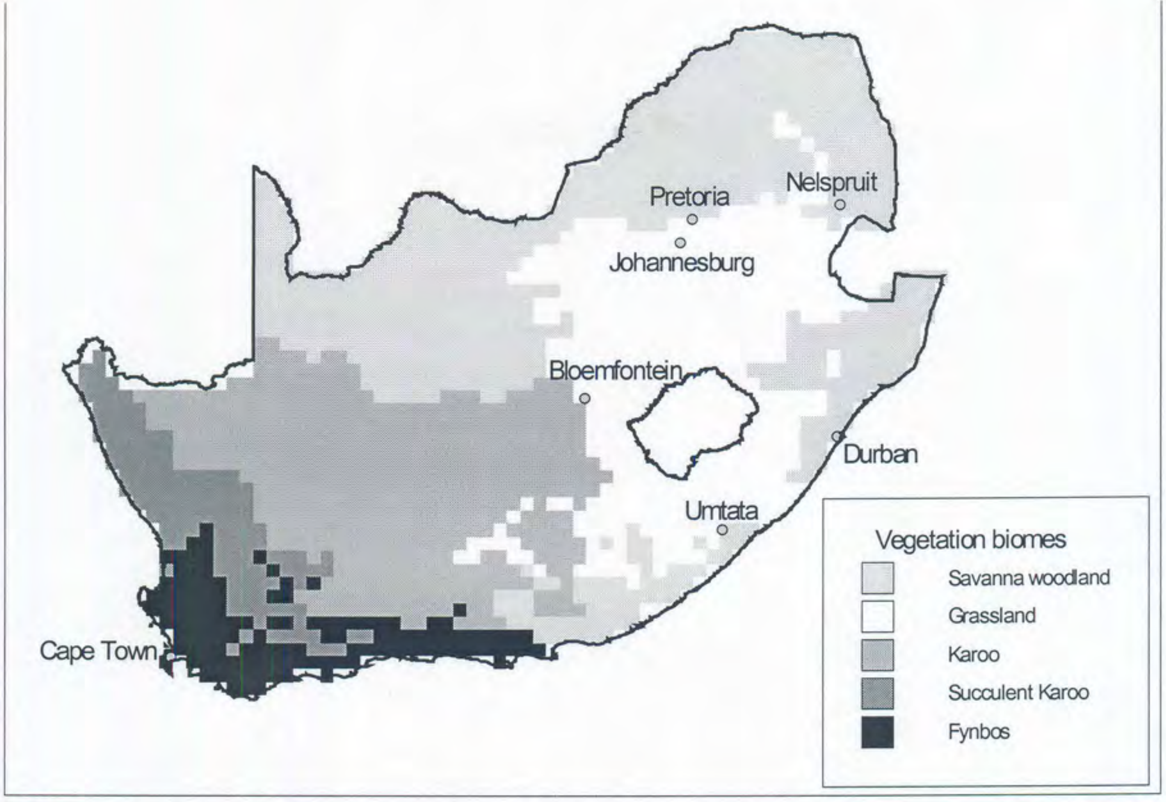

Figure 5.3: The vegetation biomes of South Africa based on the map by Low and Rebelo (1996) and from the original classification work by Rutherford and Westfall (1986).

The central tool of geostatistics is the empirical semivariance illustrated by the variogram. Variograms can be computed to determine the strength and spatial scale of any pattern, and to summarize the variation. Biodiversity measures (e.g., species richness, Shannon diversity and evenness) and human impact vary spatially and the same qualities apply. Semi-variograms may be used to examine the spatial variation in species distribution data as a function of ecological and sampling parameters. Research has indicated direct ties between measured map components and variogram form (Burroughs, 1986). The information content of a multi-species diversity map is a function of both the complexity of the terrestrial area and the spatial and temporal resolution of the sampling routine. Multi-species diversity map variance can be directly related to the frequency of observation of a species relative to the spatial resolution of the sampling unit and that this relationship is manifested in both the local and the overall variance of the diversity map (see Woodcock and Strahler, 1987 for remote sensing parallels). Recently Pearson and Carroll (1999) conducted a study of the congruency of species richness scale and extent for comparison between taxa using a semi-variogram methodology. In bird atlasing, analysis scale may vary from that of individual birds, to communities of birds, to large-scale gradients in bird turnover over tens or hundreds of kilometers. The purpose in this chapter is to use semi-variograms to describe and analyse biodiversity measures and human transformation data, and to suggest how they could be used in a complementary way to predict biodiversity changes in the future.

Variograms compare the similarity between pairs of points a given distance and direction apart (the lag), and expresses mathematically the average rate of change of a property with separating distance, which provides a measure of the form and scale of variation in a variable. Empirically derived semi-variograms may be fitted with a model, which quantifies observed patterns in spatial autocorrelation. Characteristically, the semivariance tends to increase with increasing distance. Figure 5.4 provides some examples of idealized semi-variograms fitted by the common spherical model, where a minimum nugget variance (c) is found between adjacent samples and sample variance increases throughout a region of influence (a) beyond which an asymptote, or sill ($\omega + c$), is reached.

The following is summarized from Webster and Oliver (1990). Interpreting the variogram can provide insight into the structure of the variation. In most instances, the variance increases with increasing separating distances. This corresponds with more or less strong correlation or spatial dependence at the shortest distances, which weakens as the separation increases. Variograms often flatten when they reach a variance known as the sill variance; they are bounded (Figure 5.4). Such flattened variograms are second order stationary and suggest that there are patches or zones with different levels of species richness for instance, whereas unbounded ones suggest continuous change over a region. The distance at which the 'sill' is reached, the 'range', marks the limit of spatial dependence. The variogram often has a positive intercept on the ordinate, the 'nugget variance'. This part of the variation cannot be predicted. Much of it derives from spatially dependent variation within the smallest sampling interval, somewhat less from measurement error and purely random variation. A completely flat variogram, 'pure nugget', means that there is no spatial dependence in the data.

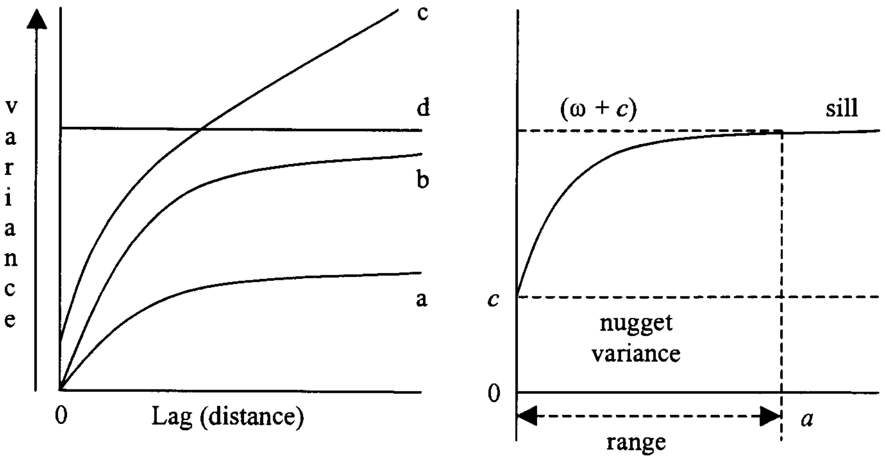

Figure 5.4: Some examples of forms of variograms: (a) and (b) bounded variograms; (c) unbounded variogram; and (d) pure nugget variogram.

Empirical semi-variograms were generated for transformation class, species richness, and evenness for the extent of each biome in South Africa. In KwaZulu-Natal, semi-variograms were generated for species richness, Shannon diversity, evenness, transformation class, road disturbance and 1996 population density estimates using the extents of each bird community class identified from ordination and clustering for each ADU life history bird assemblage. The center coordinate of each grid cell was used as the spatial component for all analyses. Semi-variograms were fitted with a spherical model in order to allow quantitative comparisons. The spherical model was chosen based on visual inspection of plots and because this model's region of influence parameter (*a*) provides a quantitative measure of autocorrelation distance. Other models were tried, but found to be inadequate. Visual assessments of the fit of the model to the data were made and displayed for the national analysis, but due to the large number of estimates that were required (~344) for the KwaZulu-Natal analysis, only a table of the range value based on the sill is provided.

5.4.3 Pattern and Process Measurement from Ordination Analysis

Gradient analysis may provide a promising analytical approach to understanding the effects of multiple stressors on ecosystem function (Whittaker, 1967; McDonnell and Pickett, 1993; Breitburg et al., 1998) by integrating multiple stress effects across the landscape. The gradient approach relies on the assumption that graduated spatial environmental patterns govern the structure and function of ecological systems. Changes in population, community, or ecosystem variables along the gradient can then be related to the corresponding spatial variation in the environmental and socio-economic variables, with specific statistical techniques dependent upon whether or not environmental variation is ordered sequentially in time or space, and whether single or multiple variables are being considered. In the case of system responses to multiple stressors, complex, nonlinear gradients are apt to be present and ordination techniques may provide insight into the biotic responses to these gradients (ter Braak and Prentice, 1988; Jongman et al., 1995).

Canonical correspondence analysis (CCA; ter Braak and Prentice, 1988), a direct gradient analysis method used widely in community ecology (Palmer, 1993), and detrended correspondence analysis (DCA), an indirect gradient analysis method (Gauch, 1982) was used as the analytical tools. CCA was chosen because the goal was to better understand environmental factors associated with avian diversity patterns. In CCA, sites and species are arranged in a multidimensional space, with the restriction that the ordination axes must be linear combinations of the specified environmental variables. DCA (using 2nd order polynomial detrending) was used before CCA to determine the dominant unconstrained avian diversity trends for the first two axes of variation based only on the species-site matrix. The two axes of variation were then hierarchically classified by Euclidean distance using Ward's linkage (Legendre and Legendre, 1998) to identify bird communities within each life history bird assemblage. The program CANOCO, version 4.0 (ter Braak and Smilauer, 1998), was used to conduct all gradient analyses. Environmental data (e.g., the 11 environmental parameters found under topography and climate in chapter one, Table 1.1) were entered with the species data using stepwise CCA, with detrending by 2nd order polynomials to avoid the arch effect. All other CANOCO defaults were used. All CCA plot scores in this chapter are linear combinations. In CCA and in this chapter, the fraction of species variation explained by a set of explanatory variables (total variation explained, TVE) is the sum of all constrained eigenvalues divided by the total variation (TV) in the species data (or "total inertia," sensu ter Braak and Smilauer, 1998), which is the sum of all unconstrained eigenvalues. The TV is the ratio of the dispersion of the species scores to the dispersion of the plot scores (ter Braak and Smilauer, 1998), a property of the species-by-plot data matrix. Data matrices with greater TV contain many species and little overlap of species occurrence among plots, and thus higher beta diversities (similar to Whittakers, 1960 beta diversity measure, $\beta_w = (S/\alpha) - 1$).

Explanatory variables are added to the model in the order of greatest additional contribution to total variation explained, but only if they were significant ($p < 0.01$), where significance was determined by a Monte Carlo permutation test using 499 permutations (H_0: additional influence of variable on avian diversity is not significantly different from random), and if adding the variable did not cause any variance inflation factors to exceed 20. Variables with large inflation factors are strongly multi-collinear with other variables and contribute little unique information to the model (ter Braak and Smilauer, 1998). These were excluded to improve the interpretability and parsimony of the model. Although several of the explanatory variables included in the stepwise models were still intercorrelated, CCA is robust to this multi-collinearity (Palmer, 1993).

CCA was also performed with variance partitioning (ter Braak, 1988; Borcard et al., 1992; Økland and Eilertsen, 1994; Ohmann and Spies, 1998), using partial CCA, to quantify the relative contributions of variable subsets to explained variation. In partial CCA, species variations associated with explanatory variables that are not of direct interest (i.e., covariables) are partialled out, in order to examine a selected set of explanatory variables of interest. The usual explanatory variables are replaced by the residuals obtained by regressing each of the variables of interest on the covariables. Those regional-scale factors (climate and topography) found to be of importance for each bird assemblage became covariables and then landscape pattern and land cover proportion factors (chapter one, Table 1.5 and 1.6) were analyzed as local scale operators to explain the residual variation. In this way the CCA with variance partitioning quantified the relative contributions to explained variation of regional-scale environmental factors vs. landscape scale spatial land pattern factors.

The CCA results are graphed as a biplot, in which arrow length and position of the arrowhead indicate the correlation between the explanatory variable and the CCA axes, arrow direction indicates how the variable is correlated with the CCA axes, and smaller angles between arrows indicate stronger correlations between variables (ter Braak and Smilauer, 1998). A comparison between CCA and DCA eigenvalue scores showed how well environmental variables accounted for variation in the avian data and suggested whether important environmental variables were overlooked. Intraset correlations and the change in eigenvalues for the first and second axes were evaluated.

5.4.4 Assessing Multi-species Temporal Distributional Changes

Community dynamics are an important area of analysis in ecology and for conservation efforts. The two survey periods provided by the bird atlases (Cyrus and Robson, 1980; Harrison et al., 1997) used in this study allow the opportunity to assess the similarity between the two sampling periods. The case provided here for the detection of species association over time has important ecological implications. Some human land transformation processes may result in continued similar species distribution patterns or impart dissimilar patterns of change. However, the detection of pattern does not provide a causal understanding of why such a pattern might exist. Rather, pattern detection should ideally lead to the generation of hypotheses of possible underlying causal factors. The study of two data sets involves two distinct components. The first is a statistical test (denoted by the χ^2 distribution) of the hypothesis that the two sampling areas are similar between times or not at a predetermined probability level ($\alpha = 0.005$). The second is a measure of the degree or strength of the association. These are regarded as separate characteristics of an association. The analysis used here relies on the properties of a contingency matrix (Table 5.1), where two survey dates are compared for each of their sampling units. The value *d*, which is joint absences, is usually disregarded in ecology when determining association by species, but in this study, *d* is important. Therefore, instead of using one of the common binary indexes of association commonly used in ecology, Jaccard or Sorenson, the Kappa index (κ) has been shown to be more sensitive in assessing agreement using the entire matrix (Foody, 1992; Fielding and Bell, 1997).

The Kappa index (κ) is typically used to adjust for expected chance occurrences on the diagonal (Congalton, 1991; Foody, 1992):

$$\kappa = \frac{P_o - P_e}{1 - P_e}$$

Table 5.1: Setup of a 2 x 2 contingency table used to compare species sampling surveys per sampling unit. †

	Survey 1		
Survey 2	Species Present	Species Absent	P_r
Species Present	a	b	$a + b / N$
Species Absent	c	d	$c + d / N$
P_c	$a + c / N$	$b + d / N$	

†$N = a + b + c + d$; P_o = observed agreement = $a + d / N$

a = Species present in sampling unit during both survey periods.

b = New species are present. Species may possess unique behavioral or physiological adaptations that have allowed it to colonize locations outside previously recorded range, or sampling unit may have been poorly surveyed originally.

c = May reflect species loss due to human impacts (i.e., fragmentation) or recent survey of sampling unit may have been poorly sampled.

d = Species absent from sampling unit during both survey periods.

Where P_o is the observed proportion of agreement, and P_e is the proportion of agreement that may be expected to occur by chance. Kappa can be calculated from the row and column marginals as:

$$P_e = \sum P_r(\mathrm{i})\, P_c(\mathrm{i})$$

where P_r is the row marginal error, and P_c is the column marginal error. The result is $0 < \kappa < 1$, where zero represents agreement no better than chance, and 1.0 is perfectly agreeing survey data with all elements on the diagonal. This implies that a high kappa (> 0.8) is better than the agreement that would result from a random survey assignment, or a high association between the two surveys was acquired. For most purposes values larger than 0.8 represent almost perfect agreement, those below 0.4 signify poor agreement, and values between 0.4 and 0.8 represent moderate to substantial agreement.

5.5 Results

5.5.1 South African level

5.5.1.1 Correlation Results

The analysis of covariance (ANCOVA) determined that there is significant covariation between species richness and transformation classes while controlling by biome (low intensity, $p < 0.014$; high intensity, $p < 0.0001$; total, $p < 0.0001$). While, the significance with evenness and transformation was not as great across all transformation classes, except for high intensity transformation (low intensity, $p = 0.185$; high intensity, $p < 0.001$; total, $p = 0.57$). These results confirm that overall correlations between land-use intensity and species richness/evenness should be controlled for expected variation in species richness and evenness with biome. Tables 5.2 and 5.3 present the spatially corrected Pearson correlation results considering all of South Africa and broken down by biome, with values for $p < 0.30$ highlighted in bold. As evidenced by the ANCOVA the national result is largely driven by the differing levels of species richness/evenness in different biomes, while the high intensity land-use is concentrated in only a few of the biomes.

At the national extent, species richness patterns are positively correlated with high intensity human disturbance (Table 5.2). This correlation is weaker for total disturbance, which also incorporates non-significant low intensity disturbance patterns, illustrating the effects when not considering spatial heterogeneity in the analysis transformation processes (no spatial co-variance between the two levels of disturbance; $r_s = -0.001$, $N = 889$, $p = 0.98$). The increased artificial landscaping and an increased number of artificial water impoundments contained in several of the biomes across the country can explain this positive relationship between species richness and human dominated areas, as artificial habitat is created for many species. Or, alternatively, the increase in species richness is a product of attracting weedy generalist taxa to developed landscapes. In contrast with richness, the evenness of the bird assemblages is negatively correlated with high intensity transformations suggesting that bird assemblage evenness could be adversely affected by high intensity human disturbance.

Table 5.2: Spatially corrected Pearson correlation coefficients (r_s) for comparisons of species richness and evenness against transformation classes among South African grid cells (only cells with records for all data sets are included). Richness and human disturbance data were square root and log-transformed before analysis to improve normality.

	Low intensity transformation		High intensity transformation		Total disturbance	
Analysis level	r_s	p	r_s	p	r_s	p
South Africa (*N* = 1046, 1405, 1562)						
Richness	0.004	0.98	**0.49**	0.002	**0.38**	0.07
Evenness	0.006	0.90	**-0.16**	0.009	**-0.10**	0.11
Woodland (*N* = 521, 499, 582)						
Richness	0.06	0.67	**0.43**	0.003	**0.29**	0.16
Evenness	**0.13**	0.03	**-0.15**	0.03	0.04	0.58
Grassland (*N* = 275, 464, 486)						
Richness	**-0.41**	0.02	**0.39**	0.03	0.04	0.77
Evenness	-0.03	0.66	-0.05	0.55	**-0.07**	0.26
Shrub Steppe (*N* = 139, 235, 280)						
Richness	**0.28**	0.03	**0.41**	0.009	**0.36**	0.002
Evenness	-0.003	0.97	-0.05	0.63	-0.05	0.57
Succulent Desert (*N* = 43, 92, 98)						
Richness	-0.17	0.32	**0.44**	0.000	**0.40**	0.002
Evenness	-0.12	0.50	**0.11**	0.27	**0.13**	0.20
Fynbos (*N* = 73, 115, 116)						
Richness	-0.06	0.66	**0.39**	0.004	**0.37**	0.006
Evenness	-0.02	0.85	**-0.18**	0.13	**-0.17**	0.12

Table 5.3: Spatially corrected Pearson correlation coefficients (r_s) for comparisons of smoothed species richness and evenness against transformation classes among South African grid cells (only cells with records for all data sets are included). Richness and human disturbance data were square root and log-transformed before analysis to improve normality.

	Low intensity transformation		High intensity transformation		Total disturbance	
Analysis level	r_s	p	r_s	p	r_s	p
South Africa (*N* = 1046, 1405, 1562)						
Richness	0.07	0.69	**0.51**	0.005	**0.43**	0.08
Evenness	-0.04	0.60	**-0.23**	0.02	**-0.18**	0.08
Woodland (*N* = 516, 495, 578)						
Richness	0.13	0.42	**0.47**	0.009	**0.35**	0.14
Evenness	0.09	0.33	**-0.17**	0.09	0.008	0.94
Grassland (*N* = 275, 464, 486)						
Richness	**-0.40**	0.05	**0.42**	0.05	0.03	0.82
Evenness	-0.11	0.33	-0.08	0.56	**-0.14**	0.17
Shrub Steppe (*N* = 139, 235, 280)						
Richness	**0.35**	0.04	**0.39**	0.06	**0.35**	0.02
Evenness	0.03	0.75	-0.12	0.37	-0.07	0.55
Succulent Desert (*N* = 43, 93, 99)						
Richness	-0.04	0.79	**0.37**	0.003	**0.39**	0.005
Evenness	0.15	0.43	**0.21**	0.16	**0.27**	0.07
Fynbos (*N* = 73, 118, 119)						
Richness	-0.12	0.48	**0.47**	0.003	**0.46**	0.003
Evenness	-0.12	0.48	**-0.22**	0.27	**-0.20**	0.27

Vegetation biome analyses highlight bird-vegetation sensitivities (Table 5.2). Low intensity disturbance tends to be correlated with bird richness in grassland and shrub steppe biomes. Low intensity disturbance in grasslands has an inversely negative effect on bird species richness, but a positive effect in shrub steppe. This could assert that heavily grazed or near to barren grassland ranges promote reduced richness in grassland related birds, while heavy grazing in shrub steppe regions opens up the shrub cover, which seems to increase bird richness. Only woodland bird assemblages are affected by low intensity disturbance, however, in a positive trend (Table 5.2). This possibly reflects the opening up of woodland areas through heavy grazing and fuelwood removal, which in turn creates grass patch mosaics favoring grassland birds, lowering the dominance of woodland species (Harrison et al., 1997). High intensity disturbance tends to promote increased species richness across all biomes, with a slight emphasis on drier biomes of woodland, shrub steppe, and succulent desert (Cowling et al., 1997). The woodland and fynbos biomes have bird assemblage evennesses that reflect an inverse relationship to high intensity transformation. While for the succulent desert biome the bird assemblage evenness has a positive effect from high intensity transformation. The tendency towards single species dominance reflected in the woodland and fynbos biomes seems to reflect the total removal of vegetation structure from these areas for replacement by low stature annual and permanent agricultural landscapes. The birds of these biomes are sensitive to land transformations, with generalist species tending to dominate (Harrison et al., 1997). The succulent desert biome has low species richness (Figure 5.1a), and typically, only a few of the species tend to dominate within these resource strained environments (e.g., Rottenberry and Wiens, 1980; Wiens and Rottenbery, 1981; Harrison et al., 1997). The slight positive influence in bird assemblage evenness may reflect the increase number of species brought about by water impoundments, wells, and tree cover around human habitation. Total disturbance in all biomes, with the exception of the grassland biome, shows increased species richness. Transformation relationship with woodland biome bird assemblage evenness is not significant, and significance is reduced for grassland, succulent desert and fynbos biome birds (Table 5.2).

The application of the data smoothing procedure improves the correlations across all analytical extents (Table 5.3). One exception includes the loss of statistically significant correlation between woodland bird evenness and low intensity transformation. The other relationships have mostly reduced significance in p against low intensity disturbance, while p is increased for high intensity transformation and richness but reduced for evenness. These exceptions may reflect instances where the smoothing of biological richness and evenness data reduced their spatial overlap with transformed areas.

5.5.1.2 Semi-variogram results

Empirical semi-variograms were generated for each measurement by biome at a distance resolution of 22.5km (distance from grid cell midpoint to neighboring grid cell midpoint). Range values representing the autocorrelation pattern for each variable by biome are provided in Table 5.4 with the modeled semi-variogram shapes shown in Figure 5.5 (Shannon diversity plots are not provided). The richness and Shannon diversity spatial extents tended to provide the same results as would be expected for the variables because of their high correlation. In grassland and fynbos this relationship does not hold with the Shannon diversity measure reaching a sill, where the variance measurements remains stable at a range of less than 112.5 km. This may show that in the case of these two biomes the Shannon diversity measure is more sensitive to the overall erosion in bird diversity than species richness especially when compared to the semi-variogram results for high intensity transformation (HI) and total transformation (TT). The spatial extent of Shannon diversity for grassland is nested within the influence extent for HI and similar in spatial extent to TT.

The spatial extents of each measurement with respect to the degree of nestedness of the spatial phenomena are important indicators. Savanna, grassland, shrub steppe, and succulent desert bird assemblages have extents greater than the human transformation processes. The fynbos bird spatial variation (richness and evenness) is completely dominated by the human transformation extent. Grassland evenness structure is also nested within the human

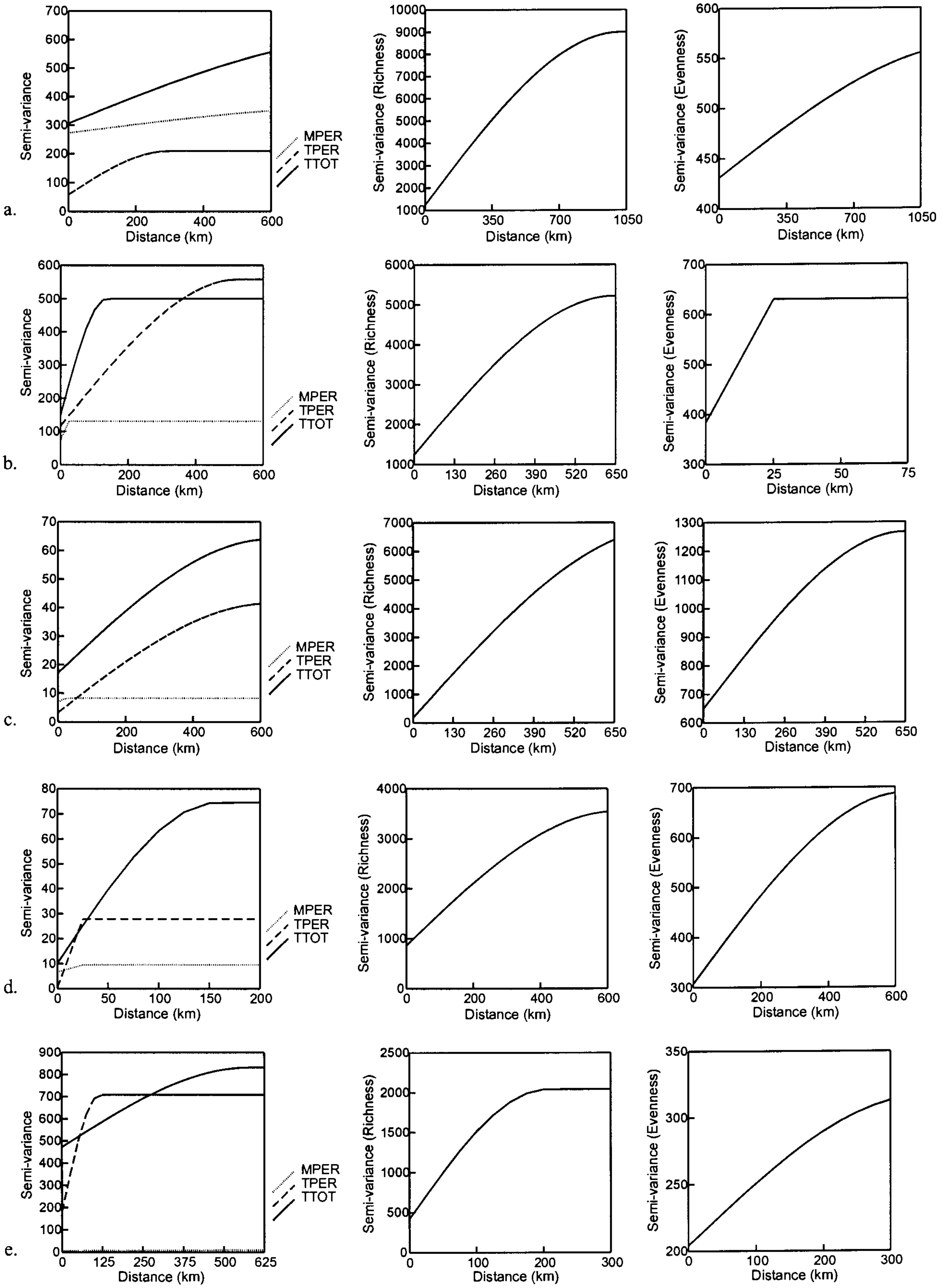

Figure 5.5: Model semi-variograms of transformation level, bird richness and community evenness in South African biomes: (a) savanna woodland; (b) grassland; (c) shrub steppe; (d) succulent desert; and (e) fynbos. (MPER - Low intensity transformation; TPER - high intensity transformation; and TTOT - total transformation).

Table 5.4: Spherical model estimates of range (km) lag value derived from the sill when a stable variance is reached for South African biomes: species richness (*S*), Shannon diversity (*H'*), evenness (*E*), low intensity transformation (LI), high intensity transformation (HI), and total transformation (TT).

Biome	*S*	*H'*	*E*	LI	HI	TT
Woodland	1260.0	1260.0	1057.5	45.0	247.5	832.5
Grassland	517.5	112.5	22.5	22.5	472.5	112.5
Shrub Steppe	832.5	832.5	652.5	22.5	562.5	540.0
Succulent Desert	630.0	630.0	630.0	45.0	22.5	22.5
Fynbos	202.5	112.5	337.5	652.5	652.5	652.5

transformation extent, but the spatial extent of richness is still just greater than the transformation indices. These geographic-scale results may provide evidence for non-randomly distributed areas of decline throughout the ranges of birds species as measured by the evenness index, with or without range contractions.

5.5.2 KwaZulu-Natal level

5.5.2.1 Ordination Results

Dataset results are denoted by the following: CR (Cyrus and Robson, 1980) and ADU (Harrison et al., 1997). Two sets of results comparing the CR and ADU bird census datasets using presence/absence data are provided, each detailing the life history bird assemblages (chapter one, Table 1.3). Analyses of the ecological habitat bird assemblages are only conducted from the ADU survey as they use the relative abundance values of the bird species to drive the ordination analyses.

For the CR bird assemblages representing all birds, summer, winter, passerine, breeding, and human, eigenvalues and gradient lengths were higher for detrended correspondence analysis (DCA) than for detrended canonical correspondence analysis (DCCA) for the first two axes (Table 5.5), indicating that a portion of the species variation was not accounted for by the environmental variables identified in DCCA. Moderate to weaker eigenvalues and gradient lengths were derived for the non-passerine, non-breeding, and non-human bird assemblages. Gradient lengths derived from DCA for the first axis showed some large species turnover pattern for all birds, non-passerine, non-breeding, and non-human bird assemblages. The human bird assemblage had the lowest species gradients. Strong correlations between the DCA for axis 1 and the explanatory variables suggested that much of the variation in avian diversity is related to the measured explanatory variables. Geographic patterns of DCA scores also were quite similar to

DCCA for the first two axes. The first two axes of significance for DCA were hierarchically clustered to identify avian community groups for each bird assemblage (Figure 5.6), except in the case of non-breeding and non-human bird assemblages that had three significant axes.

ADU bird assemblage eigenvalues were also near similar between DCA and DCCA for the first two axes (Table 5.6) with each bird assemblage showing only a small portion of its species variation not being accounted for by the explanatory variables identified in DCCA. The weakest fit was obtained for the non-breeding bird assemblage. Gradient lengths derived from DCA for the first axis showed some large species turnover pattern for non-breeding and non-human influenced bird assemblages. The human influenced assemblage had the lowest species gradients. In comparison with the CR data all the ADU data sets had lower eigenvalues, TV and gradient lengths. Strong correlations between the DCA for axis 1 and the explanatory variables suggested, however, that much of the variation in avian diversity is related to the measured explanatory variables. Geographic patterns of DCA scores were also quite similar to the DCCAs for the first two axes. The first two axes of significance for DCA were hierarchically clustered to develop avian communities for each bird assemblage (Figure 5.7).

Results from stepwise CCAs varied across CR bird assemblages and numbers of species (Table 5.5). Total variation (TV) increased and total variation explained (TVE) decreased, with increasing gradient length (Table 5.5). TV, representing beta diversity, was highest for non-breeding, non-human influenced, winter, and non-passerines. TVE was highest for non-human influenced (76%), non-breeding (64%), and winter (56%) bird assemblages. ADU bird assemblage details are in Table 5.6. TV for ADU bird assemblages was highest for non-breeding and non-human influenced; however, all bird assemblages from this census period had lower TVs than for the CR data sets. TVE was highest for non-human influenced (74%) and non-breeding (51%) bird assemblages. Unfortunately, the statistical significance of TVE differences among CCA models cannot be tested (ter Braak and Smilauer, 1998), and thus interpretations of differences are somewhat subjective.

Results of stepwise CCAs for each bird assemblage and census period are presented below. The analyses of the bird assemblages revealed considerable variation in associations between environment and compositional gradients. These within-region bird assemblage differences underscored the importance of ecological modelling approaches that consider a locations' particular biota, physical environment, and history. For each bird group, species with highest and lowest scores on stepwise CCA axes are show in Appendix B.

Table 5.5: Eigenvalues and gradient lengths (1 Standard Deviation) for the first two axes from DCA and CCA of all bird species groups in KwaZulu-Natal from the Cyrus and Robson (1970-1979) survey.

Bird assemblage	Species (no.)	TV	TVE†	Axis	Eigenvalue		Gradient length
					DCA	DCCA	DCA
All	614	1.974	0.398	1	0.28	0.23	2.514
				2	0.12	0.10	1.742
Summer	576	1.864	0.491	1	0.27	0.25	2.147
				2	0.12	0.10	1.704
Winter	591	2.642	0.558	1	0.31	0.28	2.384
				2	0.15	0.12	2.129
Passerine	260	1.469	0.422	1	0.26	0.24	2.150
				2	0.10	0.09	1.481
Non-passerine	354	2.295	0.426	1	0.35	0.24	2.632
				2	0.15	0.13	1.987
Breeding	506	1.538	0.444	1	0.25	0.23	2.111
				2	0.10	0.09	1.567
Non-breeding	108	4.146	0.640	1	0.69	0.33	3.039
				2	0.32	0.24	2.821
				3	0.14	0.06	2.423
Human	334	1.154	0.285	1	0.17	0.15	1.727
				2	0.07	0.05	1.426
Non-Human	280	3.625	0.763	1	0.49	0.42	3.780
				2	0.25	0.22	2.296
				3	0.13	0.04	1.835

† Decimal fraction of TV

Table 5.6: Eigenvalues and gradient lengths (1 Standard Deviation) for the first two axes from DCA and CCA of all bird species groups in KwaZulu-Natal from ADU Bird Atlas (1987-1992) survey.

Bird assemblage	Species (no.)	TV	TVE†	Axis	Eigenvalue		Gradient length
					DCA	DCCA	DCA
All	600	1.326	0.391	1	0.21	0.20	1.958
				2	0.10	0.08	1.587
Summer	595	1.501	0.420	1	0.22	0.21	2.022
				2	0.10	0.08	1.736
Winter	558	1.777	0.464	1	0.25	0.23	2.302
				2	0.11	0.09	1.861
Passerine	256	1.142	0.358	1	0.23	0.21	2.204
				2	0.09	0.07	1.268
Non-passerine	344	1.451	0.380	1	0.20	0.18	1.752
				2	0.09	0.08	1.582
Breeding	501	1.155	0.366	1	0.21	0.19	1.954
				2	0.08	0.07	1.359
Non-breeding	99	2.567	0.511	1	0.34	0.27	2.691
				2	0.12	0.08	2.028
Human	335	0.847	0.227	1	0.12	0.11	1.357
				2	0.06	0.04	1.332
Non-human	265	2.467	0.737	1	0.40	0.38	3.587
				2	0.19	0.	2.242
Woodland‡	135	0.821	0.391	1	0.22	0.20	1.981
				2	0.10	0.07	1.859
Forest‡	91	0.888	0.412	1	0.31	0.29	2.531
				2	0.08	0.07	1.792
Thicket‡	38	0.951	0.422	1	0.28	0.25	2.020
				2	0.16	0.13	2.195
Grassland‡	137	0.898	0.362	1	0.21	0.19	2.091
				2	0.10	0.09	1.571

† Decimal fraction of TV.

‡ The following number of samples were used: woodland, 71; forest, 114; thicket, 162; and grassland, 162. Results are derived from relative abundance values of the birds instead of presence/absence.

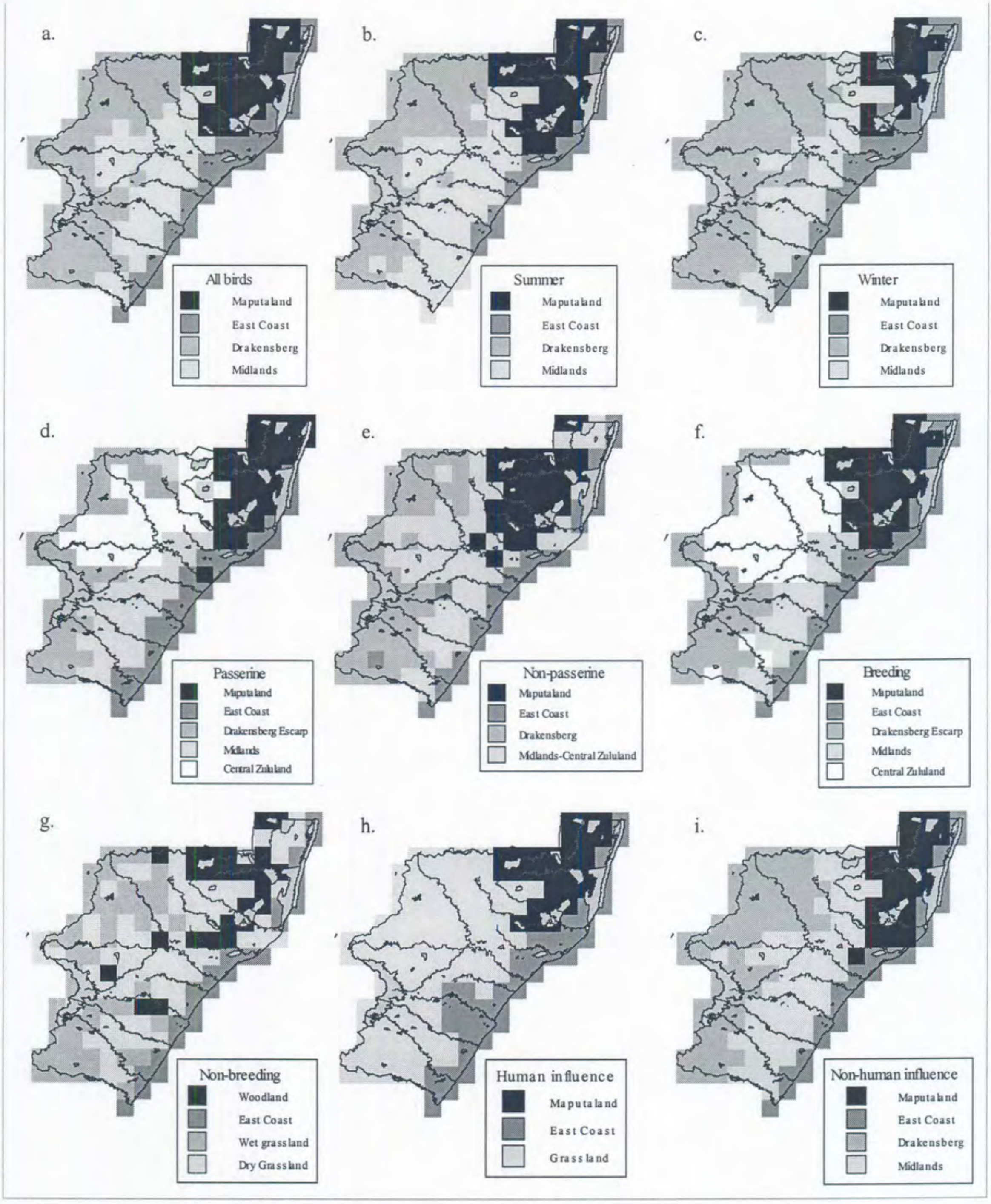

Figure 5.6: Assemblage classifications derived from ordination analysis of the CR life history bird datasets.

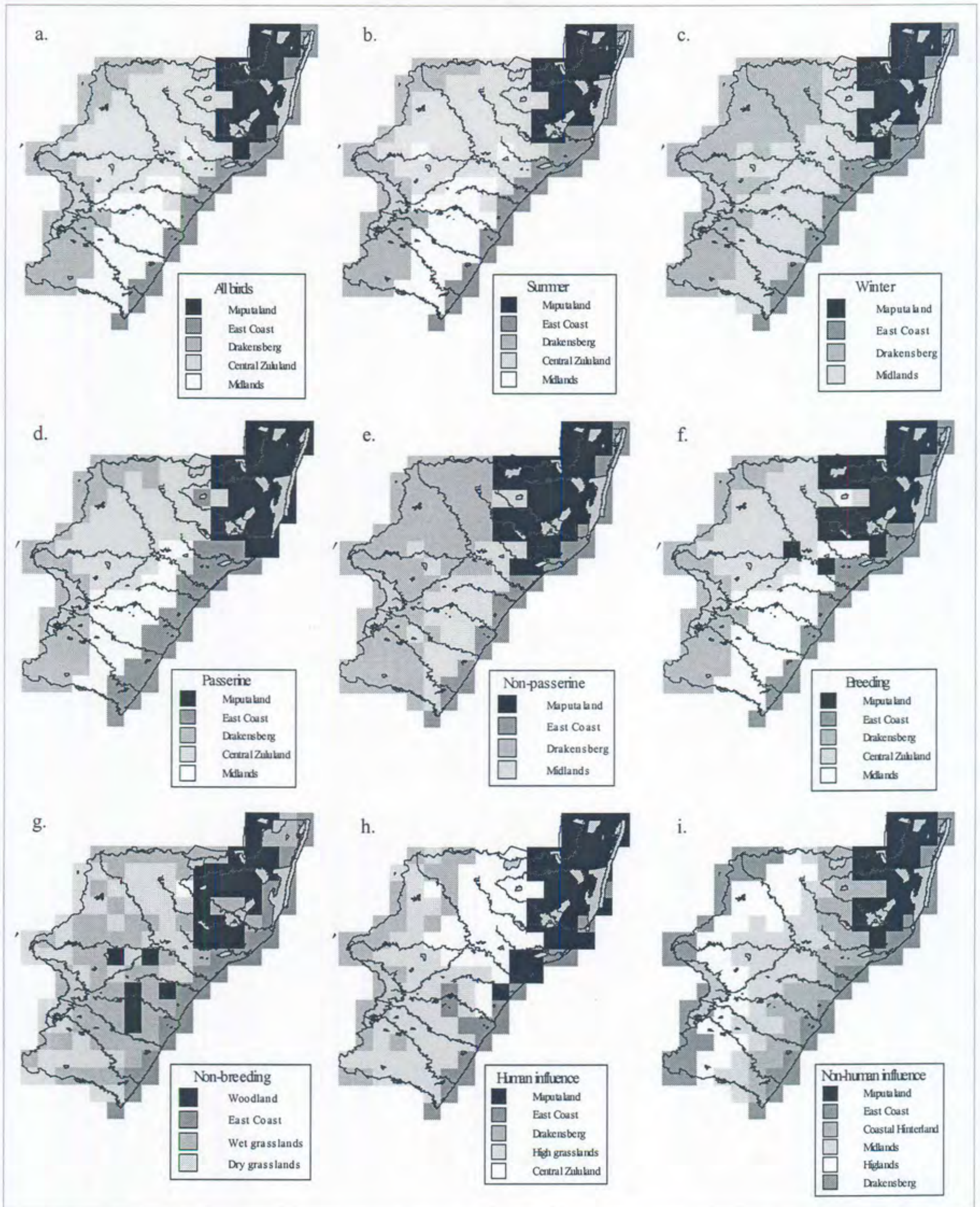

Figure 5.7: Assemblage classifications derived from ordination analysis of the ADU life history bird datasets.

All birds.—The dominant compositional gradient (CCA axis 1) reflected a gradient in elevation and topographic heterogeneity from the humid Maputaland plain and northern coast to the temperate montane climate of the Drakensberg (Figures 5.8a and 5.9a) with a TVE of 29% (Table 5.7). Grid cells with the lowest scores on axis 1 were at higher elevations and experienced higher seasonal variability in temperature, colder maximum and minimum temperatures, and higher rainfall. These plots were concentrated along the length of the Drakensberg Escarpment (Figure 5.8a) within the high grassland zone. Grid cells with high score on axis 1 were at lower elevations and experienced lower seasonal variability in temperature, warmer maximum and minimum temperatures, and higher evapotranspiration. The highest grid cell scores were concentrated along the coast from Durban north and encompassing the Maputaland plain, with the highest score situated over Ndumo nature reserve (Figure 5.8a). High-scoring grid cells fell largely within the moist and arid woodland zones (Chapter 1, Figure 1.3). With minor exceptions, the axis 1 gradient was longitudinal from the coast to the Drakensberg escarpment, reflecting the strong climatic influence of the Indian Ocean, the pronounced sharp rise in elevation from the coast, and the generally north-south orientation of the Drakensberg escarpment. The second CCA axis was a gradient in growing season moisture stress, from areas of warm, dry growing seasons to areas of humid, wet growing seasons along the coast (Figures 5.8a and 5.9a) with a TVE of 12%. Areas of low summer precipitation, high evapotranspiration and high summer temperature included the interior valleys on the western side of the Lebomo Mountains, especially the Pongola and Mfolozi River valleys, and the Tugela River valley. Lowest grid cell scores were concentrated in these areas, and tended to be in arid and mixed woodland and thicket (Chapter 1, Figure 1.3). Highest grid cell scores on axis 2 were situated at coastal river mouths, wetlands and bays. These areas included Durban Bay, Richards Bay, Kosi Bay, St. Lucia wetland, Mfolozi River mouth, Tugela River mouth and Mvoti River mouth (Chapter 1, Figure 1.2). The species at these points reflect the coastal wetland environment (Appendix B).

The ADU data set had a similar pattern and gradient on axis 1 (Figure 5.10a and 5.11a) with the addition of temperature variables and the seasonality in precipitation (TVE of 27.5%; Table 5.8). The spatial pattern of the low scores along the Drakensberg Escarpment were not as wide, but rather shrunk along the escarpment edge compared to the CR data set. High values covered the Maputaland plain and coast as far down as Durban Bay. The second axis was also similar to the CR result and identified variables, however, with the addition of seasonal variability in evapotranspiration (TVE of 10.5%). High values however were calculated down the coast to cover the region from Richards Bay to the southern border of the province.

Table 5.7: Increases in total variation explained (TVE) by explanatory variables in stepwise canonical correspondence analysis of CR bird species, by group type; the three greatest contributors to TVE in each group type are show in boldface.[†]

Variable	Additional variation explained (proportion of TVE)								
	All	Summer	Winter	Passerine	Non-passerine	Breeding	Non-breeding	Human	Non-human
Topography									
DEMMEAN	**0.23**	**0.23**	**0.26**	**0.22**	**0.22**	**0.22**	**0.27**	**0.14**	**0.42**
DEMSTD	**0.05**	**0.04**	**0.05**	**0.03**	**0.05**	**0.04**	**0.13**	**0.03**	**0.08**
Climate									
GDMEAN	**0.10**	**0.09**	**0.11**	**0.08**	**0.11**	**0.08**	‡	§	**0.21**
MAP	‡	§	§	§	‡	§	‡	0.02	§
GTMEAN	‡	‡	‡	§	‡	0.03	**0.23**	§	‡
NGTMEAN	‡	‡	‡	‡	‡	§	‡	§	‡
MAT	‡	‡	‡	‡	‡	§	‡	‡	‡
HOTMNTHMN	‡	‡	‡	‡	‡	§	§	‡	‡
MINMNTHMN	‡	§	‡	§	‡	§	‡	‡	‡
EVANNMN	0.03	0.02	0.03	0.02	0.04	0.02	‡	**0.05**	0.06
PSEAS_MN	‡	0.01	‡	0.01	‡	§	‡	0.01	‡
TSEAS_MN	‡	0.04	0.03	0.04	‡	0.02	‡	0.01	‡
MXSEAS_MN	‡	0.03	0.04	0.02	‡	0.02	‡	0.01	‡
EVSEAS_MN	‡	0.01	0.02	‡	‡	0.01	‡	0.01	‡

[†] Increase in TVE is additional species variation explained by adding the variable after previously selected variables already are included, expressed as a proportion of TVE, and thus reflects selection order. Values are for variables included by forward selection ($P < 0.01$, where significance was determined by a 499 iteration Monte Carlo permutation test, H_0: additional influence of variable on vegetation is not significantly different from random), and where adding the variable did not result in inflation factors > 20.

[‡] Variable was not significant in the stepwise procedure.

[§] Variable was significant in the stepwise procedure but excluded because of multi-collinearity.

Table 5.8: Increases in total variation explained (TVE) by explanatory variables in stepwise canonical correspondence analysis of ADU bird species, by functional type; the three greatest contributors to TVE in each group type are show in boldface.[†]

Variable	Additional variation explained (proportion of TVE)								
	All	Summer	Winter	Passerine	Non-passerine	Breeding	Non-breeding	Human	Non-human
Topography									
DEMMEAN	**0.19**	**0.20**	**0.22**	§	**0.17**	§	**0.19**	**0.11**	**0.37**
DEMSTD	0.02	0.03	0.03	0.02	0.02	0.02	0.03	**0.02**	0.03
Climate									
GDMEAN	**0.07**	**0.07**	**0.08**	**0.03**	**0.07**	**0.03**	**0.13**	0.01	**0.15**
MAP	‡	§	§	§	§	§	‡	§	§
GTMEAN	§	‡	§	§	§	§	‡	§	§
NGTMEAN	‡	‡	§	§	‡	§	‡	§	‡
MAT	‡	§	§	§	‡	§	‡	§	§
HOTMNTHMN	‡	§	§	§	‡	§	‡	§	‡
MINMNTHMN	§	§	§	**0.20**	§	**0.18**	§	§	§
EVANNMN	**0.03**	**0.03**	0.02	**0.07**	0.03	**0.06**	0.04	**0.04**	**0.06**
PSEAS_MN	0.01	0.01	0.02	0.02	0.01	‡	‡	0.01	0.03
TSEAS_MN	0.03	0.03	0.04	§	0.02	0.02	0.02	0.01	0.05
MXSEAS_MN	0.02	0.02	**0.04**	0.02	**0.03**	0.02	**0.05**	0.01	0.05
EVSEAS_MN	0.01	0.01	‡	‡	0.01	0.01	0.04	0.01	‡

[†] Increase in TVE is additional species variation explained by adding the variable after previously selected variables already are included, expressed as a proportion of TVE, and thus reflects selection order. Values are for variables included by forward selection ($P < 0.01$, where significance was determined by a 499 iteration Monte Carlo permutation test, H_0: additional influence of variable on vegetation is not significantly different from random), and where adding the variable did not result in inflation factors > 20.

[‡] Variable was not significant in the stepwise procedure.

[§] Variable was significant in the stepwise procedure but excluded because of multi-collinearity.

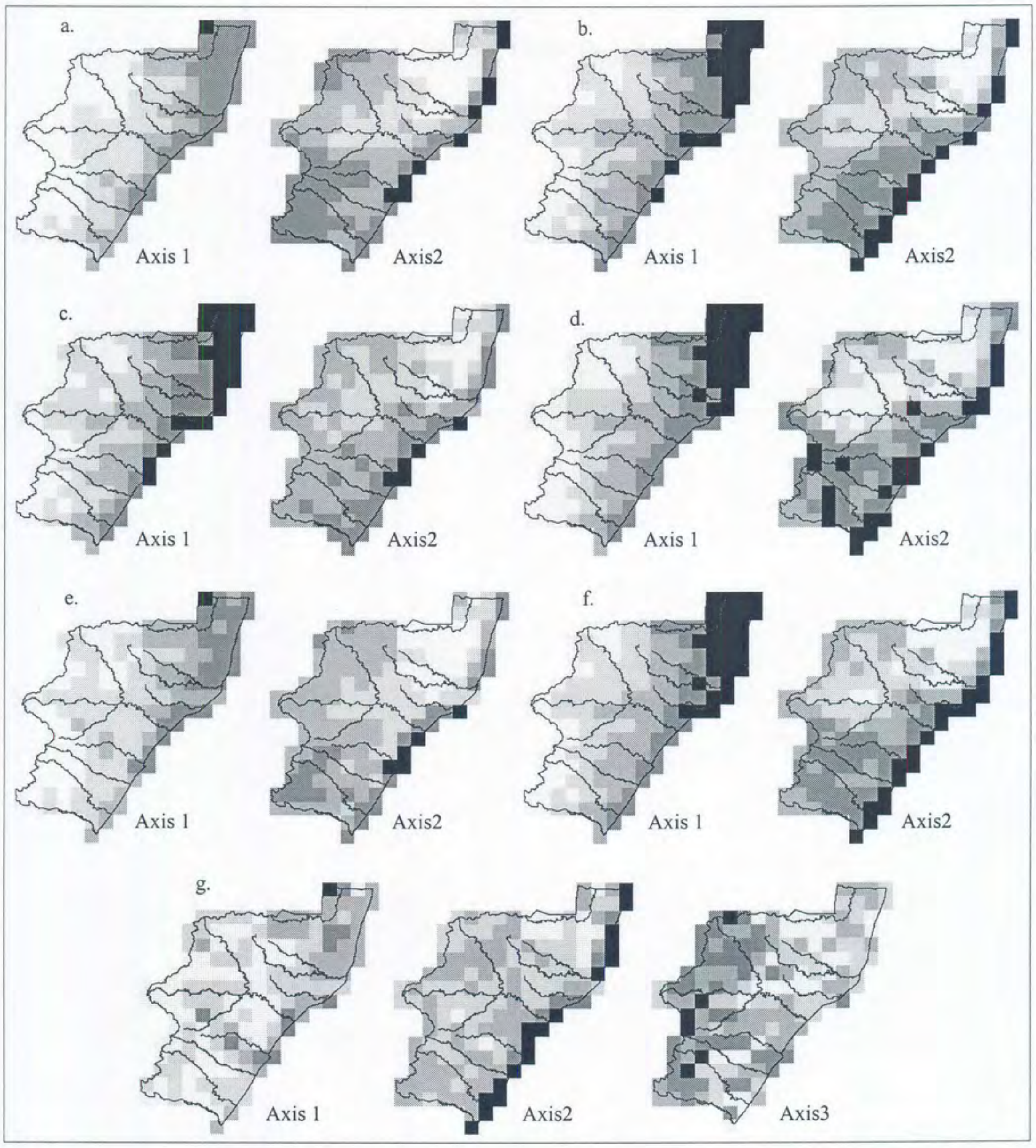

Figure 5.8: Patterns of variation in the first two axes of variation derived from detrended correspondence analysis (DCA) for each CR life history bird group, KwaZulu-Natal: (a) all birds; (b) summer; (c) winter; (d) passerine; (e) non-passerine; (f) breeding; (g) non-breeding; (h) human; and (i) non-human. (Figure continued on next page).

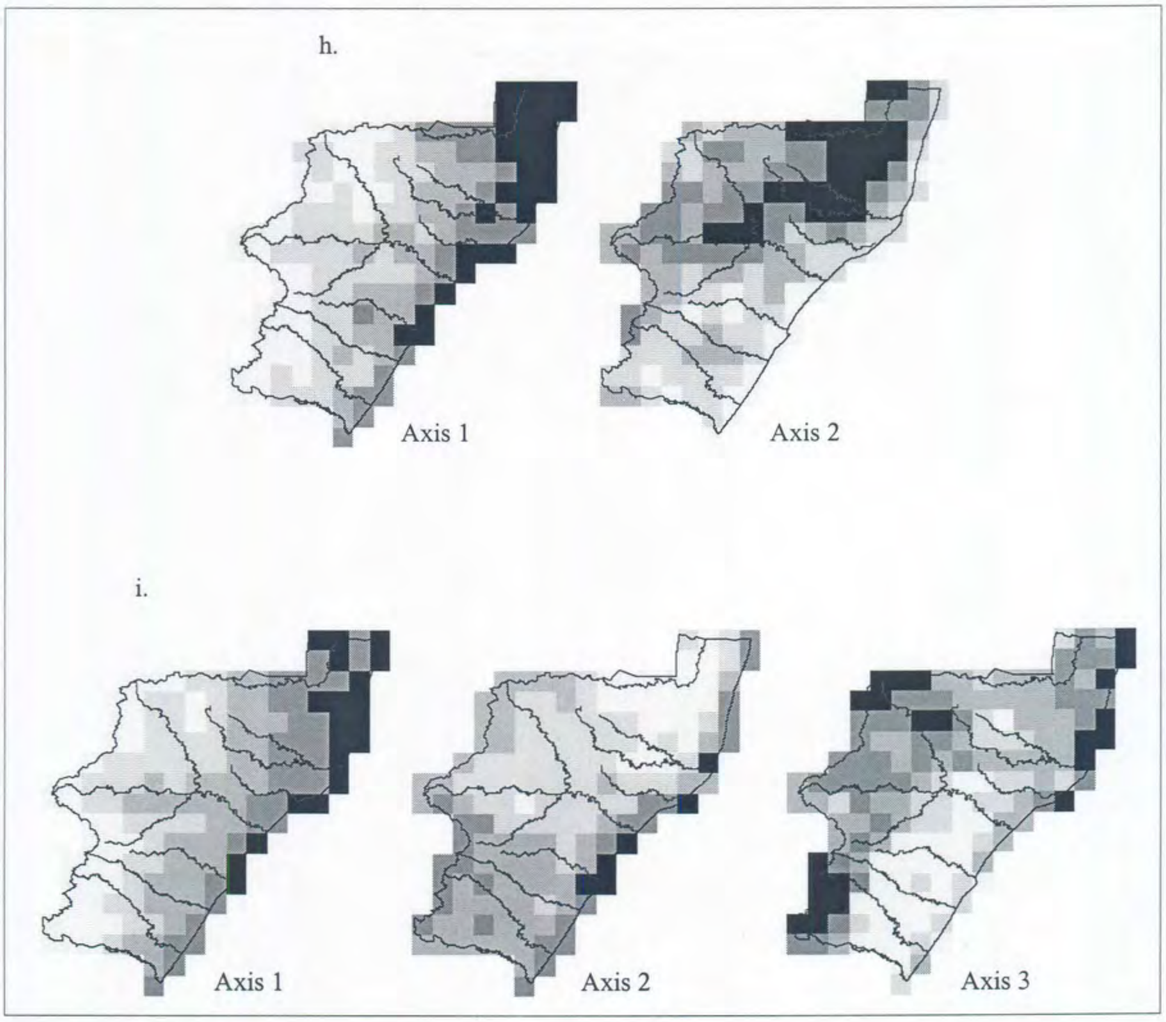

Figure 5.8: Continued.

Summer.—The first axis on the CR data set was strongly correlated with elevation and seasonality in precipitation and moderately correlated with topographic heterogeneity and seasonality in temperature and evapotranspiration (Figure 5.9b) with a TVE of 32% (Table 5.7). Low grid cell scores were on cooler, high-elevation sites along the Drakensberg Escarpment, and high scores were on warmer, low-elevation sites along the coast from Durban in the south to the Maputaland plain in the north (Figure 5.8b). The second axis was a gradient in growing season moisture stress and low variability in temperatures, from areas of warm, dry growing seasons to areas of humid, wet growing seasons along the coast (Figures 5.8b and 5.9b) with TVE of 13%. Low scores were in areas with arid and mixed woodland representing hot, moist summers along the Lebombo Mountains and the Tugela, Buffalo and White Umfolozi River valleys, and high scores were situated at coastal river mouths, wetlands, bays and south coast. These areas included Durban Bay, Richards Bay, Kosi Bay, St. Lucia wetland, Mfolozi River, Tugela River, Mkomazi River, and Mzimkhulu River mouths.

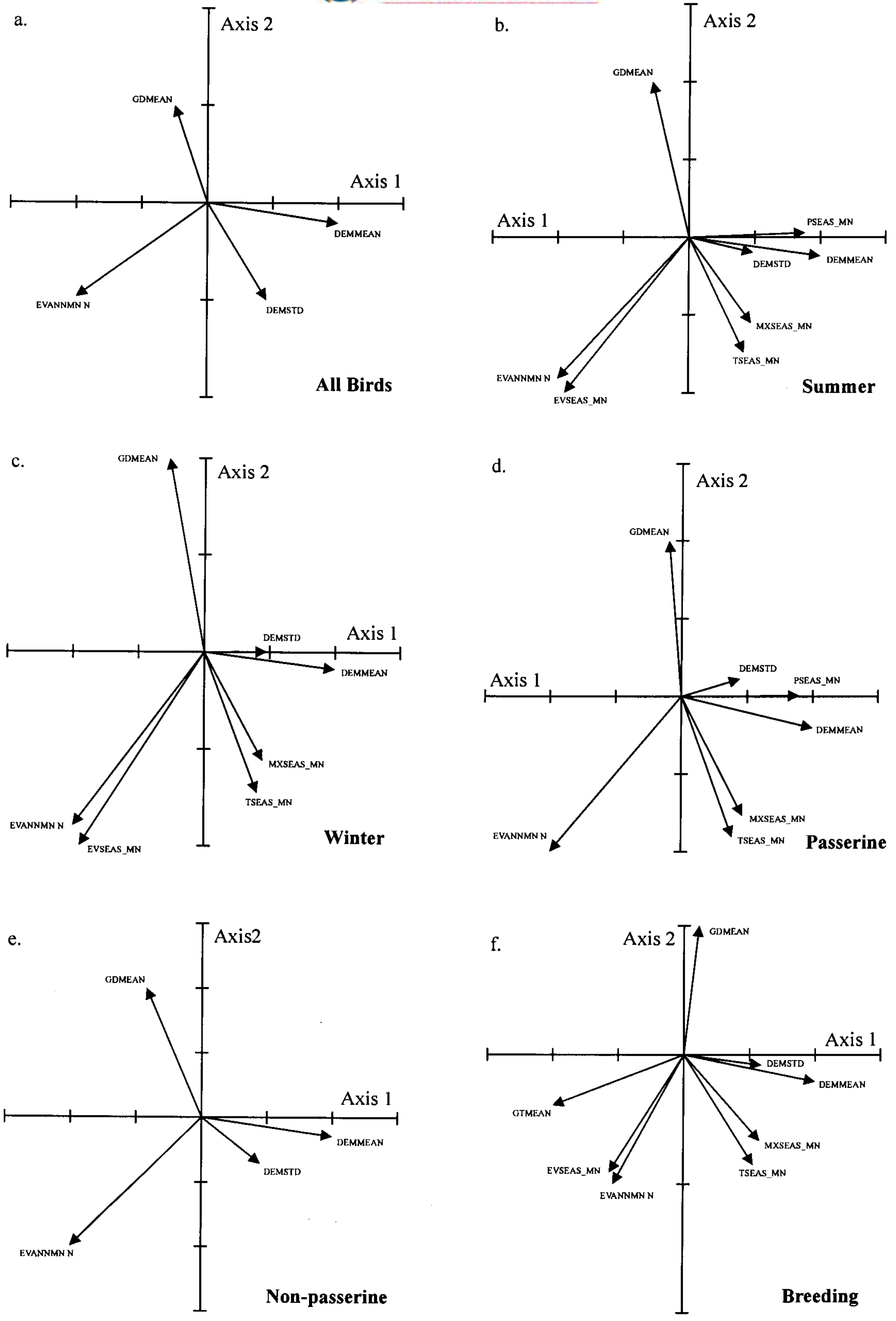

Figure 5.9: Biplots from canonical correspondence analysis of life history bird assemblages. All axes have been rescaled to range from –1.0 to 1.0. Axes for explanatory environmental variables that were not significant or that had very low correlations with the canonical axes are not shown.

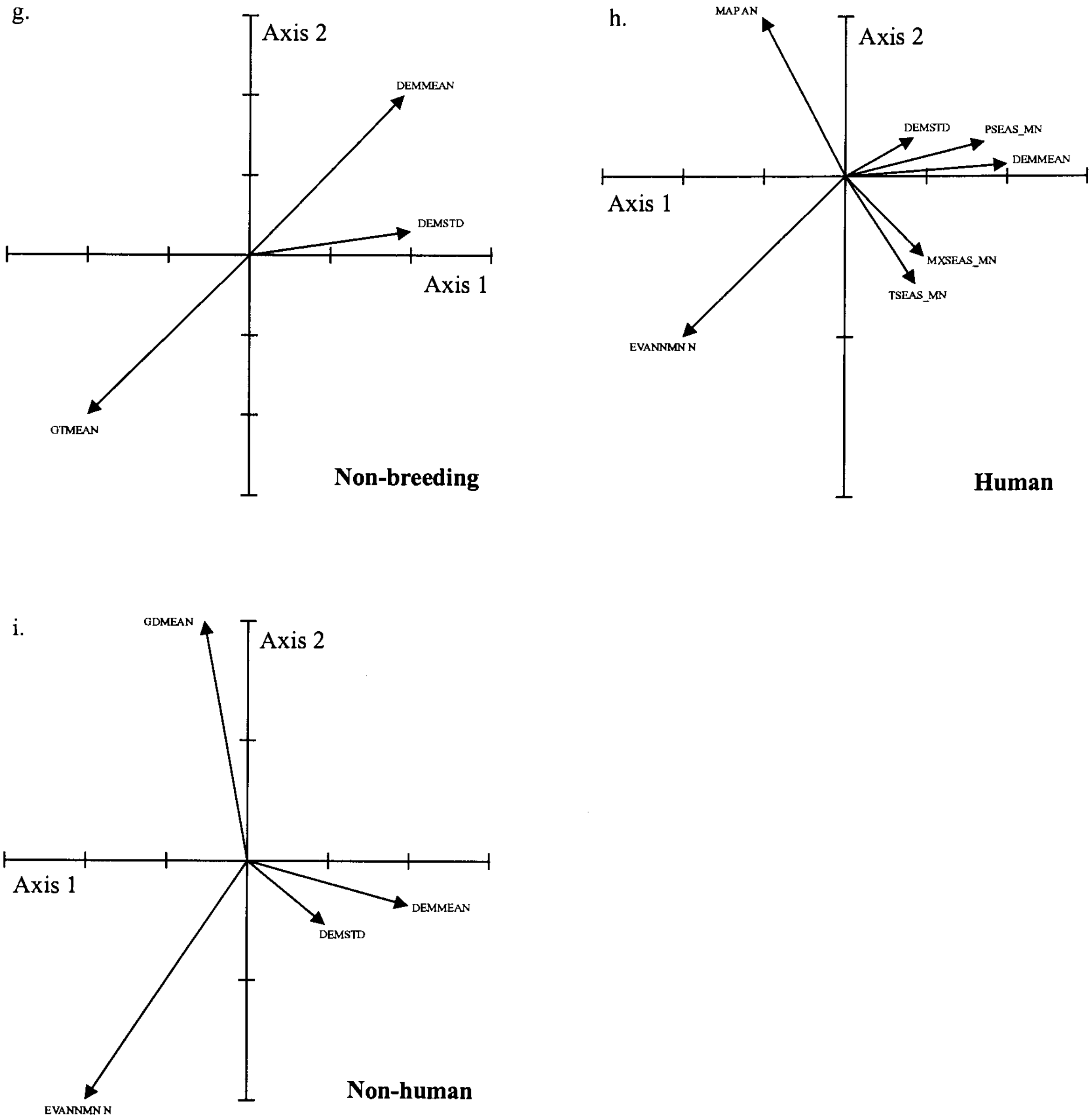

Figure 5.9: Continued.

The first axis results on the ADU data set correlate to similar variables (Figures 5.10b and 5.11b) with slight improvements in the relationships, but a lower TVE of 27.5% (Table 5.8). An arbitrary flip in scores by CANOCO derived low scores in the Maputaland plain and northern coast and high scoring grid cells in the Drakensberg Escarpment. The score calculations (between negative and positive values) are known to be calculated arbitrarily in CANOCO and have no influence on the results or for comparisons between data sets (ter Braak and Smilauer, 1998). Axis 2 was also related to water balance and seasonal variability in evapotranspiration with a similar TVE of 12.5%. Low and high scoring grid cells were in similar areas, but with reduced emphasis on high scoring cells along the north coast.

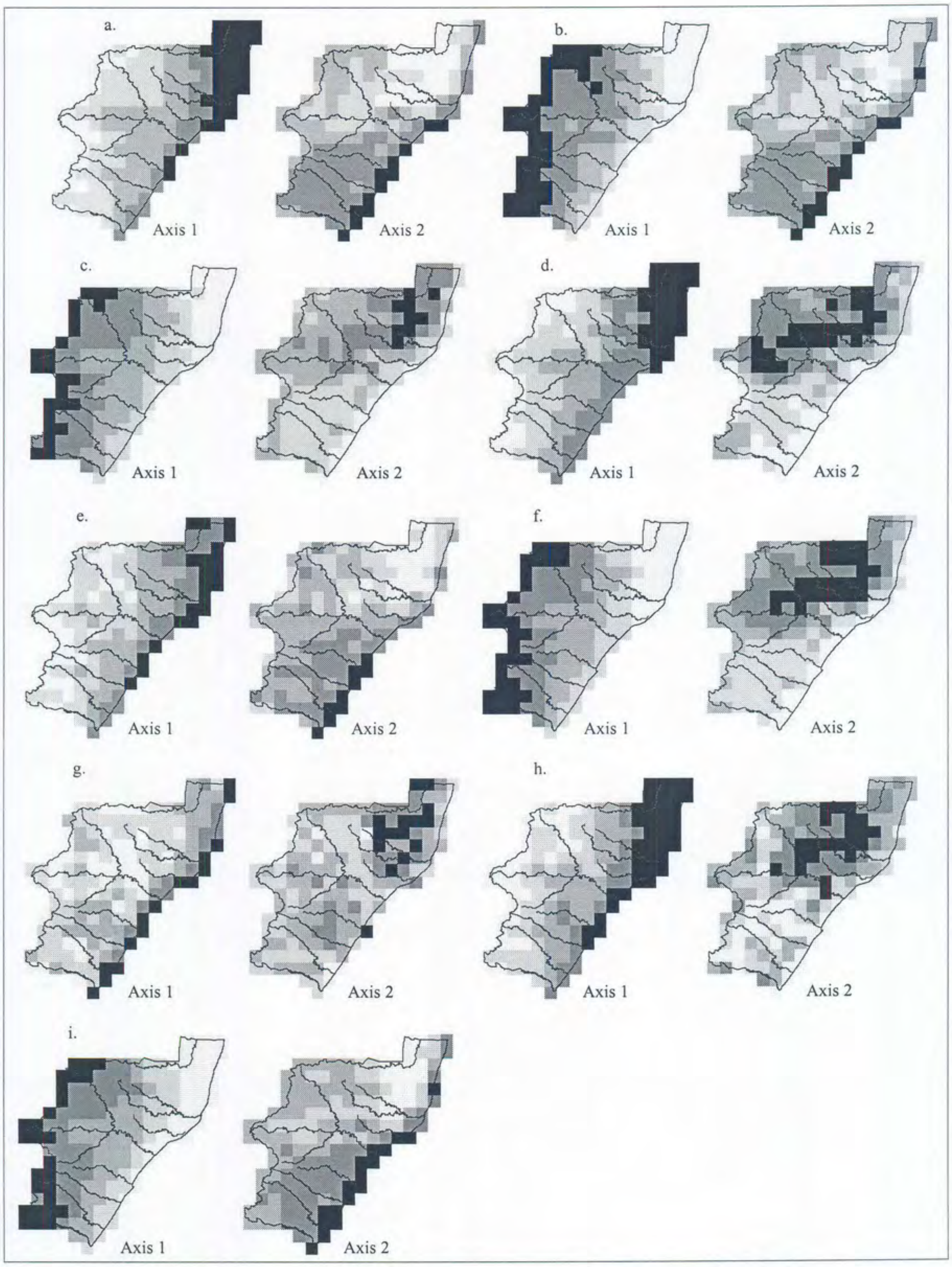

Figure 5.10: Patterns of variation in the first two axes of variation derived from detrended correspondence analysis (DCA) for each ADU life history bird group.

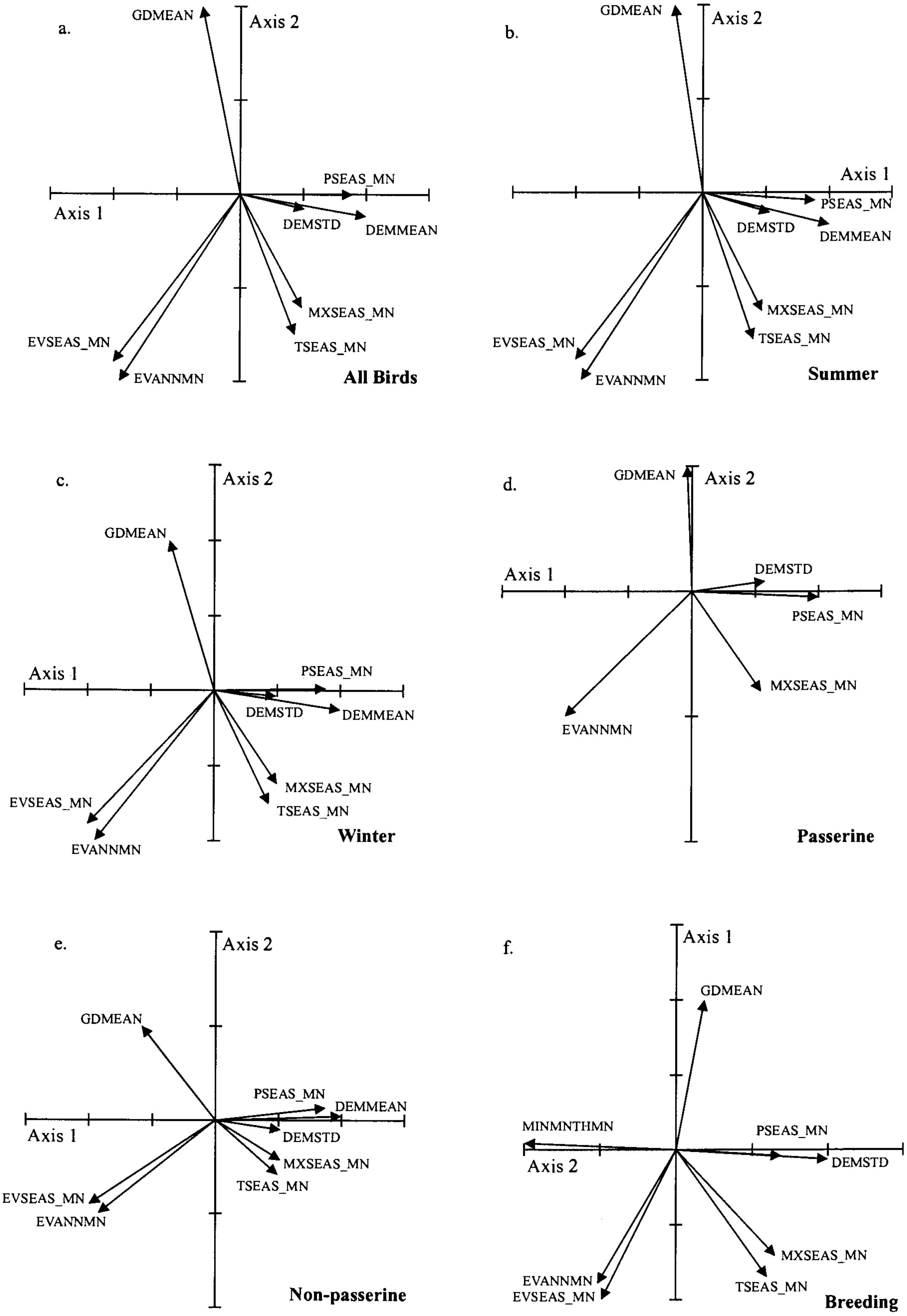

Figure 5.11: Biplots from canonical correspondence analysis of life history bird assemblages. All axes have been rescaled to range from –1.0 to 1.0. Axes for explanatory environmental variables that were not significant or that had very low correlations with the canonical axes are not shown.

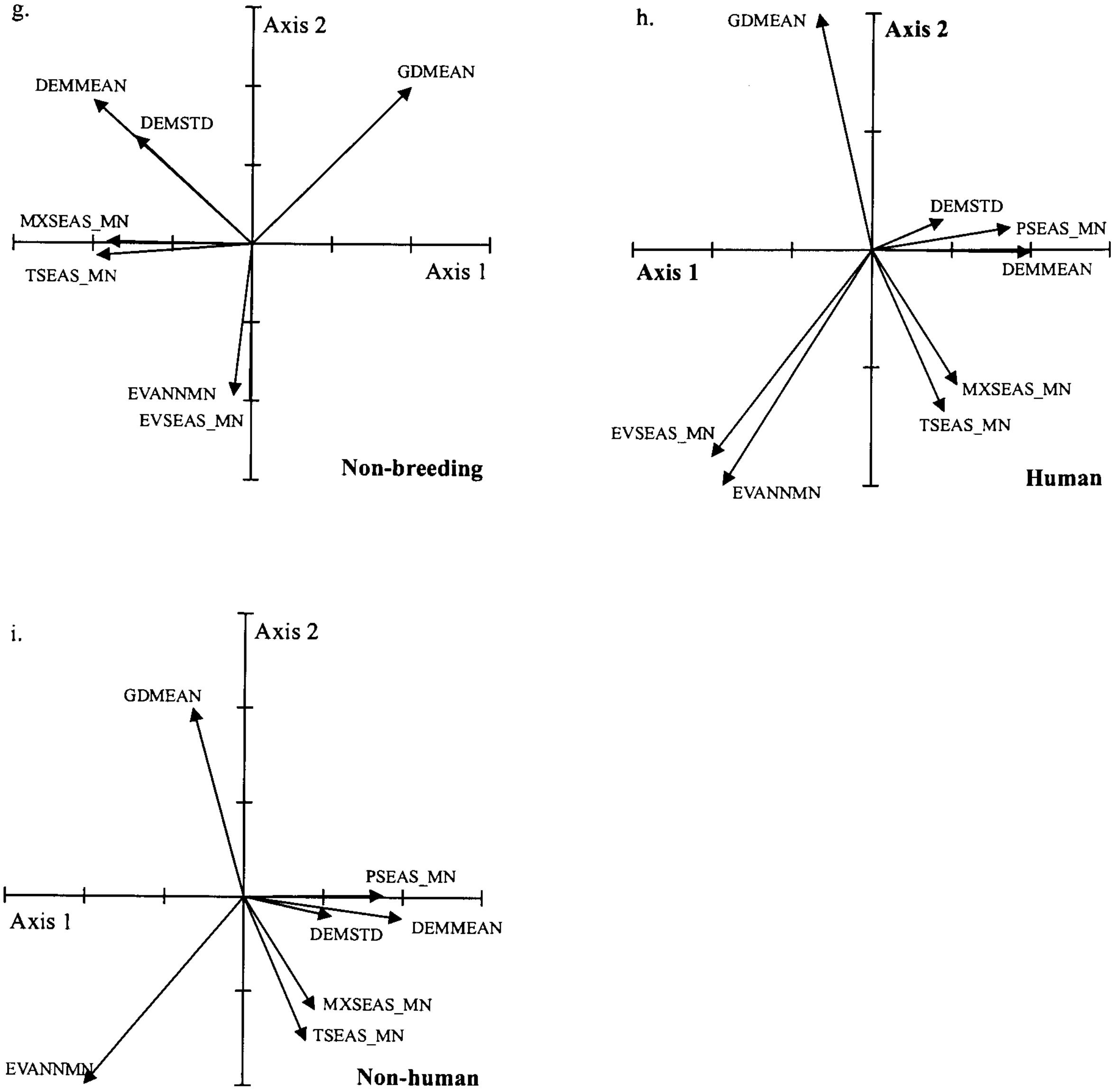

Figure 5.11: Continued.

Winter.—The first axis for the winter bird assemblage followed a similar gradient as for summer birds, an elevation gradient but with emphasis on seasonality in temperature (Figure 5.8c and 5.9c) with TVE of 29.5% (Table 5.7). The second axis was also similar to summer birds, where water balance and evapotranspiration represented the gradient, but with the addition of topographic heterogeneity and a TVE of 25%. The low scoring grid cells were in similar areas, however the high scoring grid cells were largely on the south coast and confined to Durban and Richards Bays and the Tugela River mouth.

The winter ADU data set of birds had arbitrary scoring flips on both axes of compositional variation (Figure 5.10c). Axis 1 was similar in pattern and variable selection (Figure 5.11c) with the added variable of seasonal variability in precipitation and a higher TVE of

33% (Table 5.8). Axis two had a much lower TVE of 12% with similar water balance and temperature variables selected to explain the variation.

Passerine.—The first axis gradient for the CR passerine bird assemblage was strongly correlated with elevation and seasonality in precipitation, and moderately correlated with topographic heterogeneity and maximum temperature (Figure 5.8d and 5.9d) with TVE of 25% (Table 5.7). Low scores were located in the high-elevation zone of the Drakensberg Escarpment, and high scores were located tightly covering the Maputaland plain and far north coast. Axis 2 was strongly associated with water balance, evapotranspiration and seasonality in temperature (TVE of 11%), with low scoring grid cells in the arid and mixed woodlands along the Pongola, Black and White Umfolozi, Buffalo and Tugela River valleys. High scoring plots were located either along the coast as far north as the St. Lucia wetland complex extending to the southern coast. Several of the grid cells were located in the southern interior comprising afromontane forest areas and high Drakensberg Escarpment grassland.

ADU axis 1 compositional variation was similar (Figure 5.10d and 5.11d), but with minimum temperature and seasonality in precipitation explaining the axis, however TVE was slightly lower at 25% (Table 5.8). The low and high scores were similar in location but low scores were tighter against the Drakensberg Escarpment. The second axis of variation had a flip in scores, but had similar variables explain the variation with a TVE of 11%. Low scoring grid cells were more clustered on the south coast than for the CR data set.

Non-passerine.—The dominant compositional gradient within the CR non-passerine bird assemblage was strongly associated with elevation and topographic heterogeneity (Figure 5.8e and 5.9e) with a TVE of 27% (Table 5.7). The pattern for axis 1 and environmental variables were similar to that derived using all birds. Axis 2 also related to similar variables, water balance and evapotranspiration, and elucidated similar pattern with a TVE of 15%. Exceptions to this pattern, are the confinement of high scores to only Durban and Richards Bays and the Tugela River mouth.

The non-passerine ADU data set required several more variables to explain the first axis of variation (Figure 5.11e). These were mostly variables describing seasonality in temperature and precipitation and TVE was mostly similar at 25% (Table 5.8). The low scoring grid cells were in similar areas along the Drakensberg Escarpment and high grasslands, but the high scoring areas were located along the coast from Kosi Bay to Durban Bay with clustering around the St. Lucia wetland (Figure 5.10e). Axis 2 contained similar variables with a slightly smaller TVE of 11%. Low scores were more northerly in the arid woodland and reduced in the mixed woodland

and Tugela River valley. High scoring grid cells were confined to the coast from Durban Bay southwards.

Breeding.—For breeding birds, axis 1 followed a gradient similar to that of the summer bird groups but with emphasis on temperature (Figure 5.8f and 5.9f): elevation, summer temperature, maximum temperature, and seasonal temperature variability contributed 34% of TVE (Table 5.7). Distribution of low and high grid cell scores was similar to that of the summer bird group. Axis 2 represented a water balance and evapotranspiration gradient related to the seasonality in temperature variability with a TVE of 10%. Grid cell scores and pattern were similar to axis 2 of the summer bird assemblage, but with greater emphasis on the differences between bird compositions of the interior arid and mixed woodlands and the coast.

The ADU data set of birds had arbitrary scoring flips on both axes of compositional variation (Figure 5.10f and 5.11f). Axis 1 was similar in pattern, but temperature variables largely explained this axis, but with a much lower TVE of 22% (Table 5.8). Axis two had a slightly higher TVE of 12% with similar water balance and seasonal temperature variability to explain the variation.

Non-breeding.—The non-breeding bird assemblage was much more variable than the other groups (Table 5.5). The gradients were not as well defined (Figures 5.8g and 5.9g), with axis 1 only moderately associated to elevation and summer temperature (TVE of 36%; Table 5.7). The low scoring cells were located along the Drakensberg Escarpment and in un-developed grassland areas within the Midlands and Central Zululand areas, and high scores were located in the Maputaland plain, Pongola River valley and the central coastal and Pietermaritzburg-Durban economic corridor. This pattern alignment with human dominated areas appears to relate to the summer visiting behaviour of Eurasian birds. The second axis associated moderately with elevation and topographic heterogeneity and a TVE of 14%. Low scores were undifferentiated, and high scores located along the coast. Axis 3 was less interpretable than the first two axes. Topographic heterogeneity and temperature were the correlates. Low scoring grid cells were on the river valleys and high scoring grid cells were in the Drakensberg Escarpment and foothills.

The non-breeding birds in the ADU data set were much less variable, yielding only two significant axes of variation (Figure 5.10g). Axis 1 required many more variables to explain the compositional variation (Figure 5.11g) with inclusions of topographic heterogeneity, and seasonal variabilities in temperature. The TVE was, however, higher at 36% (Table 5.8). Pattern was more interpretable with low scoring grid cells along the entire coast and high scores along the Tugela, Buffalo, Mzimkhulu, and Mooi River valleys. Axis 2 was associated with water balance and evapotranspiration variables, but with a much lower TVE of 14%. The low scores were undifferentiated, while the high scoring areas were in the arid woodland zone.

Human.—Axis 1 (Figures 5.8h and 5.9h) was correlated with elevation, seasonality in precipitation, topographic heterogeneity, and temperature (TVE of 19.5%; Table 5.7). Low scores were situated along the Drakensberg Escarpment and high scores were in Maputaland and along the coast. The second axis associated with evapotranspiration, mean annual precipitation, and seasonal temperature variability (TVE of 7.5%). Low scores were situated along the south coast and Midlands and high scores were in the arid and mixed woodland regions of the Zulu homeland.

The ADU data set for axis 1 was similar in pattern and explanatory variables (Figures 5.10h and 5.11h) but with a slightly lower TVE of 15.5% (Table 5.8). Axis 2 also required similar explanatory variables with a similar TVE of 6.5%, but the spatial pattern in allocated scores was different. Low scoring grid cells were located along the coast south of Sodwana Bay, the Midlands within the Pietermartizburg-Durban economic corridor, and along the main roads to Newcastle. The high scoring grid cells reflected these changes by becoming more constricted to the arid and mixed woodlands of Central Zululand, with a reduced presence in the Maputaland plain.

Non-human.—The non-human influenced bird assemblage was much more variable and elucidated three axes of variation (Figure 5.8i). The major compositional gradient on axis 1 was elevation and topographic heterogeneity (Figure 5.9i) with a large TVE of 50% (Table 5.7). Low scoring grid cells were located in the Drakensberg Escarpment and high scoring areas were situated along the coast from Durban north. These areas tended to be characterized by bays, river mouths, or large wetlands. Axis 2 was associated with water balance and evapotranspiration and a TVE of 27%. Low scores were in the arid and mixed woodland and thicket regions and high scores were on the coast at Durban and Richards Bays and the Tugela and Mfolozi River mouths. Axis 3 was moderately related to topographic heterogeneity and evapotranspiration with low scores throughout the Midlands and high scores in the southern Drakensberg Escarpment, northern Drakensberg Escarpment near Newcastle and Wakkerstroom, and along the coast from Richards Bay north.

The non-human influenced birds in the ADU data set were much less variable, yielding only two significant axes of variation (Figure 5.10i). Axis 1 required many more variables to explain the compositional variation with inclusions of seasonal variabilities in precipitation and temperature (Figure 5.11i). The TVE was, however, similar at 50.5% (Table 5.8). The spatial pattern was more interpretable with low scoring grid cells along the coast from Durban Bay to the Maputaland plain, and high scores were located along the Drakensberg Escarpment. Axis 2 was associated with water balance and evapotranspiration variables, with a slightly lower TVE of 23.5%. The low scores were in a much more confined area in the arid woodland and along the thickets in the river valleys. High scoring grid cells were situated along the coast from Richards Bay south, with one exception at Sodwana Bay.

5.5.2.1.1 Associations of Local and Regional Factors with Species Gradients

The relative contributions of explanatory variables to TVE in stepwise and partial CCA were influenced by location and illustrated the nested scales in processes, coarse to fine scale, that are required to explain variation within the life history species assemblages (Table 5.9). In partial CCA conducted on the ADU life history data sets, regional factors (climate and topography) accounted for more of the TVE (22-74%) than the landscape factors (8.6-32%) for all the bird assemblages (Table 5.9). Landscape factors contributed less to TVE for the human influenced (8.56%; Figure 5.12h), passerine (10.2%; Figure 5.12d) and breeding (11.1%; Figure 5.12f) bird assemblages. Contributions of landscape factors to TVE were greater for the non-breeding (32%; Figure 5.12g), non-human influenced (24.7%; Figure 5.12i), non-passerine (19.5%; Figure 5.12e), summer (18.4%; Figure 5.12b), all birds (15.4%; Figure 5.12a), and winter (14%; Figure 5.12c) bird assemblages. Passerine and breeding birds were the only assemblages not related to the richness and density of LCLU classes. The life history bird assemblages were mostly related to LCLU proportions than to the landscape mosaic pattern metrics. Passerine, breeding and non-human bird assemblages were related to the amount of woodland and forest coverage. While all, summer, winter, breeding and human bird assemblages were related to the amount of grassland coverage and extent of subsistence agriculture and degraded lands. Passerine, non-breeding, and human bird assemblage variations had the greatest relationships with human built landscapes, which included extent urbanized and road disturbance.

In order to resolve finer resolution in the power of landscape metrics to explain avian diversity patterns analysis was conducted on birds grouped by associated primary vegetation habitat (Table 1.3). These ecological habitat bird groups were ordinated using the relative abundance of each bird rather than presence/absence in order to understand the land-cover class patch characteristics relationship to bird population variation. This analysis was conducted to overcome any confusions associated with landscape mosaic measurements, which include all LCLU classes, and to come closer to an ecological explanation of bird reactions to landscape pattern that would be masked using life history assemblages. Figure 5.13 illustrates the dominant gradients derived from DCA analysis on the relative abundance of the birds group by primary associated habitat classes. Table 5.10 presents CCA results of the bird habitat groups in relation to the environmental variables chosen in the stepwise CCA to explain the ecological habitat birds.

Table 5.9: Proportion of total variation explained (TVE) by landscape variables while constrained by the topography and climate variables chosen for each group type in partial canonical correspondence analyses (CCAs) of ADU bird species; the three greatest landscape contributors to remaining TVE after constraining by the topography and climate variables in each group type are show in boldface. [†]

	Additional variation explained (proportion of TVE explained after constraining by covariables)								
	All	Summer	Winter	Passerine	Non-passerine	Breeding	Non-breeding	Human	Non-human
Partial CCA TV	0.934	1.081	1.313	0.784	1.071	0.790	2.056	0.619	1.730
Variable									
Landcover									
POPTOT96	§	‡	‡	‡	‡	‡	0.02	§	‡
POPDEN96	0.01	0.01	‡	‡	0.01	‡	‡	0.005	‡
FOR_PER	‡	0.01	‡	**0.02**	0.012	**0.02**	‡	‡	**0.03**
GRS_PER	**0.014**	**0.015**	**0.02**	‡	0.01	**0.011**	0.02	**0.01**	‡
WET_PER	0.01	0.014	0.012	‡	0.013	0.007	0.03	0.006	0.023
LOWI_PER	**0.015**	**0.02**	‡	‡	**0.02**	**0.012**	**0.02**	**0.013**	‡
PLNT_PER	0.013	‡	‡	0.012	‡	0.011	0.02	0.008	0.022
DRY_PER	0.01	0.011	0.013	‡	0.011	‡	0.02	‡	‡
IRR_PER	‡	‡	‡	‡	‡	‡	‡	‡	‡
URB_PER	0.01	0.012	‡	‡	**0.02**	‡	**0.05**	**0.015**	‡
M_PER	§	‡	**0.02**	‡	‡	‡	‡	‡	‡
T_PER	§	‡	‡	‡	‡	‡	‡	‡	0.02
T_TOTAL	§	‡	‡	0.01	‡	‡	‡	‡	‡
ROAD_INDEX	§	‡	‡	**0.014**	‡	‡	‡	‡	‡
Patchiness									
LPI	‡	‡	‡	‡	‡	‡	‡	‡	‡
NP	§	‡	‡	‡	‡	0.008	‡	‡	‡
PD	§	‡	‡	‡	‡	‡	‡	‡	‡
MPS	§	‡	‡	‡	‡	‡	‡	‡	0.02
PSSD	§	‡	‡	‡	‡	‡	‡	‡	‡
CI	‡	‡	‡	‡	0.01	‡	‡	‡	‡
Shape									
MSI	‡	§	‡	‡	‡	‡	‡	‡	‡
AWMSI	‡	‡	‡	‡	‡	‡	‡	‡	‡
FD	‡	§	‡	‡	‡	‡	‡	‡	‡
MPFD	§	0.01	‡	‡	0.01	0.007	‡	‡	‡
AWMPFD	0.01	‡	‡	0.011	‡	0.007	‡	‡	‡
Interior									
MCAPP	‡	‡	‡	‡	‡	‡	‡	‡	‡
PCASD	‡	‡	‡	‡	‡	‡	‡	‡	‡
MAPDC	‡	‡	‡	‡	‡	‡	‡	‡	0.022
DCASD	‡	‡	‡	‡	‡	‡	‡	‡	‡
DCACV	0.01	‡	‡	0.015	‡	‡	‡	‡	‡
Isolation									
MNND	‡	‡	‡	‡	‡	‡	‡	‡	‡
NNSD	‡	‡	‡	‡	‡	‡	‡	‡	‡
MPI	‡	‡	‡	‡	‡	‡	‡	‡	‡
II	‡	0.012	0.01	‡	0.012	0.008	‡	0.006	‡
Richness									
CR	0.012	0.015	0.014	0.01	0.014	0.01	0.03	0.01	0.02
CRD	**0.03**	**0.04**	**0.03**	‡	**0.04**	‡	**0.11**	0.007	**0.06**
Heterogeneity									
SHDI	§	‡	§	§	§	§	‡	‡	‡
SDI	§	‡	0.02	§	‡	§	‡	‡	§
MSDI	§	‡	‡	§	‡	§	‡	‡	‡
Evenness									
SHEI	§	‡	‡	§	0.013	§	‡	‡	‡
SEI	0.01	0.015	§	0.01	‡	0.01	‡	0.006	**0.03**
MSEI	§	‡	‡	§	‡	§	‡	‡	‡

[†] Same rules as for Table 5.8.

[‡] Variable was not significant in the stepwise procedure.

[§] Variable was significant in the stepwise procedure but excluded because of multi-collinearity.

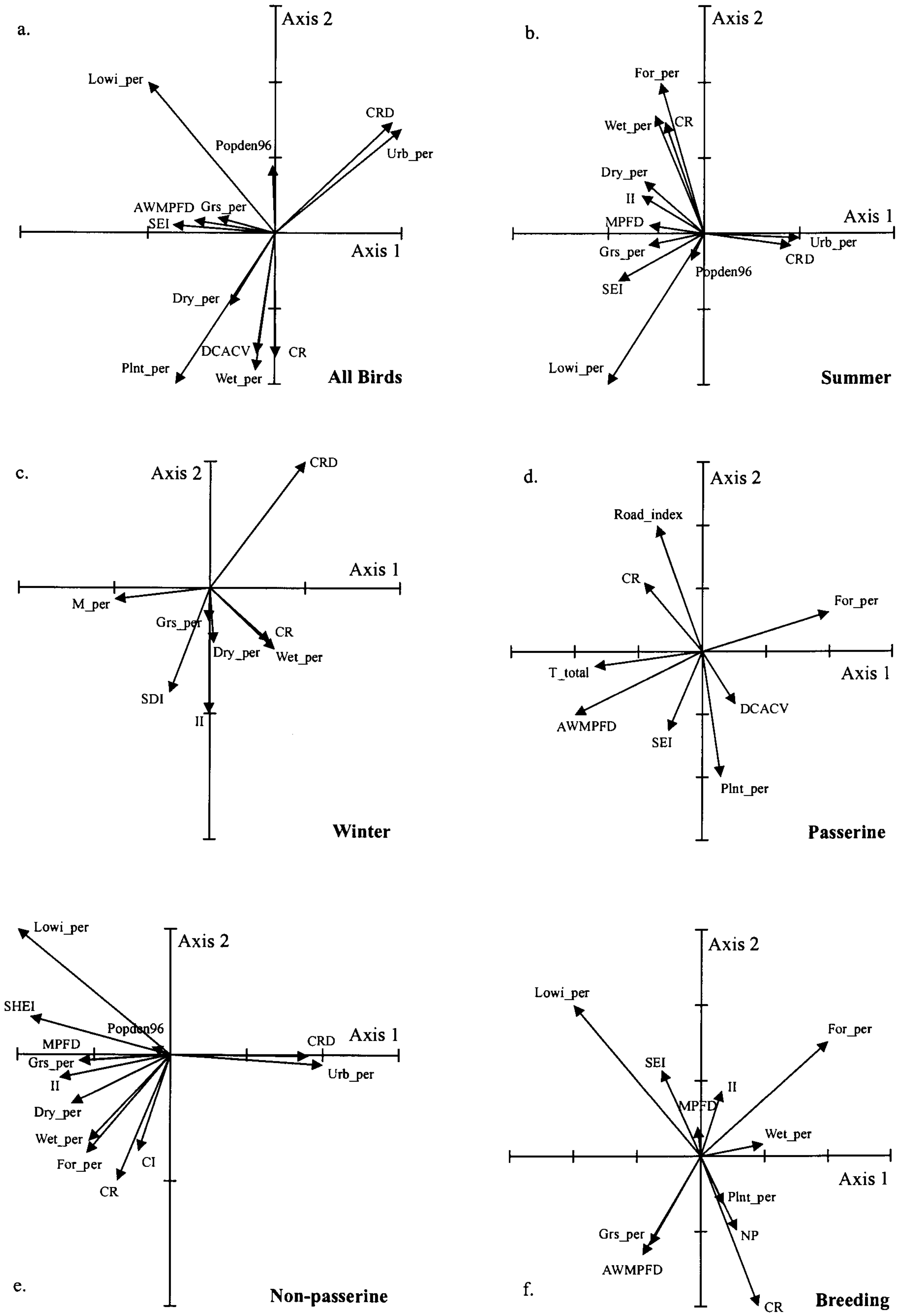

Figure 5.12: Biplots from canonical correspondence analysis of life history bird assemblages. All axes have been rescaled to range from –1.0 to 1.0. Axes for explanatory landscape variables that were not significant or that had very low correlations with the canonical axes are not shown.

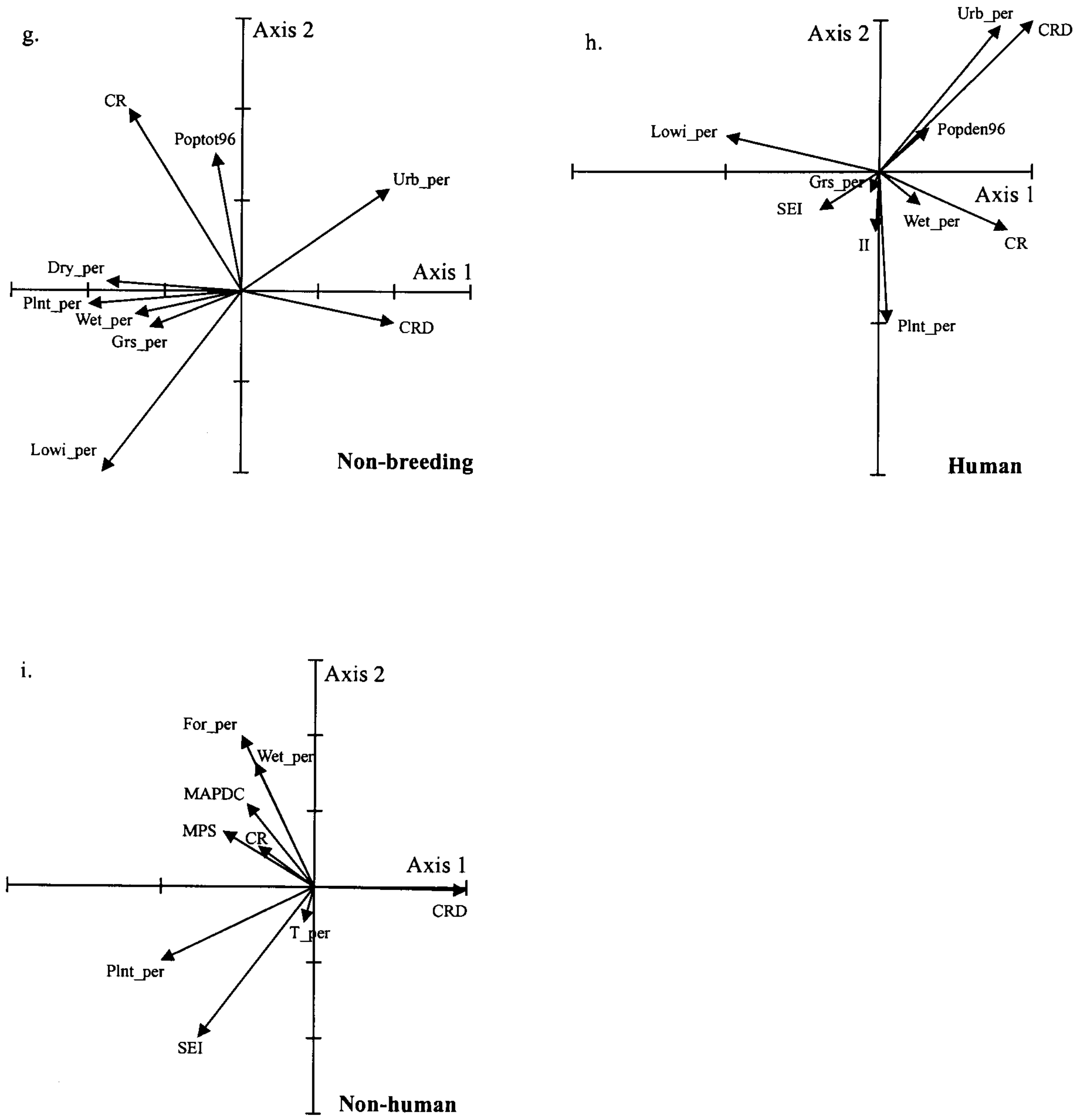

Figure 5.12: Continued.

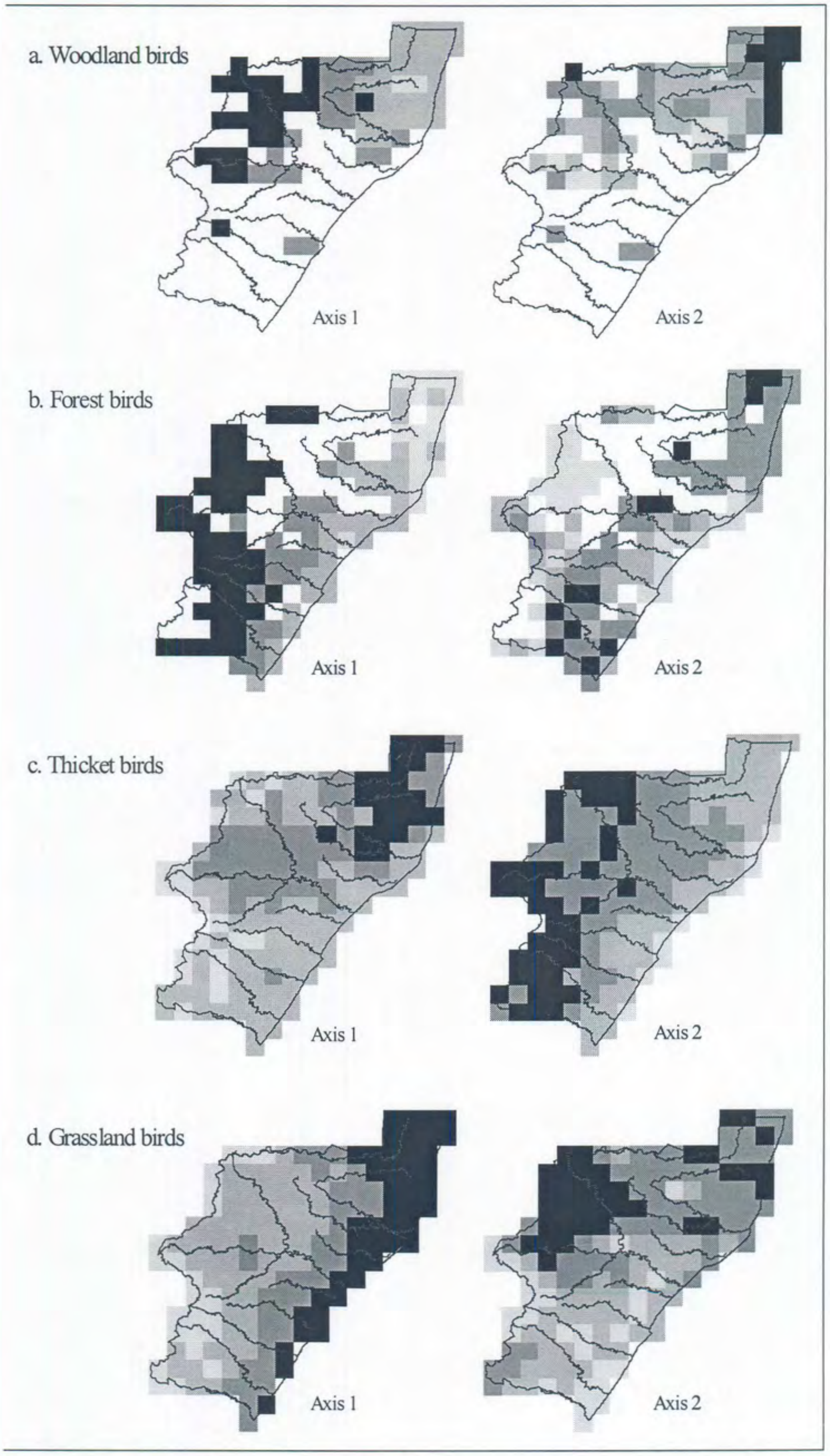

Figure 5.13: Patterns of variation in the first two axes of variation derived from detrended correspondence analysis (DCA) for each ADU ecological habitat bird group. Areas with no coverage of the respective vegetation class are depicted in white.

Table 5.10: Increases in total variation explained (TVE) by explanatory variables in stepwise canonical correspondence analysis of ADU bird species, by ecological type; the three greatest contributors to TVE in each group type are show in boldface. [†]

	Additional variation explained (proportion of TVE)			
Variable	Woodland	Forest	Thicket	Grassland
Topography				
DEMMEAN	§	§	**0.13**	**0.19**
DEMSTD	‡	0.02	0.02	**0.03**
Climate				
GDMEAN	0.03	**0.04**	**0.04**	0.02
MAP	‡	§	§	§
GTMEAN	**0.20**	§	§	§
NGTMEAN	§	§	§	§
MAT	‡	§	§	§
HOTMNTHMN	§	§	§	§
MINMNTHMN	§	**0.28**	§	§
EVANNMN	**0.10**	**0.07**	**0.21**	**0.08**
PSEAS_MN	0.02	‡	0.02	0.02
TSEAS_MN	§	‡	§	§
MXSEAS_MN	§	‡	0.01	0.02
EVSEAS_MN	**0.02**	‡	‡	0.01

[†] Increase in TVE is additional species variation explained by adding the variable after previously selected variables already are included, expressed as a proportion of TVE, and thus reflects selection order. Values are for variables included by forward selection ($P < 0.01$, where significance was determined by a 499 iteration Monte Carlo permutation test, H_0: additional influence of variable on vegetation is not significantly different from random), and where adding the variable did not result in inflation factors > 20.

[‡] Variable was not significant in the stepwise procedure.

[§] Variable was significant in the stepwise procedure but excluded because of multi-collinearity.

Woodland bird variation was related to temperature and precipitation seasonality on the first axis, with higher temperatures in Maputaland and stronger seasonality in precipitation in the Tugela and Buffalo River basins. The second axis gradient contrasted the northern coast versus the inland low-lying Tugela, Pongola, Mkuze and Mhalutze River valleys. The variables illustrated an aridity gradient represented by growth days and evapotranspiration. The forest bird's first axis gradient depicted a trend from the Drakensberg escarpment and southern midlands to the flat and warmer coastal plains of Maputaland, appropriately elevation heterogeneity and mean minimum temperature of the coldest month described the axis. The second axis of variation described the lower moisture regimes in the interior of the province and Maputaland from the wet southern coast and Drakensberg escarpment, with evapotranspiration and growth days explaining the pattern. The variation in thicket birds illustrated a trend from Maputaland and Zululand to the Drakensberg escarpment, which was explained by evapotranspiration and growth days. Axis two was related to elevation, elevation heterogeneity, seasonality in maximum temperature and a further contribution by growth days. The variation in grassland birds was the most complicated to explain with the available environmental variables, which lead to seven variables being chosen. Axis one depicted a gradient in elevation and seasonality in maximum temperature from the coast and Maputaland to the Drakensberg escarpment. Axis two was mostly represented by a moisture gradient between Tugela and Buffalo River basin and Maputaland grassland birds and birds in the Midlands, south coast and high central Drakensberg escarpment.

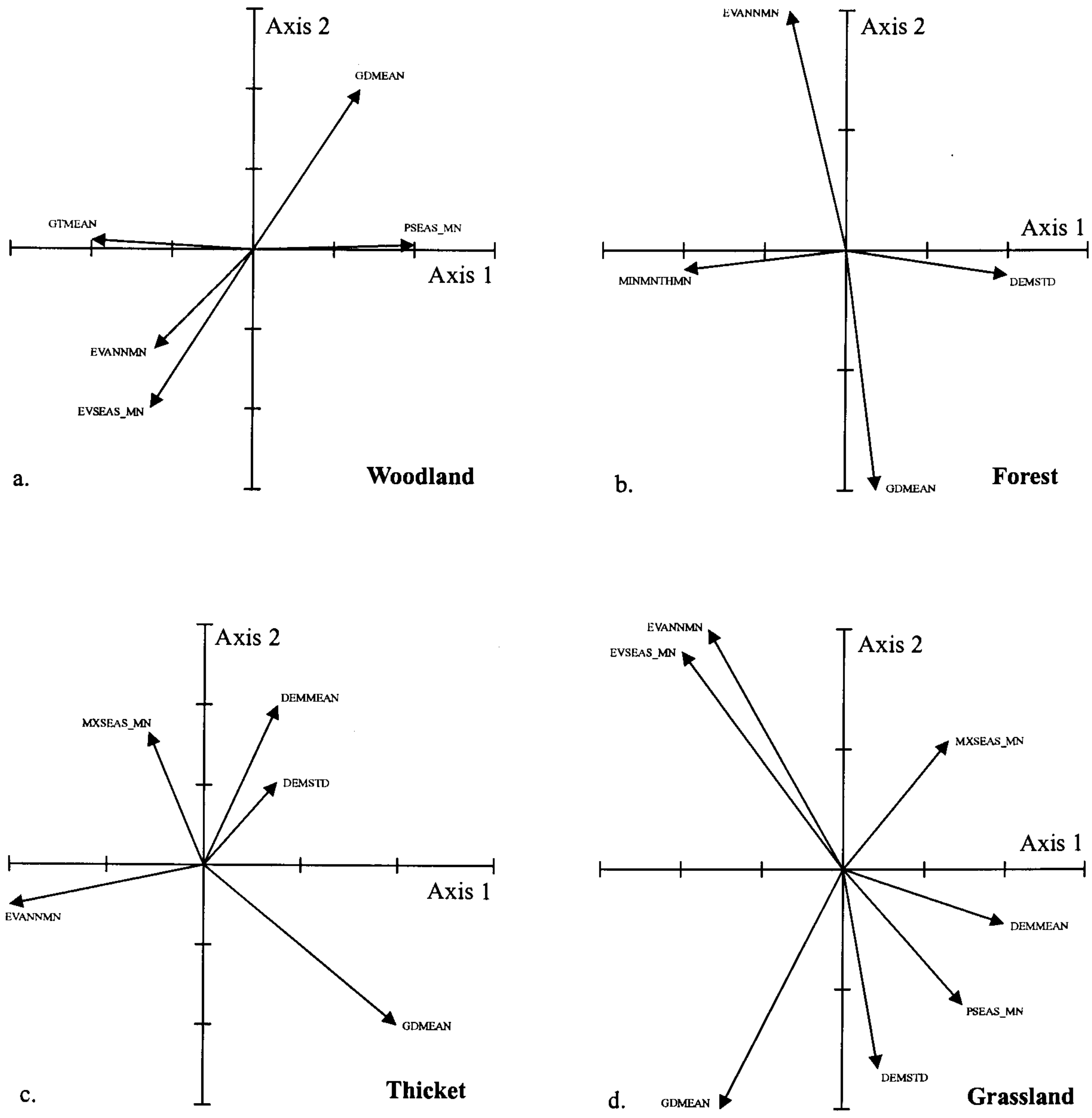

Figure 5.14: Biplots from canonical correspondence analysis of ecological habitat bird assemblages. All axes have been rescaled to range from –1.0 to 1.0. Axes for explanatory environmental variables that were not significant or that had very low correlations with the canonical axes are not shown.

In partial CCA conducted on the ecological habitat bird data sets, regional factors (climate and topography) accounted for the following in TVE: Woodland (47.6%); forest (46.4%); thicket (44.3%); and grassland (40.3%), with forest requiring the least amount of explanatory variables (Figure 5.14). The landscape class patch variables contributed to explaining a further 24.5% - 31.4% amongst the ecological habitat bird assemblages (Table 5.11), overall this is significantly higher than for the life history bird assemblages. The variable set included not only class patch pattern characteristics by vegetation type but also the proportion of human land-use and transformation impact indicators. Woodland and grassland bird variation responded more

Table 5.11: Proportion of total variation explained (TVE) by landscape variables while constrained by the topography and climate variables chosen for each group type in partial canonical correspondence analyses (CCAs) of ADU bird species; the three greatest landscape contributors to remaining TVE after constraining by the topography and climate variables in each group type are show in boldface. †

	Additional variation explained (proportion of TVE explained after constraining by covariables)			
	Woodland	Forest	Thicket	Grassland
Partial CCA TV	0.430	0.477	0.529	0.536
Variable				
Landcover				
POPTOT96	‡	§	‡	‡
POPDEN96	‡	§	‡	§
LOWI_PER	0.015	‡	0.01	‡
PLNT_PER	‡	**0.02**	‡	0.01
DRY_PER	‡	‡	‡	0.01
IRR_PER	‡	0.01	‡	‡
URB_PER	‡	**0.04**	**0.03**	**0.03**
M_PER	‡	‡	‡	‡
T_PER	**0.02**	‡	‡	‡
T_TOTAL	‡	‡	0.01	0.01
ROAD_INDEX	0.01	‡	**0.01**	0.01
Patchiness				
%LAND	‡	**0.02**	‡	‡
LPI	0.01	‡	‡	‡
NP	**0.02**	0.01	‡	‡
PD	**0.02**	‡	‡	‡
MPS	‡	‡	‡	0.01
PSSD	§	‡	‡	**0.02**
PSCV	§	‡	‡	‡
Shape				
MSI	‡	§	‡	‡
AWMSI	0.01	§	0.01	§
MPFD	‡	§	‡	‡
AWMPFD	§	0.01	‡	**0.01**
Interior				
CADI	‡	‡	‡	‡
TCA	‡	‡	‡	0.01
NCA	§	‡	‡	‡
CAD	0.02	‡	‡	0.01
MCAPP	‡	‡	‡	0.015
PCASD	‡	‡	‡	‡
PCACV	‡	0.01	‡	‡
MAPDC	‡	‡	‡	0.01
DCASD	‡	‡	‡	‡
DCACV	‡	‡	0.01	‡
TCA%	‡	‡	**0.04**	‡
MCA%	‡	0.01	0.01	‡
Isolation				
MNND	‡	‡	‡	‡
NNSD	‡	‡	‡	‡
NNCV	‡	‡	‡	‡
MPI	‡	0.01	0.01	‡
II	‡	‡	‡	0.01

† Same rules as for Table 5.8.

‡ Variable was not significant in the stepwise procedure.

§ Variable was significant in the stepwise procedure but excluded because of multi-collinearity.

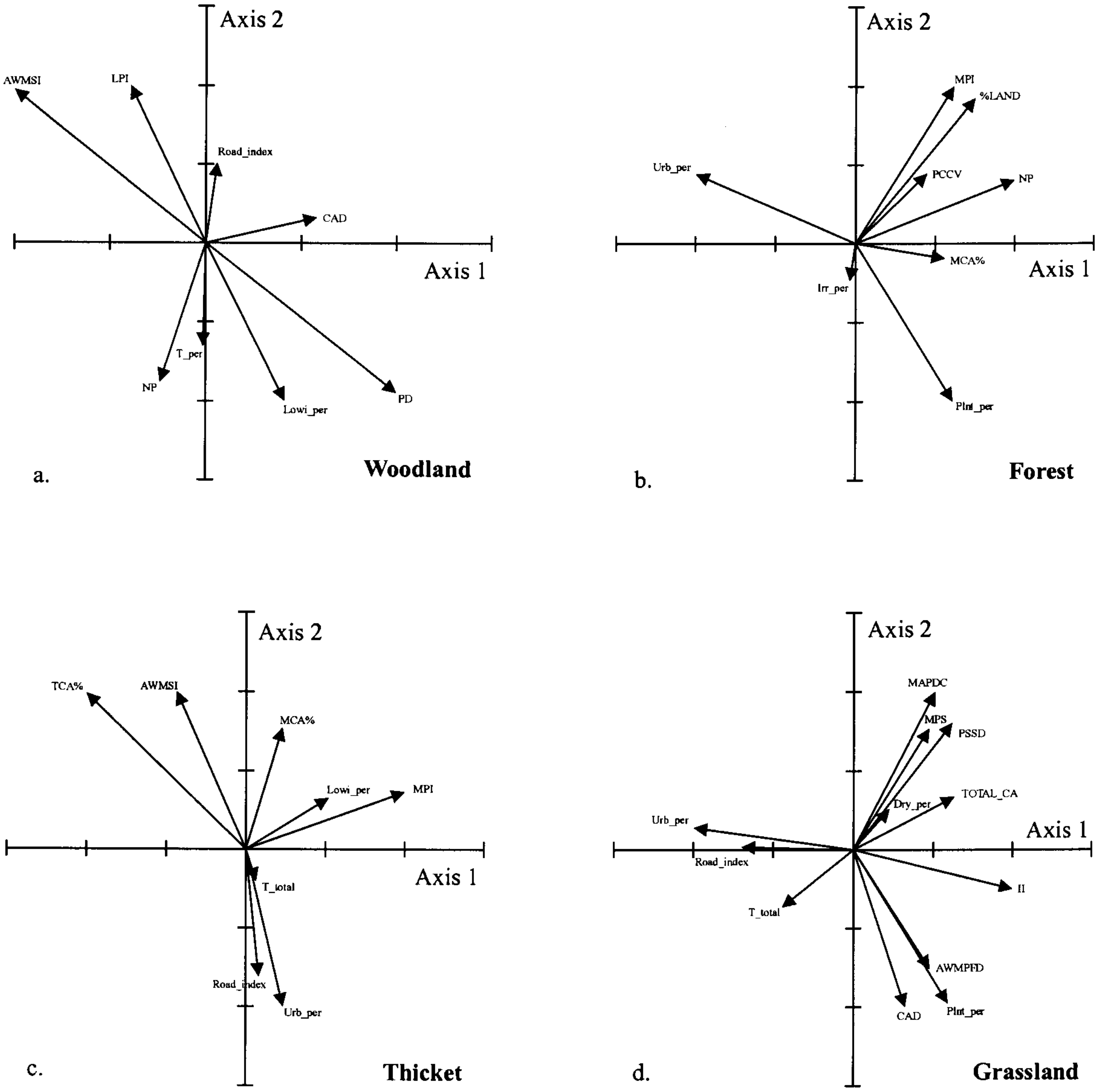

Figure 5.15: Biplots from canonical correspondence analysis of ecological habitat bird assemblages. All axes have been rescaled to range from –1.0 to 1.0. Axes for explanatory land-cover class type variables that were not significant or that had very low correlations with the canonical axes are not shown.

to the pattern metrics than to the human transformation indicators. The forest and thicket birds reacted mostly to variations in human transformation indicators. Overall the metrics explained 31.4% in woodland (Figure 5.15a), 28.3% in forest (Figure 5.15b), 24.5% in thicket (Figure 5.15c), and 27% in grassland (Figure 5.15d) bird variations. Grassland birds required the most variables to fit the remaining TV. The trend in the results suggests that as vegetation becomes more 2D in structure, i.e. trees to grass, the pattern metrics explain less of the local variations in birds. Forest, thicket, and grassland bird variation was related strongly to the extent of urbanization in the habitat class, and exotic tree plantations affected forest birds more strongly than grassland birds. Woodland birds were affected by total woodland removal, along with the number and density of the available woodland patches. Thicket bird variation was related to road disturbance and the total amount of thicket patch core area available. Grassland bird variation also related to the variability in patch size distribution of grassland patches and the shape complexity of the available patches which was related to the amount of exotic plantations in the area.

5.5.2.2 Correlation Results

These results only pertain to the ADU data sets for which biodiversity measures of assemblage structure could be calculated. Analysis by identify assemblage class within the life history bird assemblages, as derived from the ordination analysis, provides an ecological basis for the analysis from which landscape level descriptions can be made. Table 5.12 provides a breakdown of the biodiversity measure relationships to human impact for each assemblage class identified within a bird assemblage group. In almost all cases the identified East Coast and Midlands communities of each of the bird assemblages is tending towards single species dominance with a negative correlation with high intensity transformation. The correlations are even higher when compared to the road disturbance index. Exceptions include the negative correlation between high intensity transformation and evenness for the Central Zululand community of passerines, Maputaland community of non-human influenced birds, and high grasslands community of human influenced birds. The negative trends in evenness occur once grid cells in a community group record high intensity transformations of greater than 60%, which has been noted as a fragmentation transition point in other analyses (Andren, 1994; With and Crist, 1995; Bascompte and Sokal, 1996). High intensity transformation and road disturbance effects would appear to be the most important general indicators to monitor and assess the fate of bird assemblage structure. Again, the assessment of these relationships at the community extent has species richness positively correlated with high intensity transformation for many of the bird groups and assemblage groups. Exceptions to this relationship occur among the passerine and human influenced bird assemblages. Another notable exception is the Drakensberg Escarp community of non-human influenced birds, which is shown to be negatively associated with high intensity transformation and road disturbance. This alpine bird community type is not only sensitive environmentally but the majority of the birds are negatively influenced by human disturbance.

The relationship of low intensity transformation to species richness documents the negative effects of habitat degradation to overall species richness in all bird assemblages and the majority of assemblage classes were the phenomena is present. Reducing habitat quality is detrimental to interior species and because it adds no new novel land-use types through total transformation there is no immigration of edge dwelling and generalist species. This problem leads to a general reduction in sensitive species and a therefore a general evenness in bird assemblage for the areas were there was natural tendency towards single species dominance, i.e.,

Table 5.12: Pearson correlation coefficients for comparison of species richness (SR), Shannon diversity (H'), and evenness (E) against transformation and disturbance variables among classified groupings of ADU birds derived from ordination (DCA) and hierarchical classification. Human induced transformation data were square root-transformed before analysis to improve normality.[†]

	Low intensity transformation			High intensity transformation			Road disturbance index		
Community Group	SR	H'	E	SR	H'	E	SR	H'	E
All birds									
Maputaland	-0.44^{*}	-0.47^{*}	§	§	§	§	§	§	§
East Coast	§	§	§	$0.36^{\ddagger}$	§	-0.43^{*}	0.48^{*}	§	-0.68^{***}
Drakensberg	§	§	$0.31^{\ddagger}$	§	$0.29^{\ddagger}$	§	§	§	§
Central Zululand	-0.41^{**}	-0.28^{*}	§	$0.27^{\ddagger}$	§	§	0.37^{**}	§	-0.36^{**}
Midlands	-0.74^{***}	$-0.34^{\ddagger}$	0.42^{*}	0.61^{*}	§	$-0.43^{\ddagger}$	0.42^{*}	§	§
Summer									
Maputaland	-0.56^{**}	-0.56^{**}	§	§	§	§	§	§	$0.38^{\ddagger}$
East Coast	§	§	§	0.40^{*}	§	-0.44^{*}	0.46^{*}	§	-0.64^{***}
Drakensberg Escarp	§	§	§	§	§	§	§	§	§
Central Zululand	-0.38^{**}	-0.30^{*}	§	§	§	§	0.42^{**}	§	§
Midlands	-0.73^{***}	-0.41^{*}	0.38^{*}	0.57^{**}	§	-0.41^{*}	0.38^{*}	§	§
Winter									
Maputaland	-0.44^{*}	$-0.36^{\ddagger}$	§	§	§	§	§	§	§
East Coast	§	§	§	$0.36^{\ddagger}$	§	-0.53^{**}	0.41^{*}	§	-0.74^{***}
Drakensberg	-0.35^{**}	-0.26^{*}	§	§	§	§	§	§	§
Midlands-Zululand	-0.65^{***}	-0.48^{***}	§	0.61^{***}	0.48^{***}	§	0.50^{***}	0.34^{*}	§
Passerine									
Maputaland	§	§	§	§	§	§	0.38^{*}	0.39^{*}	§
Drakensberg	§	§	$0.32^{\ddagger}$	§	§	§	§	-0.33^{*}	§
Central Zululand	-0.42^{**}	§	§	§	§	-0.37^{*}	0.38^{*}	§	$-0.28^{\ddagger}$
East Coast	$-0.32^{\ddagger}$	§	§	§	§	§	§	-0.48^{**}	-0.72^{***}
Midlands	-0.74^{***}	§	0.53^{**}	0.61^{**}	§	-0.42^{*}	0.44^{*}	§	§
Non-passerine									
Maputaland	-0.33^{*}	-0.37^{*}	§	§	§	§	§	§	§
East Coast	§	§	-0.43^{*}	§	§	-0.54^{**}	$0.35^{\ddagger}$	§	-0.73^{***}
Drakensberg	-0.40^{***}	§	§	0.37^{***}	0.36^{***}	§	0.36^{***}	0.35^{**}	§
Midlands	-0.62^{***}	-0.52^{**}	§	0.54^{**}	$0.33^{\ddagger}$	§	0.56^{***}	§	§
Breeding									
Maputaland	-0.39^{*}	-0.39^{*}	§	§	§	§	0.37^{*}	0.44^{**}	§
East Coast	§	§	§	$0.35^{\ddagger}$	§	§	0.43^{*}	§	-0.49^{**}
Drakensberg	§	§	0.34^{*}	§	§	§	§	§	§
Central Zululand	-0.40^{*}	§	§	§	§	§	0.36^{*}	§	§
Midlands	-0.70^{***}	-0.37^{*}	$0.32^{\ddagger}$	0.61^{***}	§	-0.37^{*}	0.42^{*}	§	§
Non-breeding									
Woodland	-0.41^{*}	§	§	§	§	§	§	§	§
Wet Grasslands	-0.27^{*}	§	§	0.33^{**}	§	§	0.37^{**}	§	§
East Coast	§	-0.44^{*}	$-0.35^{\ddagger}$	§	§	§	0.42^{*}	§	§
Dry Grasslands	-0.52^{***}	-0.43^{**}	§	0.39^{*}	0.36^{*}	§	$0.25^{\ddagger}$	0.29^{*}	§
Human									
Maputaland	§	§	§	§	§	§	§	§	§
Drakensberg Escarp	$-0.34^{\ddagger}$	§	§	§	0.40^{*}	§	§	§	§
High Grasslands	-0.31^{*}	§	0.40^{**}	§	§	-0.29^{*}	§	§	§
Central Zululand	-0.35^{*}	-0.34^{*}	§	§	§	§	$0.32^{\ddagger}$	§	§
East Coast	§	§	§	0.71^{***}	0.60^{*}	§	0.57^{*}	§	-0.68^{**}
Non-human									
Maputaland	$-0.45^{\ddagger}$	-0.43^{*}	§	§	§	$-0.36^{\ddagger}$	§	§	§
East Coast	§	§	§	§	§	§	§	§	§
Drakensberg Escarp	§	§	0.50^{*}	-0.46^{*}	-0.52^{*}	§	§	$-0.42^{\ddagger}$	-0.48^{*}
Highlands	§	§	§	§	§	§	§	§	§
Midlands	-0.47^{**}	§	§	0.60^{***}	§	§	0.43^{*}	§	§
Coastal Hinterland	-0.53^{**}	-0.38^{*}	§	$0.31^{\ddagger}$	§	§	$0.35^{\ddagger}$	§	§

[†] Significance is denoted by the following: § not significant, ‡ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Drakensberg and Midlands. The East Coast bird assemblages for non-passerine and non-breeding birds have the only negative relationships of evenness to low intensity transformation.

5.5.2.3 Semi-variogram Results

Empirical semi-variograms were generated for each biodiversity measurement and human impact measurement, while also including a road disturbance index (Stoms, 2000; Reyers et al., in review) and the 1996 human population density. The analysis results are only for the ADU data sets, documenting the influence of extent on the variables from the identified assemblage class per bird life history group as derived from the ordination analysis. The same distance resolution of 22.5 km between grid cell centers was used to calculate the variograms. Range values where a flat sill is reached, which represents the autocorrelation pattern for each variable by assemblage class within a life history bird assemblage are provided in Table 5.13.

The semi-variogram estimates for most of the measures are bounded. As can be seen from the table, ranges with small local distances describe small autocorrelated patches in the distribution of low and high values of the measures. Large distances describe large uniform patches of uniform autocorrelated low or high values. Five situations had flat variograms (pure nugget) that depict those variables as random processes across the extents defined in the model. Focusing on all, summer and winter life history groups in Table 5.13 the winter groups measures and assemblage class extents tend to yield fine grained pattern, while the summer group generally has larger coarse grained pattern. Considering all the birds in the province further increases the coarse grained pattern in each of the assemblage classes. The trend in spatial pattern for the biodiversity measures in the other bird assemblages shows all but non-passerine bird assemblages as being generally coarse grained. A comparison between the spatial extents of evenness and high intensity transformation for the assemblage classes with negative relationships shows a trend in decreased correlation strength when the high intensity transformation pattern is larger grained than the evenness pattern. This pattern is also similar with comparisons against the road disturbance index. Any general trends in the relationship between species richness and high intensity transformation could not be discerned as changes were confounded by the changing extents among assemblage classes by bird assemblage group.

5.5.2.4 Association Analysis Results

Kappa index values and χ^2 tests were computed for each grid cell and bird assemblage between the two survey periods (1970-1979 and 1987-1992). Figure 5.16 provides a breakdown of the classified Kappa index values with indications of χ^2 tests that were not rejected (H_0: grid cells from two time period are dissimilar).

Table 5.13: Semi-variogram derived distances (kilometers) of spatial dependence for species richness (SR), Shannon diversity (H'), evenness (E), low intensity transformation (LI), high intensity transformation (HI), total transformation (TT), road disturbance index (RI), and 1996 population density (PD96) among classified groupings of ADU birds. †

Community Group	SR	H'	E	LI	HI	TT	RI	PD96
All birds								
Maputaland	45.0	112.5	157.5	157.5	90.0	157.5	67.5	157.5
East Coast	360.0	22.5	405.0	22.5	270.0	270.0	337.5	22.5
Drakensberg	337.5	337.5	292.5	337.5	45.0	337.5	22.5	90.0
Central Zululand	112.5	225.0	225.0	22.5	225.0	112.5	225.0	180.0
Midlands	135.0	22.5	235.0	112.5	180.0	180.0	22.5	112.5
Summer								
Maputaland	45.0	22.5	112.5	22.5	22.5	22.5	22.5	157.5
East Coast	405.0	22.5	405.0	22.5	202.5	270	405.0	22.5
Drakensberg Escarp	337.5	315.0	180.0	337.5	247.5	337.5	22.5	90.0
Central Zululand	135.0	180.0	225.0	22.5	225.0	112.5	225.0	180.0
Midlands	135.0	135.0	135.0	112.5	135.0	202.5	22.5	112.5
Winter								
Maputaland	45.0	45.0	22.5	22.5	90.0	112.5	22.5	157.5
East Coast	382.5	405.0	337.5	22.5	247.5	270.0	292.5	22.5
Drakensberg	157.5	337.5	337.5	337.5	247.5	45.0	22.5	22.5
Midlands-Zululand	67.5	45.0	22.5	67.5	22.5	337.5	337.5	22.5
Passerine								
Maputaland	22.5	112.5	180.0	22.5	180.0	180.0	180.0	157.5
Drakensberg	157.5	157.5	112.5	337.5	247.5	247.5	22.5	90.0
Central Zululand	112.5	225.0	225.0	67.5	225.0	112.5	225.0	112.5
East Coast	22.5	22.5	45.0	22.5	22.5	135.0	157.5	22.5
Midlands	112.5	22.5	135.0	112.5	22.5	225.0	225.0	225.0
Non-passerine								
Maputaland	67.5	22.5	202.5	22.5	202.5	‡	202.5	90.0
East Coast	22.5	22.5	405.0	22.5	247.5	270.0	292.5	22.5
Drakensberg	67.5	67.5	337.5	292.5	90.0	292.5	337.5	157.5
Midlands	135.0	112.5	112.5	22.5	45.0	157.5	202.5	22.5
Breeding								
Maputaland	225.0	225.0	225.0	22.5	180.0	180.0	180.0	225.5
East Coast	405.0	‡	22.5	22.5	247.5	270.0	292.5	22.5
Drakensberg	337.5	‡	22.5	337.5	22.5	337.5	22.5	90.0
Central Zululand	202.5	202.5	202.5	90.0	157.5	22.5	202.5	22.5
Midlands	22.5	135	135.0	22.5	157.5	22.5	202.5	22.5
Non-breeding								
Woodland	67.5	247.5	‡	202.5	315.0	315.0	292.5	270.0
Wet Grasslands	67.5	292.5	202.5	225.0	22.5	202.5	22.5	22.5
East Coast	22.5	22.5	22.5	22.5	247.5	270.0	292.5	270.0
Dry Grasslands	202.5	157.5	247.5	270.0	22.5	22.5	157.5	180.0
Human								
Maputaland	22.5	247.5	202.5	22.5	247.5	247.5	247.5	247.5
Drakensberg Escarp	157.5	‡	180.0	315.0	247.5	315.0	22.5	67.5
High Grasslands	135.0	202.5	22.5	315.0	22.5	112.5	180.0	135.0
Central Zululand	157.5	157.5	202.5	202.5	22.5	202.5	22.5	202.5
East Coast	292.5	292.5	67.5	22.5	135.0	180.0	202.5	22.5
Non-human								
Maputaland	45.0	22.5	45.0	157.5	90.0	157.5	67.5	157.5
East Coast	247.5	22.5	22.5	22.5	247.5	270.0	337.5	22.5
Drakensberg Escarp	337.5	180.0	337.5	337.5	157.5	337.5	135.0	247.5
Highlands	157.5	157.5	22.5	270.0	202.5	270.0	157.5	22.5
Midlands	157.5	202.5	22.5	22.5	157.5	202.5	270.0	22.5
Coastal Hinterland	22.5	337.5	337.5	22.5	180.0	180.0	247.5	202.5

† Semi-variogram models have been fit using a spherical function.

‡ Variable represented a completely flat variogram (pure nugget), meaning no spatial dependence in the data, i.e. no discernible pattern, and that deriving a semi-variogram is inappropriate.

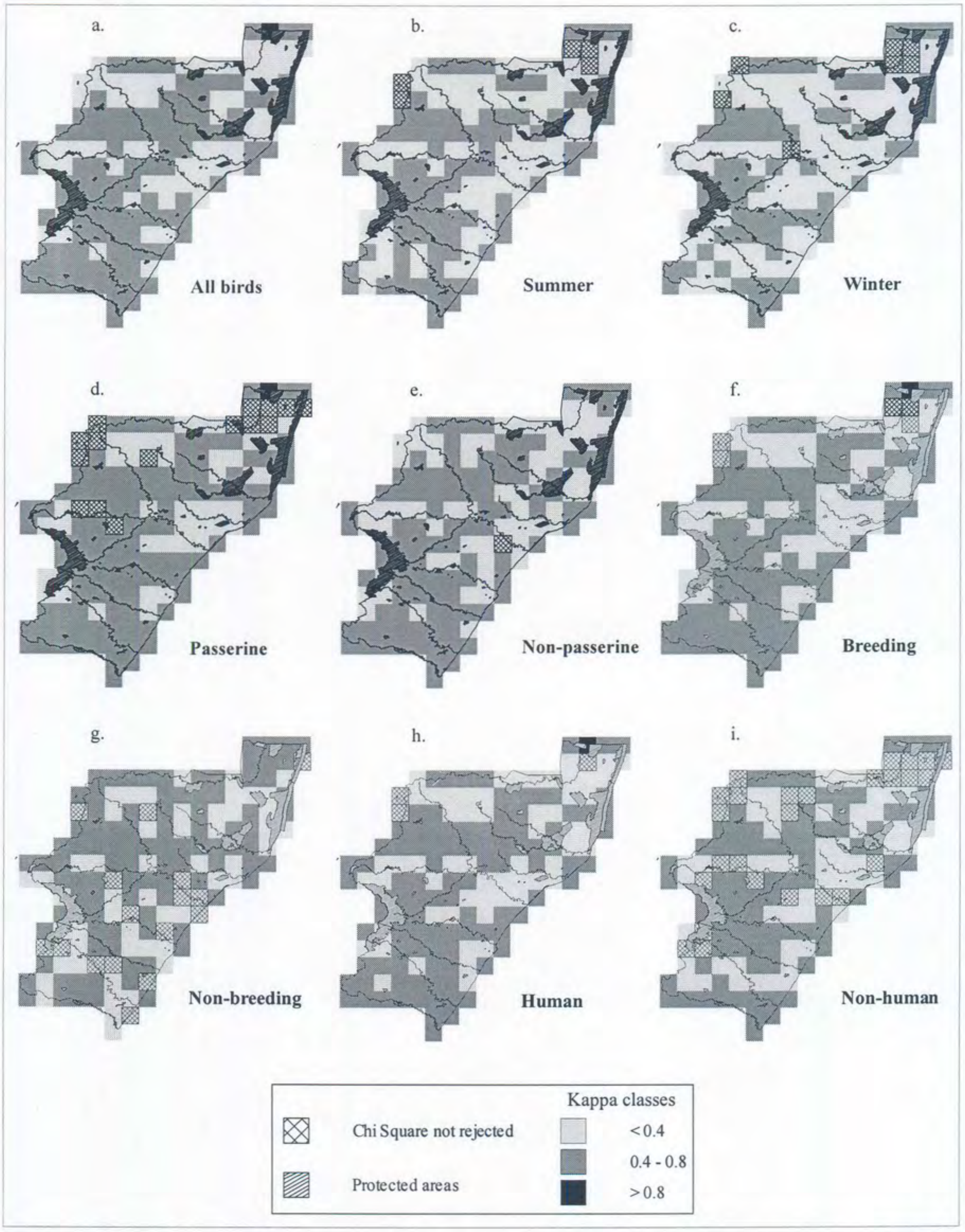

Figure 5.16: Kappa coefficient maps of each comparison between CR and ADU surveys and life history bird assemblages.

The summer, winter and non-human influenced bird assemblages have ≥ 50% of their grid cells with Kappa values < 0.4, which equates to agreements no better than chance. The only grid cell to have almost perfect agreement (> 0.8) with all, passerine, breeding and human influenced birds covered the Ndumo and Tembe nature reserves on the Mozambique border in Maputaland. This grid cell is remote, > 50% protected and the lands on the Mozambique side were in a near pristine condition with little to no human habitation during the bird census periods. Areas of moderate to substantial agreement for all bird assemblages tend to contain protected areas, are in remote regions, or have continued with substantial levels of either low intensity or high intensity development since prior to 1970. It is possible that bird inventories had either already changed prior to 1970 to a stable inventory in the previously developed areas (coastal areas in and around Durban and Pietermaritzburg since 1911) or no changes in "natural" areas up to 1992. Many of the high intensity developed areas were that way before at least 1970 (Midlands, Durban and coastal regions), while the low intensity developed areas could have expanded between census periods due to the demarcation of the KwaZulu homeland areas during the mid-1970s. Several areas are consistently represented with dissimilar bird inventories (< 0.4) for all the bird groups. These areas were also the ones targeted for development between the two governments (Republic of South Africa and KwaZulu government) between the census periods (Fair, 1975; South African Government, 1975; Thorington-Smith et al., 1978). These areas consist of the coastal and coastal hinterland regions south of Umfolozi game reserve, the areas south of Ndumo and Tembe nature reserves on the Maputaland plains, grid cells to the west of Pongola dam along the Pongola River, grid cells in the Newcastle, Vryheid and Utrecht areas, grid cells in the Bergville area and down along the Tugela River valley, and grid cells along the Pietermartizburg-Durban economic corridor fanning out north and south along the coastal hinterland. Appendix D provides a list of the birds found in the CR survey but not recorded in the ADU survey, and birds found in the ADU survey but not found during the CR survey.

5.6 Discussion

There is a growing recognition that biogeographic-scale studies are needed to gain a more comprehensive assessment of faunal response to anthropogenic disturbance. Because it is often impractical for individual investigators to collect the necessary biogeographic data (Kodric-Brown and Brown, 1993), one must rely on the independent efforts of others to develop relations. The use of comprehensive biological atlases, developed with consistent methodologies in surveying can help in this task. In this study, consistent methodologies were applied to examine two temporally distinct avian atlases, landscape structure and environmental variables. The two spatial extents of analysis provided useful insight into the avian assemblages relation to land-use intensity and pattern with spatial extent. While the two time periods provide the landscape dynamics for a selected region.

The ADU data supporting the spatial correlation and variogram analyses can be considered both comprehensive and reliable. While for South Africa the average number of bird checklists having been compiled for each grid was 30, KwaZulu-Natal Province was one of the most thoroughly surveyed regions during the atlassing effort, with an average of 105 bird check-lists having been compiled per grid cell in the province. The distributional data were also subjected to a rigorous vetting procedure by both experienced amateur and professional ornithologists. A quantitative testing against independent and more sensitive survey techniques (Allan, 1994; Robertson et al., 1995), also confirmed its reliability in reflecting relative abundance in terms of reporting rates. However, Harrison et al. (1997) do note that there were still problems in identification between species, consistency of species probability of being sighted in different habitats and the technique used in this chapter to dampen the effects of bias in recording effort cannot help in some areas of South Africa were reporting rate was less than 10 check-lists. Some may even argue that using cumulative data from a five year period is quite risky for vertebrate populations. Nevertheless, these challenges in using biological atlases should not deter from their importance for recording distributions and relative changes in bird assemblages, as their survey frameworks have the added advantages of representing less common species due to the longer survey period (Preston, 1948), which also has the added effect of not having to worry about high frequency spatial and temporal effects (Preston, 1960). In this case the averaging effects over any high frequency population changes due to the longer survey period should provide a clearer pattern of true compositional and structural changes due to large-scale land-use developments. However, the limitations noted will temper the results and discussion accordingly.

South Africa and KwaZulu-Natal correlation analyses.—Areas of high intensity human disturbance across South Africa and for each biome demonstrate the fragmentation process in developing new landscape mosaics and therefore changes in bird assemblages. Bird species richness increased, but the bird assemblage evenness across South Africa, and for the woodland and fynbos biomes showed a trend towards single species dominance. In contrast, the succulent desert biome showed increases in species richness and bird assemblage evenness. Each of these responding biomes has areas comprising urban residential, industrial, and commercial agriculture land-uses (Fairbanks et al., 2000), with fynbos, woodland, and then succulent desert ranked accordingly for the relative importance of these land-uses covering each biome. Urban, industrial and commercial agriculture forms of land-use lead to structural habitat changes (i.e., tree planting, water impoundments, infrastructure) that appear to positively influence the number of bird species found, but would also promote selected species dominance in those species adaptable to the new environments. This trend towards single species dominance may not require reduced sightings of rare species, but may simply reflect increasing populations of species that thrive in modified human landscapes due to their specific life-history requirements. These patterns, however, appear to be intimately tied to the evolving natural-urbanizing landscape. In contrast low intensity disturbance has a negative effect on the species richness of birds in the grassland biome, but a positive effect on birds in the shrub steppe. As opposed to degraded woody biomes where some level of tree or shrub structure remains, degraded grassland is highly detrimental to bird richness. In the shrub steppe biome the opening up of shrub patches from heavy grazing, which would allow for an increase in mosaic diversity (i.e., shrub, grass, and bare) appears to have a positive effect on bird richness. The woodland biome is typically over grazed and coppiced for fuelwood in South Africa (Fairbanks, 2000), which appears to cause a trend towards dominance in the assemblage structure.

The South African and biome extent analysis shows that species distributions and assemblage patterns change between natural and highly transformed areas. First, species richness increases and peaks in areas with optimal environmental resource levels containing a high proportion of highly transformed land. Secondly, the relative evenness of bird assemblages' decrease from natural to more highly transformed areas. This suggests that high intensity transformation may bring in novel resources for birds not normally found in areas, but that this does not directly translate into evenly structured communities. It appears that some species (high intensity transformation exploiters) are adept at exploiting these changes and reach their highest densities with a tendency for assemblage structure to drift towards single species dominance.

The correlation analysis amongst biodiversity measures and land transformation values by identified assemblage class in KwaZulu-Natal provided further support for the preponderance of species assemblages with negative relationships to human disturbance patterns. Also, since assemblage structure and total bird species richness summarizes a composite response of the habitat needs of individual species (Hansen and Urban, 1992), the performance of separate spatial correlation analysis for the main life history groups of birds allows to increase the predictive power of the model. Two community assemblages identified in several of the bird assemblages show this relationship: The East Coast assemblage is tending towards single species dominance in all, summer, winter and non-passerine bird assemblages, and the Midlands assemblage in all, summer, passerine, breeding, and human bird assemblages (Table 5.11). Two other communities were identified once for two bird groups: Central Zululand for passerines and Maputaland for non-human influenced birds. The non-human influenced bird assemblage structure in Maputaland could be a serious problem. These birds are neutral or negatively influenced by human activities. The Maputaland region represents South Africa's only link to the Afrotropical avifauna (Harrison et al., 1997) and therefore a greater share of the sensitive species in the region. The results in Table 5.11 show a tendency towards reduced species richness for low intensity disturbance and towards single species dominance under high intensity transformation for areas < 30% transformed. Another important aspect is the affect road disturbance has on the biodiversity measures by bird assemblage. Generally there is a similar positive relationship of roads to species richness as there is for high intensity transformation, and a negative relationship to evenness. However, these results should be interpreted cautiously as the species inventorying may be partly affected by road bias (e.g., Freitag et al., 1998), even though surveying procedures were developed to avoid this bias during the development of both atlases. Therefore, there is no reason to expect potential errors or biases to be systematically or non-randomly distributed throughout the country.

Changing the spatial extent and scale of the correlation analysis in a meaningful manner between national, vegetation biome, and ecologically identified sub-regional assemblages brought to bear important relationships regarding pattern and process. The importance of space has become a paradigm in many fields of ecology. Studies in community ecology, biodiversity, landscape ecology, and biogeography all rely on the analysis of spatial patterns. It is well known that the spatial pattern that we observe depends on the scale of the study (Wiens, 1981; Wiens, 1989b), which is conveniently summarized by its grain or resolution and by its spatial extent. While the effect of grain size has been formally explored in many studies (Turner et al., 1989), the effect of spatial extent has not always been thoroughly considered. However, this study illustrates the crucial role spatial extent can play for prominent operational definitions of richness, diversity, and community structure. The biome level results for birds incorporate a lot of variation in the biodiversity measures in association with the spatially structured response of the human transformation activity. Therefore, the results at this level of analysis are not as strong as the community level results for KwaZulu-Natal. This is probably because the bird communities, as shown in the ordination analysis, are being shaped more by the human developed land-covers at this scale rather than general vegetation characteristics (i.e., grassland or woodland). The identified communities would seem to provide a more appropriate measure of each bird groups relationship with the degree of human disturbance in a particular area. However, as identified for the national level analysis, the patterns of the birds in each group do not seem to be consistent with the intermediate disturbance hypothesis for human land-use as proposed by McDonnell et al. (1993). Therefore the results at the community extent of analysis provides little support for this suggested pattern, except for possibly the Drakensberg Escarp community of the non-human influenced birds. The smaller extent of analysis did provide some empirical support for the theoretical results found from percolation theory, which has been used to describe multi-species persistence in simulated fragmented landscapes (Gardner et al., 1987; Gardner et al., 1989;

Pearson, 1993; Bascompte and Sole, 1996). In all of the negative associations for evenness versus high intensity transformation the regression line was pulled down once sampling sites within the population were > 60% transformed. The positive relationship between species richness and high intensity transformation occurred when grid cells were > 40% transformed.

This pattern for South African birds is not consistent with the intermediate (natural) disturbance hypothesis (Connell, 1978) or with its extension (McDonnell and Pickett, 1990; McDonnell et al., 1993) to include human land-use. It has been suggested that species richness should peak at intermediate levels of human landscape development because biotic limitations are high in natural landscapes and physical limitations high in highly transformed landscapes (McDonnell et al., 1993). These results, at the coarse grid cell scale of analysis, provide little support for this suggested pattern in South African birds, and may instead provide some support for declining assemblage evenness regimes among cumulative local scale bird communities within a grid cell in response to high intensity transformation. The correlation slope increase in species richness appears to be significant once greater than 40% of the land-cover within a grid cell is transformed to high intensity land-uses. This situation would allow for both new human adaptable exploiters and the remnant natural vegetation related birds to co-exist, but with increasing high intensity land transformation the transformation exploiters appear to become dominant in the landscape. However, in the absence of land-use time series, interpretation is difficult since the rate of land-use change may be high in the woodland, grassland, and fynbos biomes (e.g., Fairbanks et al., 2000).

The use of the index of relative abundance tells us something of the changes of numerical relationship between two or more species, but nothing on the true abundance of each of them. If species #2 becomes much more numerous, it does not imply that species #1 is less abundant than before but only that species #2 has become more abundant. Therefore, an uneven assemblage in a high transformation area is not necessarily an impoverished community, but rather one that has a few species that are overly abundant in comparison to the total assemblage within an area. The potential causes for the correlations between species richness and high land-use intensity could be a function of time since transformation (i.e., recently transformed areas being richer than previously transformed areas), apparent increase due to better sampling, or to compositional or habitat differences in highly transformed versus un-transformed local scale communities that alter conspicuousness between land-use types. The apparent increase in species richness and decrease in assemblage evenness for some of the biomes may be due to maintenance of species richness in untransformed fragments in highly transformed grid cells combined with species that exploit transformed habitats well in the transformed areas (Quinn and Harrison, 1988). The pattern explored could be highly dependent on the scale and homogenizing character of grid cells on local scale bird community attributes (Wiens, 1981; Wiens, 1989a).

South Africa and KwaZulu-Natal geostatistical analyses.--Variograms also provide valuable information on the ability to sample and characterize bird assemblages at the defined grid cell resolution. The semi-variograms provide information on the spatial autocorrelation of the bird assemblage measures within each biome. Distances less than the sill derived range values are spatially autocorrelated and thus provide information about the processes and structures of the bird assemblages. The evenness assemblage measure derived for the grassland biome shows that to correctly characterize the bird assemblage structure in grassland the sampling resolution would need to be smaller than the current grid cells used for biological atlasing in South Africa. This result for grassland bird fauna may mean that characterizing birds using fine scale survey data may be required to completely understand their distributions and abundance, especially in response to land-use impact. This is important as the grassland bird species are tending towards the same problems as the fynbos species (Table 5.2), thus the current analysis may be limited because of scale. Nevertheless, the measures for all the other biomes confirm that the grid cells used for sampling are a small enough grain size to characterize the bird groups.

The variogram results for the KwaZulu-Natal provide more power in explaining the grain pattern of the life history bird assemblages within ecologically defined zones. An important aspect of the analysis points out the ecological extent of these bird assemblages against the land-use development within the assemblage classes. Most of the bird assemblages generally have a coarse autocorrelated measurement similarity across the zones, but this is not the case for species richness in non-passerine and non-breeding birds which tends to show fine scale detail. The non-passerines include the raptors, kingfishers, cranes, rollers, etc. These birds tend to have very specialized habitat requirements (i.e., river frontage, wetlands, cliffs) and are not as abundant or gregarious as the passerines. The non-breeding birds are Afrotropical and Eurasian visitors that also have special habitat requirements (e.g., blue swallow in mist belt grassland; European swallow in areas providing cliffs). Therefore, both assemblage types will tend to congregate at very specific locations producing fine scale species richness patterns. The results of the geostatistical analysis confirm the special landscape management nature that these birds would require for population persistence. The evenness index generally illustrated coarse grain pattern, except for several assemblage classes within the non-human influenced bird assemblage. The fine grained pattern in evenness structure occurs in assemblage classes that are dominated by high intensity transformation, which could reflect the fine scale abruptness in assemblage structure these birds reflect owing to their mainly negative relationship to human activity.

KwaZulu-Natal bird ordination and survey association analysis.—Ordination analysis of KwaZulu-Natal Province birds provided insight into the unique bird assemblage structures that have evolved within the region. Comparisons between the two survey periods highlighted several important changes in bird community structure over the 10-year period between surveys. Many of the shifts, contractions and splits in the assemblages are primarily associated with broad scale climate regimes and secondly to finer scale habitat patchiness and human land-use impacts. In particular the creation of woody patches of alien trees in the grasslands, the addition of water impoundment's, dryland agriculture, and urbanization have all played a part in changing the geography of bird distributions. This was reflected in the general decrease of the gradient lengths for each species assemblage, with the more recent ADU survey reflecting the homogenising affects land-cover changes are having on bird diversity. Comparisons between Figures 5.6 and 5.7 show several general trends: thinning of the East Coast bird zone around Richards Bay, compaction and stretching of the Maputaland zone southwards, shrinking of the Drakensberg zone, and a general split in the Midlands zone from the CR period into a Midlands and Central Zululand zones during the ADU survey. Several hypotheses could be driving these changes. First, rainfall varies above or below the mean in approximately 10-year cycles (Dyer and Tyson, 1977) in the region, with the CR survey coinciding in with a pluvial cycle and the ADU survey coincided with a dry and in some areas drought cycle. Therefore, species responding to this wet cycle could have moved into KwaZulu-Natal down along the Mozambique coast, or some species from the dry interior of South Africa could have moved in during the ADU period. Second, an increase in land transformation within the economically active areas along the coast and Midlands could have added more artificial habitats for transformation exploiters to distribute against (Figures 5.6h and 5.7h), or alternatively sensitive species could have withdrawn from those areas into the underdeveloped Zululand region (e.g., Winterbottom, 1962). Finally, there is still the possibility that despite the thorough surveys conducted in both periods, a majority of the species could still reflect biased distribution estimates.

Elevation contributed more to total variation explained (TVE) than any other variable (Tables 5.7 and 5.8). However, elevation is a complex-gradient (sensu Whittaker, 1960; 1965) that co-varies with a host of historical and environmental factors such as vegetation and climate. Therefore, in many of the datasets the elevation gradient was collinear with climate variables, such as minimum temperature. Nevertheless, the strong association between elevation and species composition observed in both sampling periods is consistent with other studies (e.g., Liversidge, 1962; Brown and Barnes, 1984).

One could debate excluding elevation from the analyses because it measures spatial position and only indirectly reflects physical environment. Excluding DEMMEAN from stepwise

CCAs, however, did not appreciably affect TVE, probably because of multicolinearity with other climate measures, nor the relations among species, grid cells, and explanatory variables. This robustness to multicolinearity among explanatory variables is a strength of CCA (Palmer, 1993). Therefore, DEMMEAN was retained in the analyses because of its value in interpreting results.

Results for the gradient analysis supported the hypothesis of primary importance of macroclimate and the secondary role of land-cover proportion and pattern in controlling regional compositional gradients in the bird diversity of KwaZulu-Natal. These findings can only be compared indirectly with previous studies because of differences in methods. Similar type studies in North America used plot sampling or linear sampling along predefined road transects, and examined relative contributions of regional climatic measures and plot based vegetation pattern statistics or coarse-scale land-cover (Flather, 1996; Wiens and Rotenberry, 1980; Rotenberry, 1978; Wiens, 1973; McGarigal and McComb, 1995; Flather, 1996; O' Connor et al., 1996).

Evapotranspiration, seasonal variability and extremes in climate were more important in explaining species gradients than were mean annual climatic conditions. The two dominant species gradients were associated with elevation, which integrates temperature extremes, seasonal variability in moisture and temperature related to the Indian Ocean and escarpment (continentality), and climatic gradients that integrate elements of both temperature and moisture. The importance of continentality in this study was consistent with Rotenberry's (1978) study that spanned a west-east gradient from Oregon to Colorado, although this present study spanned a much narrower latitudinal range (see also Cody, 1981; Cody, 1985; Cody, 1993). Species gradients for all groups and survey periods were much more strongly associated with minimum temperature during winter and moisture stress during summer. This association was consistent with observed correspondence between growing season precipitation and temperature gradients and latitudinal vegetation gradients in the grassland (Ellery et al., 1995) and woodland (Fairbanks, 2000) biomes of South Africa.

Topographic heterogeneity contributed slightly more to TVE for the non-breeding and non-human influenced bird groups in the CR datasets, but had a smaller contribution across all the ADU datasets (Tables 5.7 and 5.8). The CR datasets all responded more significantly to topographic heterogeneity than to evapotranspiration and seasonal variability's in temperature and precipitation. In the ADU datasets, only the gradients in human influenced birds showed significant relationships with topographic heterogeneity. In western KwaZulu-Natal, moisture is substantial and temperatures are colder and more variable, topography is deeply dissected from the rivers flowing off the Drakensberg Escarpment, and topographic effects would be more pronounced (Fairbanks and Benn, 2000).

Analysis of the birds grouped by ecological habitat associations and using their relative abundance values to examine relationships illustrated that the effects of elevation were only substantial for the thicket and grassland bird assemblages, and elevation heterogeneity was only significant for the grassland bird assemblage. These two vegetation types were found to extend across the entire province and thus reflect the strong gradient between coastal and Drakensberg Escarpment grassland and thicket type bird variation. Climate variables of temperature and evapotranspiration explained most of the variation in bird variation. Structural changes in woodland types between the arid woodlands of Maputaland and the mixed woodland of the Tugela and Buffalo River basins are largely determined by growing season temperature (Fairbanks, 2000). Growing season moisture stress accounted for the variation in forest and thicket associated birds, with minimum monthly temperature explaining the differences in bird community type in forest. This reflects the differences in forest structure and composition between the coast and afromontane forests of the Midlands and canyons along the Drakensberg Escarpment (Everard et al., 1995).

The findings on the influence of landscape structure variables on regional species gradients were not very conclusive with the life history bird assemblages and varied widely in importance with regard to remaining TVE (Table 5.9). Under partial CCA the landscape variables explained between 8.6-32% of TVE for the life history bird assemblages, with the most sensitive bird assemblages more significantly influenced. Non-breeding, non-human influenced and non-passerine bird assemblage gradients were associated the strongest with landscape variables. For all the bird assemblages, however, the proportion of land-cover was more important to TVE under the stepwise CCA than landscape mosaic pattern variables. There were several exceptions with class richness density having significance for all, summer, winter, non-passerine, non-breeding, and non-human influenced bird assemblages. LCLU evenness was important for the non-human influenced birds and the variability in patch size with distance was important for explaining the passerine assemblage. Contrary to the idea that landscape structure (i.e., configuration) plays a dominant role in the regulation of wildlife populations (e.g., Turner, 1989), these results suggest that LCLU proportion (i.e., habitat and land-use area) in southern African landscapes explain most of the TVE. Of the 9 life history bird assemblages studied, landscape variables typically explained less than half of the variation in presence/absence distributions among grid cells. Grassland, forest, subsistence agriculture, low intensity transformation, urban, and road disturbance percentages contributed significantly to the partial CCAs. In contrast, passerine, breeding and human influenced bird assemblage gradients were conspicuous by their "insensitivity" to variation in landscape structure with only 8.6-11.1% of TVE from the partial CCAs. The remaining data sets of all, summer and winter bird assemblages had moderate explanation and really only represent more homogeneous combinations of the other stratified bird assemblages. The moderate performance of the landscape structural variables may be explained by the CCA partialling procedure. Though partialling out covariables allows one to test other data without the confounding effects of other unwanted pattern. Those co-variables may have a confounding relationship with the new variables of interest and therefore reduce the explanatory power of the new variables, once they are removed. Table 5.14 presents the relationship of the primary environmental variables to the landscape structure variables. There are an abundance of collinear effects between DEMMEAN, MINMNTHMN and MXSEAS_MN and the landscape variables of interest. However, what is more striking in this table, is the strong presence of collinearity in bird species gradients (identified by environmental variables) and historical human development (identified by land-cover variables) within the province. The two biotic processes are competing and evolving together along the same environmental gradients. These results would suggest that policy makers and managers should consider emphasizing the landscape-avian diversity-human development relationship for defining and implementing conservation policy. Avian community structure seems to react well to changes in the landscape brought about by human development and therefore could be good monitoring agents (sensu Furness and Greenwood, 1993; Dufrene and Legendre, 1997).

These results also suggest that temperate migrants, non-passerines and species deemed neutral or negatively affected by humans are related to landscape structure in a way that is unique when compared to species from other functional groups. Past studies from North America have noted differences among migratory habitat categories with respect to population trends (Robbins et al., 1989b). Explanations for these differences include: differential susceptibility of Neotropical migrants to forest fragmentation (Robbins et al., 1989a); differential susceptibility of permanent residents, and to a lesser degree, tropical migrants, to severe weather (Robbins et al., 1989b); and the broader environmental tolerances expected in permanent residents (O'Connor, 1992). The patterns of association between the compositional gradients in bird assemblages and landscape structure (Table 5.9) seem to be consistent with these explanations. Flather and Sauer (1996) uncovered similar associations to landscape structure for Neotropical migrants in North America.

Analysis of the birds assembled by their association with ecological habitat, using relative abundance and patch level statistics of their habitat sharpened the relationships, with landscape structure explaining roughly half of the variation in abundance among landscapes. Examination by habitat association brought forth clearer results that tied in well with biome level results and past studies (e.g., Armstrong et al., 1998; Allan et al., 1997). The variation in woodland bird species related closely to gradients in high intensity land transformation, which related to fragmentation represented by the number of patches and the patch density. In relation to the other

Table 5.14: Spearman's rank correlations of landscape variables with the five important climate and topography variables from the ADU CCAs, by bird group. Values > 0.5 are in boldface.

Variable	Spearman's rank correlation				
	DEMMEAN	GDMEAN	MINMNTHMN	EVANNMN	MXSEAS_MN
POPTOT96	-0.27	0.04	0.25	-0.03	-0.42
POPDEN96	-0.26	0.05	0.25	-0.04	-0.43
FOR_PER	-0.49	-0.39	0.49	0.38	-0.24
GRS_PER	**0.81**	0.03	**-0.80**	-0.18	**0.71**
WET_PER	0.16	0.27	0.14	-0.02	0.02
LOWI_PER	-0.35	-0.25	0.34	0.10	-0.31
PLNT_PER	0.14	0.46	-0.11	-0.34	-0.18
DRY_PER	0.06	0.37	-0.07	-0.26	-0.22
IRR_PER	0.37	0.07	-0.39	-0.23	0.20
URB_PER	0.18	0.30	-0.21	-0.23	-0.01
M_PER	-0.32	-0.26	0.31	0.09	-0.29
T_PER	0.06	**0.51**	-0.06	-0.38	-0.27
T_TOTAL	-0.24	0.17	0.24	-0.18	-0.48
ROAD_INDEX	-0.17	0.21	0.15	-0.12	-0.35
LPI	**0.56**	0.06	**-0.53**	-0.14	0.47
NP	0.42	0.09	-0.40	-0.14	0.22
PD	0.14	0.37	-0.15	-0.23	-0.01
MPS	-0.14	-0.37	0.14	0.23	0.01
PSSD	**0.53**	-0.19	-0.51	-0.02	**0.50**
CI	**0.68**	-0.01	**-0.67**	-0.17	**0.54**
MSI	**-0.77**	-0.19	**0.76**	0.36	**-0.53**
AWMSI	**0.51**	-0.10	-0.49	0.02	0.42
FD	-0.35	-0.15	0.36	0.41	-0.12
MPFD	**-0.72**	-0.14	**0.71**	0.29	**-0.53**
AWMPFD	0.45	-0.12	-0.43	0.06	0.38
MCAPP	-0.09	-0.36	0.09	0.20	0.05
PCASD	**0.52**	-0.18	-0.49	-0.02	0.48
MAPDC	0.20	-0.30	-0.20	0.04	0.23
DCASD	**0.59**	-0.14	**-0.56**	-0.09	**0.51**
DCACV	**0.71**	0.12	**-0.68**	-0.24	**0.51**
MNND	0.03	-0.04	-0.06	-0.06	0.00
NNSD	-0.07	-0.11	0.05	0.04	-0.06
NNCV	-0.21	-0.18	0.23	0.22	-0.14
MPI	0.06	-0.19	-0.04	0.17	0.06
II	**-0.58**	0.14	**0.57**	0.03	**-0.51**
SHDI	**-0.68**	0.03	**0.66**	0.17	**-0.54**
SDI	**-0.67**	-0.03	**0.66**	0.19	**-0.53**
MSDI	**-0.67**	-0.03	**0.66**	0.19	**-0.53**
CR	-0.04	0.04	0.01	0.05	-0.02
CRD	-0.30	0.35	0.26	-0.08	-0.25
SHEI	**-0.69**	-0.02	**0.68**	0.18	**-0.54**
SEI	**-0.68**	-0.04	**0.67**	0.19	**-0.54**
MSEI	**-0.67**	-0.06	**0.66**	0.19	**-0.53**

habitat assemblages studied it would appear that woodland bird variations at the landscape level are highly related to structural relations brought forth at the landscape level from human impact.

This was noted as a factor in changing species richness and structure at the woodland biome level of examination. These results are similar to other bird-forestry studies conducted in North America (e.g., Askins et al., 1987; Derleth et al., 1989; McGarigal and McComb, 1995). Though always small in extent to begin with (e.g., Midgley et al., 1997), birds of indigenous forest habitat are being strongly affected by the amount of surrounding exotic tree plantations and urbanization. The size and number of patches of forest play an important part in the variation in bird species, but the surrounding human land-use matrix is overshadowing them. Thicket birds are also responding to increased levels of urbanization, which is being caused by actual urban extent and the dissection of habitat caused by roads, this leads the thicket birds to be sensitive to the amount of core area in thicket. Grassland bird variation is being influenced by urbanization, planations, and dryland agriculture, which creates gradients in patch size variability and increased flexibility in grassland patch shape. Grassland birds are the most sensitive functional bird group in South Africa, and respond strongly to changes in the continuous cover in grasslands required for their maintenance (Allan et al., 1997).

No single landscape descriptor is likely to consistently explain variation in assemblage composition across sets of landscapes. A descriptors explanatory power is probably a function of its range of variation, which typically increases with the area encompassed (Wiens, 1989b), as well as the biota's sensitivity to change in the descriptors. For example, elevation and elevation heterogeneity were dominant explanatory variables for bird variation recorded in the 1970s, but for the ADU birds they had a reduction in significance or were replaced with temperature related variables. Changing landscape structure (i.e., increased exotic trees in grasslands, development of dams, urbanization, etc.) may largely be changing the majority of bird distributions altering biotic pattern that were at one time closely related to broad environmental gradients. Although landscape structure was demonstrably strongly related to several species assemblage types, one cannot conclude that it was a dominant factor given the large amount of unexplained variation. Therefore, the limited evidence gathered so far for this region containing woodland, grassland, forest and thicket suggests that one should not blindly accept the landscape structure hypothesis described in the introduction. Habitat configuration and subdivision undoubtedly play a role in regulating population dynamics, but the magnitude and nature of this role may vary geographically and over time in relation to changes in regional habitat conditions and other factors, and probably varies among species in relation to habitat selectivity, vagility, and scale.

The inclusion of the association analysis was able to further highlight several areas of concern that may have driven the changes found in the ordination analysis. Unfortunately, with the rather rapid development processes being conducted currently within post-apartheid South Africa, the comparisons between the 1970s and early 1990s would seem woefully out of date. Nevertheless, the use of the kappa index value and χ^2 test provided important results that could address precautions to future development options in the province (i.e., Lebombo Spatial Development Initiative). The areas that had changed bird inventories were generally targeted for development in the former KwaZulu homeland and Natal province (Thorington-Smith et al., 1978; Fair, 1975; South African government, 1975).

In the Maputaland region the changes were quite substantial and may in fact demonstrate how sensitive the birds of the region are to low levels of human disturbance. The cells with < 0.4

kappa values and χ^2 values not rejected were in areas developed since 1980. These include the Makhatini flats agricultural development region (sugarcane and cotton), which began large-scale farming in 1984 and had > 30 kms of irrigation canals installed and substantial bush clearing concluded by 1987. Also during the 1980s the road from Jozini to Kosi Bay was paved for greater traffic mobility. At the same time, the Tembe elephant reserve was created next to Ndumo in 1983, which seemed to have helped that grid cell area retain a similar bird inventory over the 10 year period. Probably the greatest change, however, to the area that precipitated the changes associated between the two bird surveys is the increase in human population. As recorded from the combined magisterial districts of Ubombo and Ingwavuma, the human population expansion occurred as follows: 1970- 108964; 1980- 148453; 1991- 260948; and 1996- 304222. Therefore, between 1979 and 1992 (between survey periods), there was a 75% increase in the human population within the Maputaland region.

Other areas of significant change include the Richards Bay development, where the harbor was partially completed by 1977 and fully completed in the 1980s with increased shipping, industrialisation and surrounding exotic forest plantations. The Newcastle, Vryheid, and Ladysmith areas were denoted by the government in 1975 to be development nodes (Fair, 1975; South African government, 1975), and therefore during the 1980s saw industrial expansion through mining, smelting and irrigated agriculture expansion.

5.6.1 Scope and Limitations

The scope of this study was restricted in several ways. These limitations identify additional research required before management recommendations can be suggested. First, the scale of the investigation placed lower and upper limits of resolution on the ability to detect habitat configurations and assess bird-habitat relationships (Wiens, 1989a,b). The extent of the landscapes was roughly 62500 ha; this defined the upper limit of resolution. Populations of the species undoubtedly are subjected to demographic influences operating over larger areas. These areas should also be related to more ecological defined types, rather than the use of an arbitrary grid cell. The use of the grid cell more than anything makes this study a test against a random sample structure and therefore any relationships found would be more than likely stronger using another sampling system (e.g., landscapes, catchments, vegetation types, etc.). The lower limit has been set by the resolution of the landscape structure variables, 1ha based on $100m^2$ raster. Patchiness occurs at many scales and patches can be defined in hierarchical fashion at progressively finer and finer scales (Kotliar and Wiens, 1990). Because landscape metrics are not invariant to scale (Turner et al., 1989), changing the minimum patch size would have significant effects on measures of landscape structure for specific patch types.

Second, the analysis presented is largely limited to a single scale. As the studies by Wiens and Rotenberry on shrubsteppe birds (Wiens and Rotenberry, 1981; Wiens and Rotenberry, 1985; Rotenberry, 1986; Wiens et al., 1987) demonstrate, habitat selection occurs at multiple scales, and habitats association often very among scales of investigation or analysis. This study is unable to infer about habitat associations at finer or even coarser scales.

Third, the classified habitat is based on structural characteristics that could be reliably mapped from satellite imagery. The broad vegetation definitions may not be important from an organism-centered or even community-centered perspective. Moreover, vegetation patches were somewhat arbitrarily and subjectively made discrete during the cover mapping and digitization process (Fairbanks et al., 2000). Vegetation structural differences were in many cases not abrupt (i.e., grassland-thicket or thicket-woodland transition). Thus, the final patch mosaics represented over-simplified representations of the actual spatial heterogeneity present in the grid cells.

All three limitations were originally pointed out by McGarigal and McComb (1995), and are inherent to all landscape ecological investigations as they deal with the issue of "measured heterogeneity" vs. "functional heterogeneity" (Kolasa and Rollo, 1991). Measured heterogeneity may or may not correspond to something functionally meaningful to a particular species or group of species (Wiens, 1989a; Wiens 1989b). Thus, results based on measured heterogeneity may lead to erroneous conclusions. This study had no *a priori* knowledge of what the functionally relevant scale would be, so even though the scale was set based on available data the bird assemblages were designed to make-up for any scale limited functional configurations and were meaningful from a land management perspective.

5.7 Summary

This study was the first systematic quantification, synthesis, and mapping of avian-environment gradients across a large, contiguous region of southern Africa based on two periods of biological atlas data. The goals of faunal atlases are sound and there is a need for continued national biological surveys of taxa (Balmford and Gaston, 1999). However, the uncritical use of these data to determine conservation priorities (Scott et al., 1993; Williams et al., 1996), as well as to understand the environmental mechanisms behind biodiversity patterns (O'Connor et al., 1996; Bohning-Gaese, 1997) could prove problematic. Distribution and abundance may change over time; therefore, ideally their estimate should be conducted within a sufficiently short period. This is a potentially serious problem with biological atlas surveys, on which estimates of distribution are often based, because such studies are forced to accumulate observations across several years. The results are frequently used to develop "hot spot" indices, provide data for reserve selection analyses or are used as inputs into macroecology studies. Biological atlases effectively show the compound errors in richness over time diverging from ecologically meaningful community assemblage indices. Thus, that contemporary biological atlases may already present transformed distribution and diversity patterns can easily be overlooked.

Atlasing projects, however, do provide a unique opportunity to explore at a macro-scale, contemporary species distribution-abundance relationships with human disturbance, and especially how human disturbance may be providing contradicting effects in commonly used ecological indices. While this analysis underscores the value of sound species-related distribution data and emphasizes the necessity for survey research in conservation biology (Haila and Margules, 1996), equal emphasis must be placed on the role of human influence in shaping extant biological communities. Although largely transformed areas may currently harbor many species, these areas may not be able to sustain natural ecological processes and viable populations (Baudry, 1993; Hobbs, 1993; Freemark, 1995).

Understanding the influence of landscape structure on spatial and temporal patterns of species is an important component of developing prescriptive management recommendations to conserve biological resources. Wiens (1992), and Flather and Sauer (1996), however, note that much of what has been reported in the literature is of a descriptive nature, documenting patterns of association such as has been reported here. There is a great danger from inferring causation from correlations, especially as associated to the scale of this study. However, Flather and Sauer (1996) also note that careful interpretation and analysis of extant data sources serves an important heuristic function (Carpenter, 1990), can lead to insights into the factors affecting patterns in the distribution and abundance of species (Brown, 1984), and can provide a regional context for interpreting and guiding future local studies (Wiens, 1992).

This chapters findings support a conceptual model of multi-scaled controls on bird distribution, and the related notion that local community structure is the result of both regional and local scale abiotic/biotic processes, landscape structure and human action. Broad-scale climate and topography were the primary controls to the differences in bird composition within the KwaZulu-Natal province. The study also showed that the broad scale environmental relationships are not stable over time and bird assemblage changes may be related to longer climatic cycles and land-cover change processes. The use of ordination analysis provided a good exploratory tool for untangling this ecological complexity. Even though the landscape measures explained a portion of the variation in bird variation, this analysis demonstrates the potential limitations of using a simple pattern association with presence/absence or relative abundance data. It is suggested that investigators use several analytical approaches and use the consistency in results among approaches to gauge confidence in the conclusions. This study tried to adhere to this approach using spatial correlation, geostatistics, ordinations, and temporal association analysis. Each provided key pieces to understanding the changes in bird distributions and structure.

Despite strong ecological contrasts within the KwaZulu-Natal province, the analyses presented here succeeded in synthesizing species-environment relations. These findings suggest that apparent conflicts among local bird studies can be explained by real ecological differences among places. Indeed, the results in this chapter provide a broader context for considering gradient and classification studies conducted at a finer, local scale within a landscape. This analysis also places crucial questions on the roles of establishing isolated nature reserves and their ability to persevere bird community persistence. In Baillie et al. (2000) several theoretical points regarding bird populations were examined and are supported by this chapter's result. These include: (1) Habitat deterioration may not only lead to population declines within that habitat but also in adjacent habitats of good quality; and (2) if dispersal is an important process then protecting only isolated areas may be insufficient to maintain the populations within them, which provides support to the landscape ecology principles involving conservation of the wider landscape through connectivity.

Macro-economic policies fueled by globalization and human population growth are rapidly changing the landscapes of southern Africa, which in turn affect wildlife populations (and consequently the results of longer term surveys). Consequently, we cannot just identify and manage for "species diversity", as measured by richness and diversity indices, alone as they ignore species assemblage structures (Soulé and Simberloff, 1986). Results suggest that the detrimental effects of development on bird species populations may cause the erosion of persistence of South African bird assemblages, while biological atlasing may artificially inflate the species richness recorded in a study region.

6. Analyzing Human Factors that Affect Biodiversity Conservation: the Co-evolutionary Model

> If everything occurred at the same time, there would be no development. If everything existed in the same place, there would be no particularity. Only space makes possible the particular, which then unfolds in time...to let this space-conditioned particularity grow without letting the whole run wild—that is political art.
>
> -AUGUST LÖSCH, *The economics of location*, 1954, p.508

Landscape ecologists treat human factors as the primary driving force for landscape change and subsequent biodiversity loss (Forman and Godron, 1986; Soulé, 1991; Dale et al., 1994; Forman, 1995; Forester and Machlis, 1996; Chapin et al., 2000; O'Neill and Kahn, 2000). Nevertheless, there are few empirical studies or methodologies describing human actions developing across a region and their affect on biodiversity (but see Dale et al., 1994; Farina, 1997; White et al., 1997; Abbitt et al., 2000). The study of human spatial development remains within schools of geography and in particular human and economic geography (Thoman et al., 1962; Haggett et al., 1977; Chapman, 1979; Bradford and Kent, 1986; Healey and Ilbery, 1990).

It is important for conservation planning purposes to understand the interactions between landscapes and the cultural and social forces, which have shaped them in the past and are driving them at present (Nassauer, 1992; Norgaard, 1994; Forman, 1995; Zimmerer and Young, 1998; Farina, 2000; sensu Chapter 2). Agricultural development, which can lead onto urban development, can be thought of as a co-evolutionary process between a social system and an ecosystem (as discussed in Chapter 2). Human agricultural activities modify the ecosystem while the ecosystem's responses can determine the nature of individual actions and social organization. When these sequential adaptations of one system to the other are complementary and beneficial to humans, either fortuitously or by strategic design, agricultural and subsequently urban development emerges (Von Thünen, 1826; Weber, 1909; Hägerstrand, 1956; Friedmann and Alonso, 1974; Norgaard, 1981; 1984). In modern terms, this process is referred to as the development of a space economy, which is the direct product of culture, personality, and environment within a political economy.

This study builds on the previous chapters and the conceptual framework outlined in Chapter 2 to develop and examine an inter-disciplinary model of biodiversity threat using socio-economic, environmental, and landscape pattern indicator datasets within a geographic framework. The results highlight the importance of identifying relationships between human social systems and biodiversity conservation strategies and the potential offered by inter-disciplinary research for exploring pathways to sustainable biodiversity conservation.

6.1 Geographic Development Models, Cultural Landscapes, and Co-evolution

Space economies represent open systems, as they exchange materials, energies, or information with their environments (e.g., von Bertalanffy, 1968). Since a space economy may be viewed as a system of interrelated and interconnected parts, it should be possible to uncover a degree of spatial order within its structure. Dacey (1964) observed that it is unlikely that geographic distributions, particularly those determined by human decisions, are random, and thus most geographic patterns reflect some system or order. Forman and Godron (1986), and Forman (1995) acknowledged this logic in the development of landscape ecology theory. The search for order not only relies on observation, measurement, and description, but also demands the study of system behavior and processes responsible for evolving emergent patterns (see Chapter 2 for review).

Friedmann (1972), and Friedmann and Alonso (1974) recognized that human activities are distributed in particular rhythms and patterns within a space economy, which are the results of interdependencies that shape the economic space. Berry (1970) formalized a general framework for economic space relationships, which highlights these interdependencies, based on the following three components:

1. A national pattern of heartland and hinterland;
2. An urban hierarchy; and
3. Gradients of urban influence on their surrounding dependent regions.

This framework allows for the identification of a national core-periphery structure. Previous studies by Fair (1965), Board et al. (1970), and Browett and Fair (1974) confirmed that South Africa had developed towards this norm. Whereas, regional inequalities are inherent in the spatial structure because growth does not happen everywhere and at once; it is concentrated in points or development nodes, of variable intensity and spreads along diverse transportation and communication networks (Hansen, 1967).

The work of Myrdal (1958) first recognized that the dominant factor responsible for the persistence of the core-periphery structure appears to be the process of cumulative and circular causation. The existence of external economies, economies of scale, and agglomeration in core areas, compounded by the provision of transportation networks, serve to enhance and capitalize upon existing advantages of relative locations (e.g., along coasts, or major navigateable rivers).

This has meant that the balance of forces have consistently led to development concentration in core areas and a cycle of poverty in the periphery (Browett and Fair, 1974). In addition, spatial political policy, such as the development of the former homeland system in South Africa had further accentuated the poverty periphery (Fair and Schmidt, 1974; Christopher, 1982). Moreover, once initiated, the core-periphery structure is perpetuated by a compelling inertia (see Rogerson, 1975) and, as noted by Richardson (1973), the existing spatial distribution of population and economic activity in a region in turn drives patterns of regional growth. Fair (1976) presented evidence that South Africa had reached the stage where the spatial economy was past the period dominated by a single national center and associated periphery, with clear signs of a multinuclear network of regional economic core centers (e.g., Cape Town, Durban, Johannesburg, Pretoria), minor metropolitan centers, regional market towns, and peripheral country towns (see Chapter 1, Figure 1.1b for a settlement hierarchy structure in KwaZulu-Natal Province).

The identification of homogeneous geographical regions and their interpretation through environmental or socio-economic variables has always been an important topic of biogeography and regional geography studies. The primary purpose of this chapter is to identify and describe the socio-economic-environmental and landscape mosaic patterns of KwaZulu-Natal, in support of the conservation pattern studies conducted in Chapters 3, 4 and 5. This line of investigation accepts challenges posed from within the landscape ecology community (O'Neill, 1999), to apply and integrate theories of economic geography within landscape ecological analysis to biodiversity conservation problems. The geographical structure of KwaZulu-Natal is explored by examining the covariance between socio-economic-environmental, LCLU, and landscape mosaic pattern indicators. The exploratory use of principal component analysis and pattern recognition techniques are employed to investigate the spatial significance of socio-economic and environmental relationships in KwaZulu-Natal Province. First, the structure and spatial patterns derived from a multivariate analysis of available socio-economic-environmental variables for KwaZulu-Natal are examined. Secondly, these patterns are related to LCLU patterns derived from landscape metric analysis. Thirdly, the implications of the distribution of socio-economic resources and needs in the province, as well as, priority avian conservation areas and required habitat are assessed collectively. The study relies on the fact that socio-economic activity is the primary determinant of landscape pattern and change, and in turn drives biological community responses (see Chapter 5). Development needs and tensions with regard to environmental preservation are identified in order to develop a socio-economic and ecologically sound strategic conservation plan for the bird diversity of KwaZulu-Natal.

6.2 Methods

For each of the 1996 magisterial districts in KwaZulu-Natal (Figure 1.10) three separate datasets were first used to identify homogeneous regions: LCLU, socio-economic-environmental indicators, and landscape mosaic pattern indices. This was done either using detrended correspondence analysis or principal component analysis depending on the type and structure of the dataset, to derive axes of variation in data space. Hierarchical and *k*-means classification strategies were then applied to derive homogeneous clusters based on the type of results and their variance characteristics. The multivariate analysis is aimed at uncovering the most important underlying dimensions from the relationships between a range of socio-economic-environmental, land-cover, and landscape pattern data. Results are loosely compared with results from other multivariate studies in Africa, notably those in Ghana, Kenya, Tanzania, Swaziland, and Nigeria (Forde, 1968; Soja, 1968; Gould, 1970; Lea, 1972; Weinand, 1973). The results are explained and then inserted into a pattern recognition procedure to derive rules that describe the development regions. The variations within the datasets and regional rules are then discussed in relation to the conservation planning results obtained in Chapters 3, 4 and 5.

6.2.1 Data

The success of the analyses depends upon the selection of a suitable cross-section of variables that would enable conclusions to be drawn about the structure and geographical patterning in the province. The socio-economic-environmental variables chosen were made up of eighty-four variables, under six main subject groups (Appendix A):

1. Population characteristics (11 variables);
2. Social characteristics (18 variables);
3. Economic characteristics (23 variables);
4. Development needs (16 variables);
5. Physical characteristics of economic importance (9 variables); and
6. Environmental characteristics (7 variables).

These variables were checked for normality and transformed using log or square root transformations, where required, before principal component analysis.

The landscape pattern indicators used in the analysis are those found in Chapter 1, Table 1.5. The last data set represented the class type and proportion of LCLU (Chapter 1, Table 1.3) found within each magisterial district.

6.2.2 Relationships Among Variables and Geographic Regions

The original LCLU map was used to extract presence/absence and areal abundance of each class type per magisterial district. The hectare measurement was standardized by transformation into a percentage before analysis. The data matrix consisted of fifty-two magisterial districts and twenty-nine LCLU classes comprising 753 occurrences. A correspondence analysis was used to describe the interactions among characters and bring out the main covariance relationships. The model assumes a relationship between the environment and the LCLU class occurrence as a unimodal response to the environmental condition (Gauch, 1982). It is assumed that LCLU classes across the province are related to environmental gradients, which controls their presence and abundance. For example, consider the exotic plantation land-use category. This type of land-use is strongly related to the water balance of a region (Fairbanks, 1995; Fairbanks and Smith, 1996). Therefore, this type of land-use will only be developed where there is sufficient moisture for economic production and the area size of the development will depend on the amount of land with the required moisture regime. Of course, this simple model ignores government development policy and land ownership issues, which will skew the spatial development of land-uses within a region. Other classes of land-use generally follow the same patterns, except for historical colonization patterns along coasts. A detrended correspondence anlaysis (DCA), as outlined in Chapters 4 and 5, was applied to the dataset to avoid the horseshoe effect and to obtain linear representations for linear gradients (Gauch, 1982; ter Braak and Simlauer, 1998). A hierarchical linkage agglomerative clustering algorithm (Legendre and Legendre, 1998) using Wards minimization was then used to develop a series of maps corresponding to the various clustering levels found from the ordination. The hierarchical clustering procedure was adopted because it is assumed that recorded LCLU variables have a nearest-neighbor relationship when measured by the magisterial districts due to past development policy and known general patterns in human spatial development (sensu Bradford and Kent, 1986).

The 84 socio-economic-environmental and 32 landscape mosaic pattern indicators were subjected to a principal components analysis (PCA). PCA is a multivariate procedure designed to reduce a large number of variables to smaller set of "factors" that account for most of the variance among the original variables. Factors are typically extracted by applying PCA to a standardized correlation matrix. A table of factor loadings shows which variable are grouped together on which common factors, and the degree of correlation between individual variables and the factors. The factors are interpreted as axes in state space, and the meanings of the axes are inferred from the variables that are most correlated with them. Highly correlated variables are said to "load heavily" on that factor. Factors can be rotated in an attempt to account for additional variance.

Changes in sample area and landscape mosaic indices were highly confounded in the 52 magisterial districts; that is magisterial district area and landscape mosaic indices covaried in a somewhat predictable manner. Following McGarigal and McComb (1995), regression analysis was used to remove any significant empirical relationship between magisterial district area and landscape mosaic indices. Magisterial district area was regressed on each of the configuration indices using general linear models. Based on an analysis of the residuals, appropriate dependent variable transformations (log or square root) were conducted to ensure that regression assumptions were met. Models were constructed for each landscape mosaic index separately, trying for the most logical model exhibiting the largest significant R^2, and best residual distribution. Using this process, the 32 original pattern metrics were transformed into 32 new residual metrics representing variation in magisterial districts independent of their area.

Factor scores were calculated for each magisterial district by each dataset. The factor scores from the socio-economic-environmental indicators dataset were then used to group the magisterial districts using first the same hierarchical procedure described earlier and then a *k*-means method (Legendre and Legendre, 1998). The *k*-means method produced *k* groups (the value of *k* is decided by the user) after an iterative procedure of object reallocation; the procedure stops when the overall sum of squares, which is the sum of the within-group sum of squares, has reached a minimum. The clusters obtained by the hierarchical clustering were used as initial configurations to the *k*-means algorithm in order to develop a parsimonious set of clusters, since the *k*-means algorithm relies on the user to decide the number of classes to obtain. The *k*-means approach was deemed appropriate over the hierarchical approach because the socio-economic indicators were not necessarily hierarchical in nature with reference to the magisterial districts.

The factor scores that were calculated from the landscape pattern indices by magisterial district were grouped together using the hierarchical agglomerative procedure with Ward's minimization. A hierarchical method was considered the most appropriate to cluster the districts based on the same reasoning for the LCLU dataset. Both datasets measure patterns that have strong geographic contiguity between magisterial districts, which makes them appropriate for hierarchical clustering.

6.2.3 Pattern Recognition

Systems for inducing concept descriptions from examples are valuable tools for assisting in the task of knowledge acquisition for expert systems. Such systems include the class of neural networks and others that produce rules to describe a problem set. Neural networks are popular, but hampered by the fact that they are difficult to use, resemble "black box" thinking, assume no noise in the domain, search for a concept description that classifies training data perfectly, and the rules developed are not easily deciphered for further investigation. Instead, a system able to handle noisy data and generate interpretable rules is required. In particular, mechanisms for avoiding the overfitting of the induced concept description to the data are needed, requiring relaxation of the constraint that the induced description must classify the data perfectly.

A rule induction program used for data mining purposes, CN2 (Clark and Niblett, 1989; Clark and Boswell, 1991), was used to develop if-then rules to describe each of the classified datasets against the other indicator variable data sets. CN2 uses a beam search to find a rule, or rule set, that best describes each class. Each rule set, referred to as a complex, consists of a conjunction of conditions. Complexes are built using the beam search over the space of all possible complexes (conjunctions of conditions). The best complexes for a class are found using the efficient Laplacian error estimate as a search heuristic (Clark and Boswell, 1991).

The CN2 program was used to identify if-then rules from the variable sets in order to explore the tension between variables identified for the regions in relation to required avian conservation areas. These rule sets provide good indicators of issues that define a region and may need to be addressed, and they can be interpreted with the PCA results for a comprehensive view of the co-evolutionary links within the province. For this analysis the landscape pattern indicators were used to develop descriptive rules to describe the geographic regions developed from the PCA of the socio-economic-environmental indicators. In addition, the socio-economic-environmental indicators were used to develop descriptive rules to describe the regions developed from the landscape pattern indicators. The regions grouped using the DCA results of the LCLU had rules developed from both the socio-economic-environmental and landscape pattern indicators.

6.2.4 Conservation Assessment

Implications for avian conservation are assessed by using the "ideal" reserve network developed in Chapter 4 (Figure 4.7) to identify magisterial districts required for further conservation assessment. Class patch metrics were developed for each of the major vegetation types found within a magisterial district (woodland, forest, thicket, or grassland) and then a simple habitat index was developed to depict habitat importance and quality (e.g., White et al., 1997). It is calculated by taking the total area of each vegetation class and dividing by the number of patches of that class found within each district. To avoid the confounding nature of vegetation area and number of patches being affected by the variable size of a magisterial district, an area weight based on the district size in relation to the total area of the province was multiplied against both variables in the numerator and denominator. This transformation removed area size effects from the index. This habitat index provides a simple measure of the size and fragmentation level of each vegetation type. These vegetation class indices can then be summed together for each district and divided by the number of vegetation classes present within each district. The resulting value is an index measure of habitat connectivity amongst all the vegetation types. These measures were only calculated for "undisturbed" vegetation types, and therefore leaving out the lower quality degraded classes of each vegetation type (Chapter 1, Table 1.4). This approach provides an alternative look at the landscape patterns in the magisterial districts by focussing only on the available vegetation habitat rather than the total landscape mosaic pattern (section 6.2.2), which measures the total pattern of land-use and land-cover.

6.3 Results

6.3.1The Co-evolved Regions of Productivity in KwaZulu-Natal

The detrended correspondence analysis (DCA) results using a 2nd order polynomial fit on the LCLU data yielded strong eigenvalues on the first two axes with acceptable strength on the third axes to be kept for further analysis (Table 6.1). The first axis's gradient length was quite large, confirming the difference in land-uses and land-cover across the province from the coast to the Drakensberg Escarpment. Gradient lengths greater than three standard deviations represent almost complete differences in features found on the opposite ends of the gradient (Table 6.1).

The DCA results are graphed as two biplots, one with the patterns of the magisterial districts in data space and the other displaying the LCLU classes responsible for that pattern (Figure 6.1a). The first axis clearly separates out the urban-industrial regions from the remainder of the province (Figure 6.1b). The second axis of variation separates out the ex-KwaZulu homeland areas from the White commercial farming regions based on agriculture, plantations, and dominant vegetation type.

6.3.2 The Socio-economic-environmental Organization of Space in KwaZulu-Natal

Using rules of thumb developed by Johnston (1980), it was decided to limit the number of axes calculated to only those with an eigenvalue greater than or equal to one using the principal components method applied to the standardized correlation matrix, followed by an orthogonal (varimax) rotation of axes. Twelve factors were extracted for the socio-economic-environmental data explaining 91% of the variation among indicators in the dataset (Table 6.1).

Table 6.1: Eigenvalues and cumulative proportion of variance explained by principal component analysis for socio-economic-environmental indicators and landscape pattern indicators, and eigenvalues and gradient length for detrended correspondence analysis of LCLU.

Data set	Factor	PCA Eigenvalue	Cumulative Variance
Soci-economoic-environmental	1	41.49	.40
	2	10.94	.54
	3	4.70	.60
	4	3.64	.67
	5	3.08	.71
	6	2.60	.74
	7	2.51	.76
	8	1.95	.79
	9	1.83	.83
	10	1.34	.85
	11	1.13	.87
	12	1.01	.91
Landscape mosaic pattern	1	17.56	.45
	2	7.80	.66
	3	3.52	.77
	4	1.52	.82
	5	1.44	.88
Data set	**Axis**	**DCA Eigenvalue**	**Gradient length**
LCLU	1	0.56	3.4
	2	0.29	1.6
	3	0.13	2.3

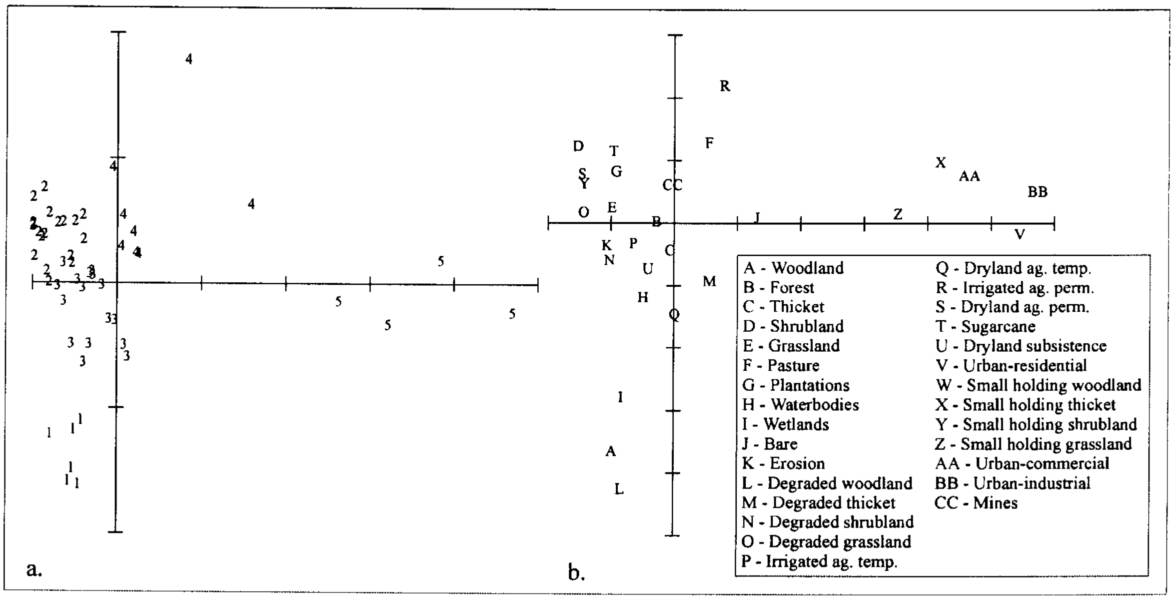

Figure 6.1: Detrended correspondence analysis biplots: (a) two axes of magisterial district data space (numbers match Figure 6.4a); and (b) two axes of feature variable data space.

Factor 1, the modernization dimension

The large and general factor one is defined by population, employment, housing, and land transformation indicators (Table 6.2). The highest loadings are on population total (POPTOTAL, 0.97), male/female population (MALE96, 0.97; FEMALE96, 0.96), various age classes (0.81-0.96), pupils in school (IN_SCHL, 0.96), number of children (under 14 years old) working (CHLDNWRK, 0.94), unemployment (UNMPLOY, 0.96), total people living in poverty (POVERTY, 0.95; NO_APP, 0.96; IND_NEC, 0.91) construction (CONSTRUC, 0.90), modern houses (HOUSE, 0.88), and the percentage of untransformed land (UT_PER, -0.60). This latter moderate inverse association confirms the fact that a high percentage of untransformed lands is not located within or near economically active or urban-industrial core areas. The other strong correlations relate to commercial and industrial enterprise, government employment, and housing related to South African urban areas (i.e., which includes townhouses, shack dwellings, and worker hostels).

Factor one would thus appear to indicate that the greatest percentage of the total variance among the eighty-four variables is explained by large populations covering all age groups, high numbers of children in school, high child labor, high unemployment, high poverty, employment associated with a large urban metropolitan area, and modern housing associated with South African urban areas. Figure 6.2a illustrates the basic pattern of geographic variation for the variables associated with this factor. This emphasizes the findings of similar research conducted in Swaziland (Lea, 1972), namely that the distribution of the working population and skilled employment sector give a measure of the distribution of modernization. The axis is fundamental to the understanding of the distribution of social and economic space in KwaZulu-Natal.

Factor 2, the urban/rural socio-economic duality dimension

The second factor is primarily associated with high loadings on access to a flush toilet (FTOILET, 0.87), possession of basic household items (BASIC, 0.85), refuse management services (REFUSE, 0.84), access to safe water (PROXH20, 0.81), satisfaction with government services (SAT_SERVICE, 0.81), satisfaction with the general environment (SAT_ENV, 0.81), access to electricity (ELECTRIC, 0.78), and poverty ratio (POV_RAT, -0.73). A moderate inverse association with the ratio of household dependents (-0.57), highlights the lower quality of life the African rural areas have when compared to the urban conditions in the former Whites only areas. Other moderate associations are satisfaction with housing (SAT_HOUSE, 0.66), functional literacy (F_LITERACY, 0.60), male to female ratio (RATIO_MF, 0.58), adult literacy (A_LITERACY, 0.57), satisfaction with economic situation (SAT_ECON, 0.56), and satisfaction with life in general (SAT_LIFE, 0.53). This group of variables is related to the availability of basic "quality of life" amenities urbanize areas versus the stark realities of poverty and lack of the most basic services in parts of the former KwaZulu homeland districts (Figure 6.2b).

Factor 3, the development needs dimension

The highest loading variables on this factor were around supporting development goals within the province, including addressing people's basic needs (BNEEDS, 0.95), upgrading of infrastructure (UPGRADE, 0.95), improving the general development situation (DEVELOP, 0.94), and improving administrative dependability and equity (DEPEND, 0.93). The other two variables associated with the development group included both measures of literacy as in factor two. It would appear that the acknowledgement of supporting development needs and goals must coincide with the basic attainment of education to contribute to community and economic development. The pattern of high scores for this factor corresponds to highly underdeveloped rural districts, as well as semi-urban and urban economic areas (Figure 6.2c).

Factor 4, the community services dimension

This axis represents a gradient in the availability of government services. The high loadings that define the pattern are total available hospital beds (BEDSTOT, 0.86), total number of post offices (TOTPOSTOF, 0.85), total number of police stations (TOTPOLSTA, 0.77), and the total number of people living in flats/apartments (FLAT, 0.78).

Table 6.2: Factor loadings from principal component analysis with varimax rotation for the socio-economic-environmental indicators based on the 1996 magisterial districts. [†] (Table continued next page).

	Factor											
Indicator [‡]	1	2	3	4	5	6	7	8	9	10	11	12
PARK_PER	-0.12	-0.13	0.09	-0.07	-0.08	-0.07	**-0.77**	-0.15	-0.05	0.14	0.03	0.18
UT_PER	**-0.60**	-0.06	0.04	-0.18	-0.34	-0.45	-0.25	-0.13	-0.02	0.08	0.01	0.33
M_PER	0.15	-0.36	-0.31	0.00	-0.15	-0.05	0.14	0.19	-0.16	0.18	-0.04	**-0.72**
T_PER	0.49	0.32	0.19	0.18	0.45	0.47	0.15	-0.01	0.14	-0.22	0.02	0.20
POPTOTAL	**0.97**	0.16	-0.04	0.11	0.06	0.06	0.00	0.04	-0.06	-0.02	0.04	-0.09
POPDEN	0.36	0.23	-0.02	0.00	-0.12	**0.86**	0.06	0.02	0.06	0.07	-0.06	0.07
MALE96	**0.97**	0.18	-0.03	0.11	0.07	0.07	0.00	0.03	-0.04	-0.01	0.03	-0.08
FEMALE96	**0.96**	0.15	-0.04	0.10	0.05	0.05	0.00	0.04	-0.08	-0.03	0.05	-0.11
RATIO_MF	0.10	**0.58**	-0.03	0.05	0.27	0.12	-0.26	-0.30	0.39	0.14	-0.08	0.18
AGE_0_4	**0.95**	0.07	-0.07	0.06	0.04	0.04	-0.02	0.04	-0.17	-0.02	-0.02	-0.18
AGE_0_5	**0.93**	0.07	-0.09	-0.04	0.05	0.04	-0.03	0.07	-0.20	-0.03	0.02	-0.22
AGE_5_14	**0.93**	0.06	-0.10	-0.03	0.05	0.01	-0.03	0.07	-0.22	-0.06	0.02	-0.23
AGE_15_44	**0.96**	0.20	-0.02	0.11	0.07	0.09	0.00	0.02	0.00	-0.01	0.02	-0.03
AG_15_64	**0.96**	0.21	-0.01	0.14	0.07	0.08	0.01	0.02	0.00	-0.01	0.03	-0.03
AG_65_99	**0.81**	0.11	-0.02	0.48	0.01	-0.01	0.02	0.06	-0.01	-0.07	0.22	-0.16
NO_SCHL	**0.76**	-0.13	-0.09	-0.11	0.11	-0.05	-0.13	0.19	-0.32	-0.08	0.04	-0.35
IN_SCHL	**0.96**	0.19	-0.05	0.04	0.08	0.07	0.03	0.00	-0.06	-0.03	0.01	-0.06
NO_DEGRE	**0.78**	0.26	0.08	0.48	-0.05	0.03	-0.02	-0.01	0.18	0.01	0.19	0.00
YES_DEGR	**0.85**	0.27	0.05	0.38	-0.01	0.12	0.02	0.00	0.14	0.03	0.08	0.04
CHLDNWRK	**0.94**	0.07	-0.09	-0.01	0.05	0.03	-0.03	0.06	-0.20	-0.04	0.01	-0.22
EMPLOYED	**0.89**	0.29	0.05	0.28	0.09	0.08	0.03	0.01	0.11	0.05	0.05	0.09
UNMPLOY	**0.96**	0.09	-0.06	-0.08	0.03	0.12	0.00	0.00	-0.07	-0.06	0.01	-0.11
DEP_RAT	-0.12	**-0.57**	0.03	-0.08	-0.32	-0.03	0.22	-0.02	-0.29	0.16	0.01	-0.42
POVERTY	**0.95**	0.11	-0.07	0.01	0.08	0.03	-0.02	0.06	-0.14	-0.02	0.00	-0.16
ABV_POVR	**0.85**	0.27	0.06	0.39	-0.02	0.10	0.03	0.01	0.14	0.07	0.05	0.08
POV_RAT	-0.27	**-0.73**	0.08	-0.09	-0.29	-0.10	0.19	0.05	-0.15	0.11	-0.07	-0.21
RR_INDST	-0.03	0.10	0.10	0.04	**0.94**	-0.04	-0.03	0.04	-0.05	-0.10	0.11	0.13
NR_INDST	-0.05	0.47	-0.09	0.02	-0.06	-0.18	-0.23	0.06	0.03	-0.11	-0.37	-0.33
MANUFAC	**0.86**	0.32	0.04	0.22	0.06	0.11	0.09	0.04	0.05	0.13	-0.09	0.16
ENERGY	**0.87**	0.31	0.07	0.23	0.01	0.02	0.00	-0.01	0.14	-0.02	0.18	0.07
CONSTRUC	**0.90**	0.25	0.06	0.21	0.10	0.04	0.02	0.01	0.13	0.12	0.07	0.07
TRADE	**0.88**	0.25	0.06	0.34	0.03	0.06	0.03	0.00	0.11	0.09	0.01	0.10
TRAN_COM	**0.88**	0.27	0.04	0.30	0.00	0.15	0.02	0.00	0.10	0.09	-0.05	0.10
BUS_SERV	**0.79**	0.23	0.08	0.49	-0.05	0.09	0.01	0.00	0.19	0.05	0.12	0.06
SOC_SERV	**0.88**	0.27	0.04	0.31	-0.02	0.11	0.00	-0.01	0.12	-0.01	0.09	0.03
PRIVATE	**0.89**	0.27	0.04	0.16	0.07	0.06	0.02	-0.02	0.18	0.01	0.19	0.05
EXT_ORG	**0.70**	0.10	0.04	0.36	0.08	-0.04	-0.03	-0.08	0.03	0.19	-0.16	0.12
REP_FORG	**0.80**	0.23	0.05	0.38	-0.07	0.02	0.01	0.06	0.00	0.10	-0.20	0.17
IND_NEC	**0.91**	0.30	0.04	0.21	0.06	0.07	0.01	0.03	0.11	0.00	0.09	0.08
NO_APP	**0.96**	0.09	-0.08	0.01	0.05	0.05	-0.01	0.05	-0.15	-0.05	0.02	-0.17
NA_INST	**0.65**	0.25	0.08	0.37	-0.05	0.05	-0.09	-0.09	0.21	-0.21	0.39	-0.12
HOUSE	**0.88**	0.36	0.02	0.17	0.11	0.05	0.03	-0.01	0.09	-0.01	0.13	0.04
TRADHOME	0.21	-0.39	-0.18	-0.13	0.06	-0.20	-0.03	0.13	-0.43	-0.32	0.25	**-0.50**
FLAT	**0.55**	0.11	0.08	**0.78**	-0.05	0.01	-0.01	-0.02	0.15	0.09	0.00	0.02
TOWN	**0.85**	0.23	0.04	0.17	-0.02	0.01	0.11	0.09	0.07	0.11	-0.12	0.17
RETIRE	**0.62**	0.21	0.14	0.19	0.05	-0.07	0.01	0.05	0.25	0.04	**0.56**	0.01
ROOM	**0.73**	0.34	0.07	0.30	0.00	0.29	0.07	0.08	0.17	0.00	0.31	0.04
SHCK_BCK	**0.83**	0.28	0.05	-0.10	0.01	0.00	0.09	-0.01	0.09	0.21	0.06	0.13
SHCK_EW	**0.84**	0.14	0.07	0.00	0.09	0.30	0.07	-0.11	0.07	0.17	-0.20	0.16
FLATLET	**0.70**	0.22	0.10	0.09	0.23	-0.01	0.05	0.09	0.23	-0.06	0.45	0.05
CARAVAN	**0.65**	0.17	0.05	0.21	0.19	-0.17	-0.11	0.03	0.06	0.04	0.49	-0.01
HOMELESS	0.46	-0.09	-0.17	0.17	**0.52**	-0.08	0.04	0.01	0.05	0.34	0.06	-0.32
HOSTEL	**0.54**	0.24	0.09	0.45	0.20	0.01	-0.41	-0.12	0.06	-0.09	-0.09	-0.07
SERVE_I	0.05	-0.28	0.16	-0.11	-0.09	-0.04	-0.16	0.06	**-0.84**	0.04	-0.08	-0.10
SE_INDEX	0.04	-0.21	0.18	0.00	0.01	-0.05	-0.03	-0.02	**-0.90**	0.00	-0.06	-0.07
SAT_ENV	0.27	**0.81**	0.23	0.05	-0.04	-0.04	0.03	-0.05	-0.05	0.03	0.09	0.12
SAT_HOUSE	0.36	**0.66**	0.35	0.28	-0.04	-0.12	-0.06	-0.13	-0.01	0.07	0.14	-0.04
SAT_ECON	0.38	**0.56**	0.20	0.04	0.03	-0.20	0.12	0.35	0.03	0.02	0.11	-0.33
SAT_SERVICE	0.36	**0.81**	0.21	0.03	-0.10	0.04	0.04	-0.03	0.07	0.07	0.10	0.06
BASICS	0.35	**0.85**	0.06	0.18	0.04	0.14	0.13	-0.04	0.14	0.03	0.00	0.07
DEVELOP	-0.05	0.22	**0.94**	0.07	0.03	0.02	-0.02	-0.03	-0.02	-0.11	0.02	0.12
BNEEDS	-0.08	0.14	**0.95**	0.04	0.02	0.04	-0.04	-0.08	-0.11	-0.04	0.00	0.07
UPGRADE	-0.15	0.03	**0.95**	0.04	0.06	-0.10	-0.11	-0.02	-0.09	-0.06	-0.02	0.09
SAT_LIFE	0.36	**0.53**	0.28	0.00	0.05	-0.28	0.01	0.08	0.18	-0.17	0.06	-0.29
DEPEND	-0.02	0.15	**0.93**	0.07	0.03	0.01	-0.09	-0.07	-0.01	-0.12	0.04	0.12
PROXH2O	0.34	**0.81**	0.10	0.11	0.11	0.22	0.07	-0.13	0.15	-0.05	-0.03	0.07

[†] Factor loadings > 0.50 are indicated in bold, factors > 0.70 are considered significant.

[‡] Variable definitions are found in Appendix A.

Table 6.2: Continued.

ELECTRIC	0.36	**0.78**	0.10	0.13	0.09	0.11	0.13	-0.01	0.11	-0.03	-0.05	0.01
REFUSE	0.36	**0.84**	0.03	0.14	-0.06	0.15	0.13	-0.07	0.13	0.05	0.00	0.10
FTOILET	0.27	**0.87**	0.01	0.17	0.05	0.14	0.13	-0.09	0.17	0.02	-0.03	0.10
A_LITERACY	0.34	**0.57**	**0.50**	0.08	-0.01	0.12	-0.05	0.14	-0.17	0.24	0.09	-0.05
F_LITERACY	0.20	**0.60**	**0.60**	-0.01	-0.02	0.11	0.06	-0.09	-0.12	0.22	0.07	-0.06
FOR_PER	-0.03	-0.32	-0.13	-0.08	-0.07	-0.05	-0.27	**0.81**	-0.10	0.04	0.11	0.02
GRS_PER	-0.49	0.16	0.10	-0.11	-0.24	-0.34	0.03	**-0.62**	0.06	0.04	-0.06	0.28
WET_PER	0.01	-0.08	0.14	0.00	0.00	-0.04	**-0.87**	0.24	-0.11	0.00	-0.04	-0.02
LOWI_PER	0.14	-0.36	-0.31	0.02	-0.15	-0.06	0.13	0.18	-0.16	0.18	-0.04	**-0.72**
PLNT_PER	-0.08	-0.09	0.29	-0.02	0.10	-0.09	0.15	-0.03	0.02	**-0.81**	-0.01	0.14
DRY_PER	0.31	0.14	0.06	-0.08	**0.87**	-0.10	0.08	0.02	0.09	-0.02	-0.06	0.05
IRR_PER	-0.19	0.04	0.14	0.15	-0.09	-0.05	-0.19	**-0.62**	-0.06	-0.01	0.17	0.35
URB_PER	0.43	0.33	0.03	0.25	-0.17	**0.72**	0.07	0.07	0.11	0.14	0.06	0.10
PERCAPINC	0.42	**0.52**	0.13	0.38	0.10	-0.06	-0.35	-0.01	0.00	0.03	0.13	0.23
TOTPOLSTA	0.38	0.27	0.03	**0.77**	0.00	-0.03	0.08	-0.03	-0.07	-0.03	0.12	0.08
TOTPOSTOF	0.31	0.21	0.11	**0.85**	0.08	0.08	0.07	0.01	0.02	0.01	0.08	0.03
BEDSTOT	0.36	0.09	0.04	**0.86**	0.00	0.14	-0.04	-0.10	0.03	-0.02	-0.07	-0.08
TELSHAREPR	0.36	**0.55**	0.08	0.30	0.19	0.00	0.06	-0.16	-0.05	0.09	0.06	0.33

[†] Factor loadings > 0.50 are indicated in bold, factors > 0.70 are considered significant.

[‡] Variable definitions are found in Appendix A.

The housing variable refers to low cost high-density living conditions that tend to represent modern urban living conditions. Urban and semi-urban areas tend to have more health, postal, and crime prevention facilities proportional to population density. This pattern is illustrated by the high factors found in the Durban and Pietermaritzburg magisterial districts versus many of the former KwaZulu homeland and rural districts with low populations (Figure 6.2d).

Factor 5, the renewable resources employment dimension

Number of employed people in renewable resource industries (RR_INDST, 0.94) and the percentage of commercial dryland agriculture (DRY_PER, 0.87) possess the highest loadings for this factor, these two variables being clearly interrelated. The only other moderately significant loading is the total number of people considered homeless (HOMELESS, 0.52), suggesting a relationship between commercial agriculture and the migrant African labor it employs. Figure 6.2e highlights the high scoring magisterial districts along the coasts consisting of sugarcane farming.

Factor 6, the population growth dimension

This factor has a clear association with human population growth and urbanization. High loadings are with the 1996 population density (POPDEN, 0.86) and the percentage of land classified as urban (URB_PER, 0.72). The result for this factor should be compared to the size of the magisterial district that the indicators are calculated by, as the results are clearly scale dependent. The high loading magisterial districts of Chatsworth and Umlazi (see also Figure 1.10 and Table 1.8) shown in Figure 6.2f illustrate the size scale problem, but the variable pattern is reliable.

Figure 6.2: Factor patterns of variation derived from principal component analysis (PCA) of the socio-economic-environmental indicator data set, where shading indicates factor scores.

Factor 7, the conservation dimension

The highest loadings on this axis represent the percentage of land covered by waterbodies and wetlands (WET_PER, -0.87) and the percentage of land conserved in protected areas (PARK_PER, -0.77). This pairing of indicators reflects the policy of protected areas being developed around dam constructions (DWA, 1986), as well as the protection of the major wetlands in KwaZulu-Natal's north coast regions. This was done historically to combat malaria (Pringle, 1982) in the region. The pattern of factor scores (Figure 6.2g) illustrates the same results as outlined in Chapter 3, however the PCA extracts the detail of the historical nature of conversation development in the province better. The interior areas along the Tugela River, central Zululand, Midlands, and south coast regions are largely under protected.

Factor 8, the vegetation structure/land-use dimension

This axis relates to the duality in major vegetation structural types covering the province (Figure 6.2h; also see Figure 1.3 and 1.7 for detail). The high loadings are with percentage land covered in forest and woodland (FOR_PER, 0.81) and the moderate inverse represented by percentage of land covered in grassland (GRS_PER, -0.62) and the percentage of land under commercial irrigated agriculture (IRR_PER, -0.62). This relationship contradicts the perception in the province that grassland and plantation forestry cover are related to one another (e.g., Armstrong et al., 1997). The results provide evidence for agriculture as the primary related transformation agent within grasslands in the province and supports earlier conjectures by Fairbanks et al. (2000) for South Africa as a whole.

Factor 9, the service needs dimension

The socio-economic index (SE_INDEX, -0.90) and service index (SERVE_I, -0.84) loaded the highest on axis of factor nine. These two indices provide a global view to encapsulate the development profile and needs of the magisterial districts. The axis displays a socio-economic and service gradient, displaying districts requiring development intervention. The pattern on this axis generally makes sense with larger areas of the former homeland areas requiring development assistance and the former White controlled areas and Durban economic core requiring less assistance (Figure 6.2i). Two districts, Babanango and Kranskop, do not quite fit the gradient pattern, but were both noted in the original data set (Kok et al., 1997) as having tentative survey results due to small sample sizes for these indicators. In addition, the eigenvalues and importance of the variance explained on this axis is very low in comparison to the previous factors.

Factor 10, the plantation/woodlot dimension

The percentage of land covered in exotic woodlots and commercial plantations (PLNT_PER, -0.81) is the only significant loading on this axis. Figure 6.2j clearly shows the pattern of the commercial forestry plantation sector and the importance of woodlots in the homelands not endowed with sufficient natural woodlands (particularly in the southern midlands and south coast). As explained for factor nine, this axis does not contribute significantly to the variation within the province.

Factor 11, the pensioners dimension

The loading on this factor is moderately significant with a minor contribution to explaining the variation. It relates to the total number of people living in retirement villages and retirement holiday homes (RETIRE, -0.56). The eigenvalue is very low and the contribution to overall explanation to the variation in the province is negligible. The pattern of the axis is, however, interesting as it highlights areas with high numbers of pensioners residing along the south coast and Midlands regions (Figure 6.2k). Each of these areas is prized for their scenic natural beauty and tranquil living conditions (see www.kzn-deat.gov.za/tourism; www.tourism-kzn.org for details).

Factor 12, the land degradation dimension

The last factor had high loadings represented by two variants of percentage land covered by low intensity transformation (M_PER, -0.72; LOWI_PER, -0.72). This result is surprising since there is a strong difference in levels of land transformation between the former KwaZulu homeland areas and the original white managed regions. The duality was obviously not strong enough to be extracted earlier in the principal component analysis, or has been distorted with the zoning created for the 1996 census. The other loading barely considered as related, regards the total number of people living in traditional built homes (TRADHOME, -0.50), which is associated with subsistence agriculture and degraded rangelands. The eigenvalue and contribution to the overall variance is, however, the lowest and could be dropped from the overall results without any loss of provincial description. It is shown because it does describe and highlight spatially (Figure 6.2l) the levels of low intensity transformation within the province. The Msinga and Ndwendwe magisterial districts have the largest factor scores (see Figure 1.10 and Table 1.8).

6.3.3 The Landscape Pattern Organization in KwaZulu-Natal

Significant eigenvalues were calculated for five axis factors from the landscape mosaic pattern indicators explaining 88% of the variation among indicators in the dataset (Table 6.1). The factor loadings are illustrated in Table 6.3. In KwaZulu-Natal magisterial districts, indicators depicting contagion and texture measures of diversity and dominance dominated the first axis (Figure 6.3a). The latter strong inverse association with the diversity and dominance measures indicated that magisterial districts in the Maputaland, coastal, Midlands and parts of the Zululand region are characterized by a high population diversity of classes in relative equity. Whereas one coastal district (dominated by sugarcane) and much of the districts in the interior grassland areas are characterized by large contiguous patches. The second axis gradient contrasted districts with large mean core areas per patch of LCLU versus those districts with large densities of core area patches (Figure 6.3b). This axis largely reflects class-fragmented districts from districts with lower class fragmentation and large patches. Axis three characterizes the higher complexity of patch shapes in mainly the Midlands and Zululand regions versus districts with richer and higher densities of classes found in the economic core area and Maputaland region (Figure 6.3c). Class richness is a product both of exposure to human interference and intensity of human activity, and components of natural landscape diversity found along the north coast. Indicators of distances between patches (Figures 6.3d and e) dominate the fourth and fifth factors. As with other research experiences (e.g., Cain et al., 1997; Riitters et al., 1995) the results here confirm from a statistical point of view that, most landscape mosaic pattern indicators actually measure one of just a few independent dimensions of pattern. Many indicators are redundant, which appears to dampen the need to calculate many pattern metrics in this region of South Africa.

6.3.4 Regional Geographic Clusters

Figure 6.4a, b, and c presents the results obtained by hierarchical and *k*-means clustering. Geographically compact groups were obtained without applying any constraint of geographic contiguity. This indicates strong regional trends in all the datasets subject to the analysis. The general structure consists of clumped groups of magisterial districts following a pattern from the coast to the Drakensberg Escarpment or from the northern Zululand woodlands to the high grassland regions. The use of magisterial districts suggests that the analysis of LCLU and landscape pattern indicators support claims by Cain et al. (1997) that land patterns are more

Table 6.3: Factor loadings from principal component analysis with a varimax rotation for the landscape pattern indicators derived from the 1996 magisterial districts.[†]

Indicator[‡]	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
LPI	**0.95**	-0.11	0.11	-0.05	-0.10
NP	0.38	**-0.74**	0.35	0.17	-0.11
PD	0.36	**-0.76**	-0.48	-0.08	-0.07
MPS	-0.30	**0.90**	0.07	-0.01	0.19
PSSD	**0.86**	0.21	0.37	0.08	0.03
PSCV	**0.83**	-0.22	0.47	0.10	-0.10
MSI	**-0.79**	0.46	-0.09	-0.14	0.30
AWMSI	**0.66**	-0.30	**0.59**	0.07	0.09
FD	**-0.63**	0.08	0.21	-0.19	0.41
MPFD	**-0.65**	0.42	-0.14	-0.23	0.28
AWMPFD	0.40	-0.14	**0.84**	0.17	0.12
TCA	**0.71**	0.49	-0.10	0.05	-0.07
NCA	-0.14	**-0.85**	0.28	0.01	-0.03
CAD	0.02	**-0.92**	-0.27	-0.11	0.04
MCAPP	-0.22	**0.93**	0.06	0.01	0.16
PCASD	**0.86**	0.23	0.34	0.08	0.02
PCACV	**0.83**	-0.24	0.46	0.10	-0.10
MAPDC	0.19	**0.92**	0.03	0.13	0.05
DCASD	**0.72**	0.34	**0.56**	0.13	-0.07
DCACV	**0.86**	-0.26	0.37	0.11	-0.13
TCA_P	**0.61**	**0.70**	0.01	0.01	-0.19
MCA_P	**-0.65**	0.47	0.08	0.13	0.20
MNND	0.01	**0.58**	-0.04	**0.71**	0.24
NNSD	-0.05	0.43	-0.02	0.48	**0.74**
NNCV	-0.16	0.07	0.16	-0.01	**0.90**
MPI	**0.53**	0.10	**0.65**	-0.10	0.05
SHDI	**-0.94**	0.01	0.01	0.25	0.08
SDI	**-0.97**	0.07	0.04	0.11	0.08
MSDI	**-0.97**	0.09	-0.05	0.12	0.08
CR	-0.09	-0.06	0.22	**0.79**	-0.01
CRD	0.25	-0.25	**-0.76**	-0.16	-0.12
SHEI	**-0.97**	0.02	-0.04	-0.01	0.04
SEI	**-0.97**	0.06	0.02	0.05	0.06
MSEI	**-0.97**	0.09	-0.07	-0.05	0.05
II	**-0.78**	0.11	-0.02	0.22	-0.14
CI	**0.96**	0.04	0.03	0.03	-0.04

[†] Factor loadings > 0.50 are indicated in bold, those factors > 0.70 are considered significant.
[‡] Variable definitions are found in Chapter 1, Table 1.5.

homogeneous within areal units that roughly correspond to physiographic and political economy processes that determine land cover pattern over large regions. The magisterial districts are defined not unlike catchments, as their boundaries tend to follow major rivers and physiographic divides, with minor exceptions in the northern Zululand region.

The unimodal ordination and hierarchical clustering analyses derived five "co-evolved" LCLU regions within the province (Figure 6.4a). These regions correspond to the spatial economic development of the province emanating outwards from the Durban metropolitan economic core. Durban harbor started as the original colony by the British on the east coast of South Africa in 1835, with Pietermaritzburg being founded just inland from Durban in 1838. Since 1911, Durban has witnessed an economic consolidation due to its strategic location

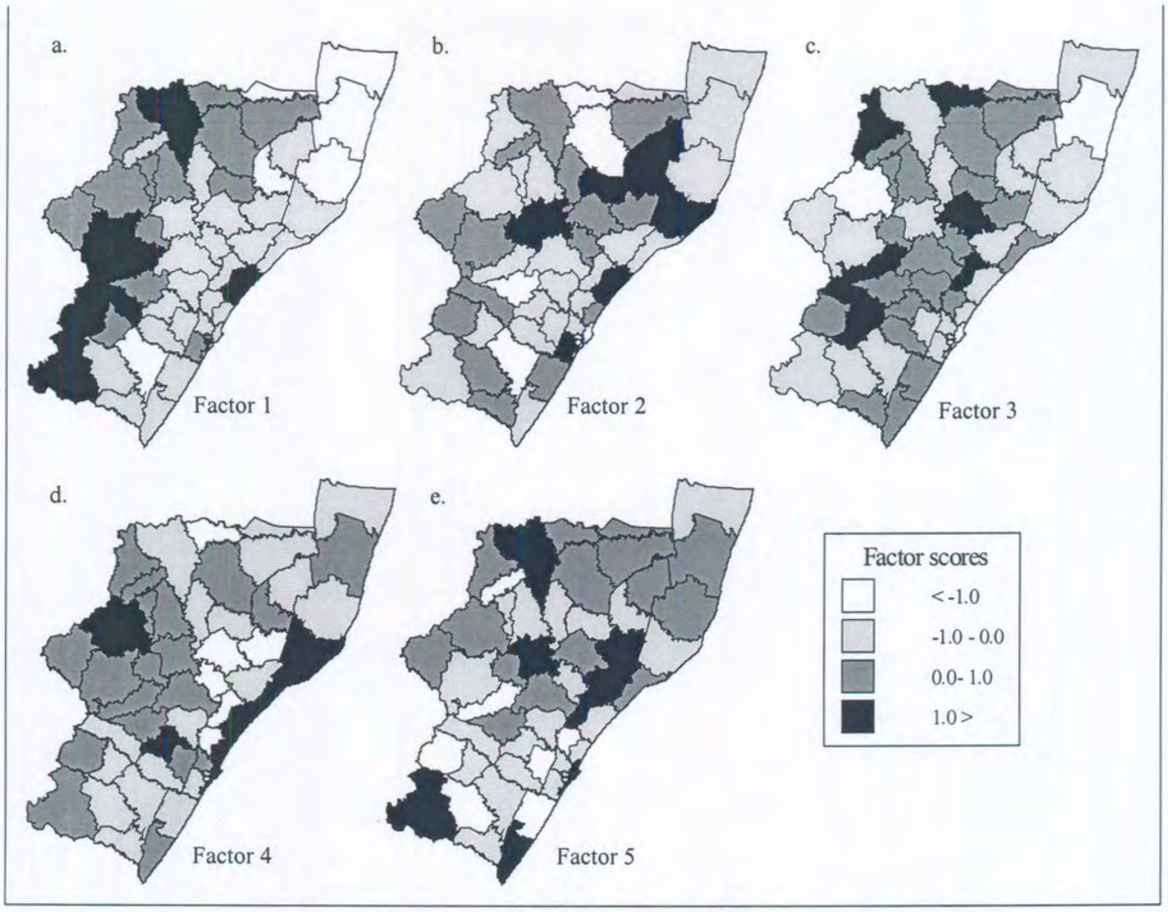

Figure 6.3: Factor patterns of variation derived from principal component analysis of the landscape mosaic pattern indicators.

and proximity to the Gauteng province mining-industrial metropolitan region (Browett, 1976). This proximity has also driven its emergence as the eighth busiest port in Africa (see Christopher, 1982). At the analysis scale of magisterial district, the pattern is similar to Von Thünen's (1826; see Bradford and Kent, 1986) prediction of zones of intensity in economic activity, diffusing outwards via an economic core-periphery pattern as defined by Friedmann (1972). The pattern for KwaZulu-Natal is very similar to the development pattern described for New South Wales, Australia by Rutherford et al. (1966; see Haggett et al., 1977). In this case the economic core is based at Sydney (with its industrial habor) and renewable resource zones emanate out from the core to the interior bush. The regionalization of KwaZulu-Natal illustrates a gradient from urban-industrial core to sugarcane-forestry, agriculture-forestry, and rural African subsistence regions.

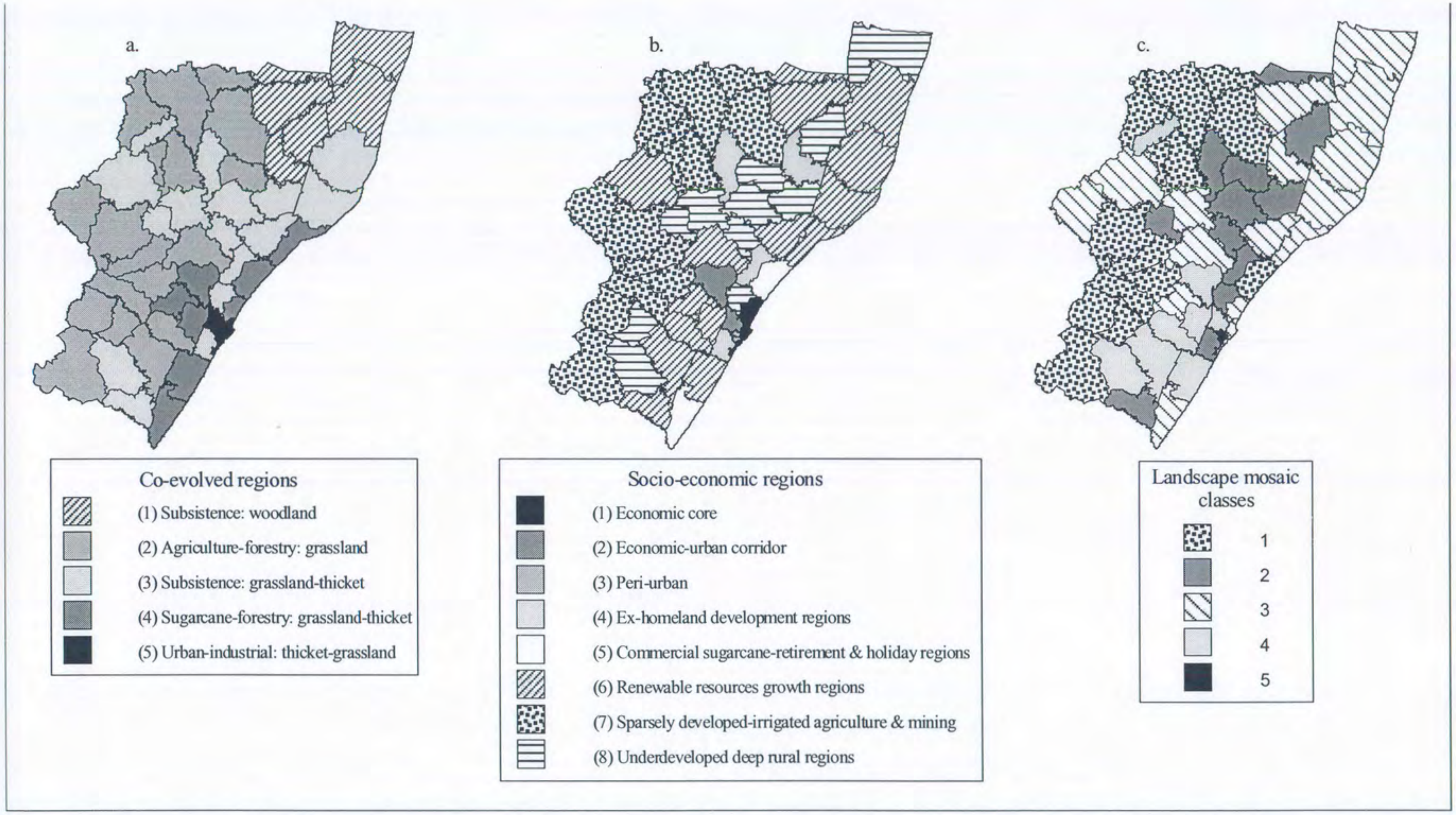

Figure 6.4: Mapping of the clusters produced from hierarchical and *k*-means cluster classification procedures on the dimensions derived for each data set.

In the case of this province, the policy of homeland separate development created by the Ex-apartheid State distorts the land-use intensity gradient (see Fair and Schmidt, 1974). In particular the subsistence:grassland-thicket zone has three districts, Umbumbulu, Ndwendwe, and Mapumulo (Figure 1.10), situated within near proximity of two major economic zones. These districts are not consistent with the economic intensity development pattern. These districts represent ex-homeland regions created close to the White controlled commercial farming and industrial core areas for African labor exchange purposes, owing to their failure to develop economic core activities in their own right due to past government economic policy (see Fair and Schmidt, 1974; Board, 1976).

The five zones were also analyzed for their association with dominant landscape structures as developed in Chapter 3. Figure 6.5 details the dominant landscapes found within each magisterial district, while the dominant landscapes identifying the five co-evolved regions are: (1) coastal undulating/flat dry; (2) highland undulating/flat moist; (3) highlands undulating/flat dry; (4) lowlands undulating/flat moist; and (5) coastal undulating/flat moist. The most striking feature of this result is the poor moisture regimes of the ex-KwaZulu homeland areas, which would have partly hampered commercial dryland agriculture and plantation forestry development (and therefore the first stages of economic development). An ANOVA was performed to determine whether there were statistically significant differences in co-evolved regions based on the variety of landscape types (Figure 3.5) found within a magisterial district. The hypothesis considered was that the diversity of LCLUs found in a district was dependent on the variety of the original landscapes found within that district. Since the regions were developed from ordination axes of the diversity and abundance of LCLU types this could be tested (a Spearman rank correlation of landscape variety against DCA axis 1 was -0.41). The analysis postulated that the properties of the physical environment still significantly affect spatial patterns of human activity, despite uneven development patterns determined by past government policy. The landscape diversity explained 41% ($N= 52$; $P < 0.0001$) of the spatial structure derived from LCLU analysis. By removing current magisterial districts that were completely ex-KwaZulu homeland territory (see Figure 1.10b), a moderate increase to 52% ($N = 37$; $P < 0.0001$) could be explained by landscape diversity. It can be tentatively concluded that the co-evolved regions of development within KwaZulu-Natal are partly due to physical environment constraints and opportunities. Nevertheless, former apartheid policy and other economic development instruments have added distortions to the present pattern.

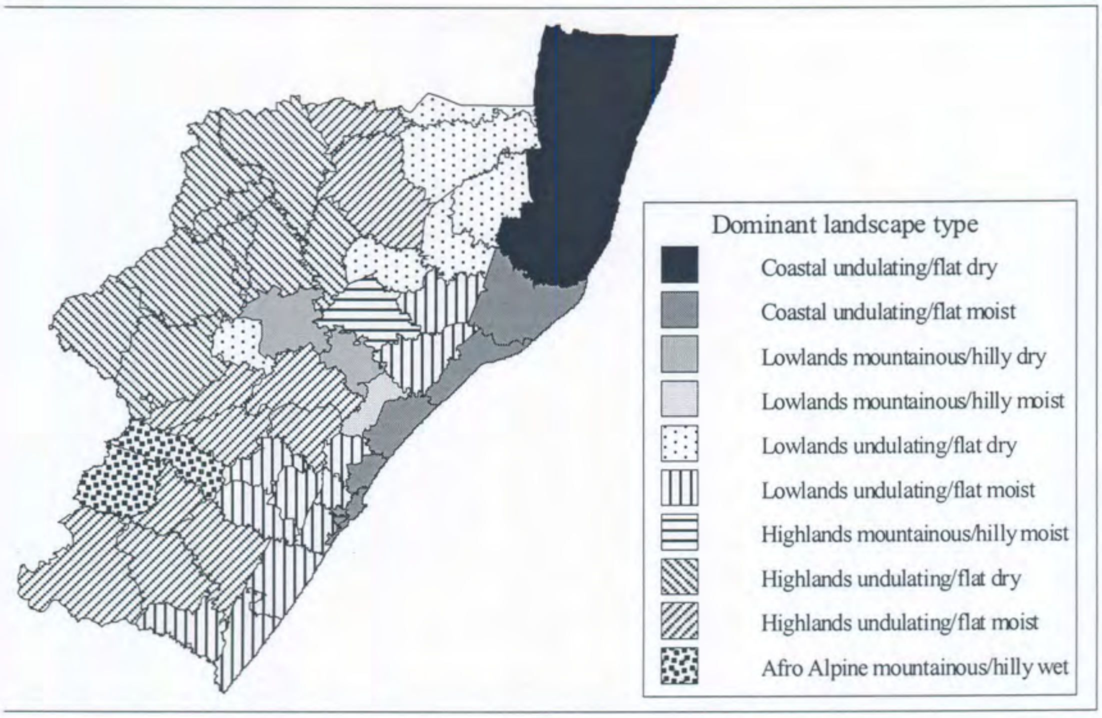

Figure 6.5: The landscape types identified in Chapter 3 are used to identify the dominant class for each magisterial district based on a simple majority.

Figure 6.4b illustrates the result obtained from *k*-means clustering after examining for values of *k* (the number of clusters) from 5 to 13. There was strong regional socio-economic-environmental trends in the data and the clustering generally showed that above thirteen groups, many local minima are found with very similar values for the within-group sums of squares criterion, so that no single clustering structure emerges; this is why the analysis was stopped at thirteen groups. The maps for each clustering criterion were examined visually and with the hierarchical linkage plots. A natural level of eight homogeneous clustered regions was selected, as these could be explained based on other independent criteria (see Legendre and Legendre, 1998). Using terminology developed by Mydral (1958) the significance of the results from the PCA and clustering of the socio-economic-environmental indicators is addressed. Myrdal (1958) coined the terms spread and backwash to describe the various economic and social effects associated with unbalanced growth, with spread effects being beneficial to the periphery and backwash effects as detrimental. The relative strengths and spatial distribution of these effects determine whether the gap between core and periphery is widening or narrowing. Spread effects are the mechanism whereby growth is transmitted from core to periphery (i.e., growth at the core may be expected to generate demands for the products of the periphery). On the flipside, backwash effects show evidence that growth may seem to be transmitted to the periphery but instead are actually refocusing growth at the core (i.e., capital transferred to the periphery in return for its products 'leaks' back to the core because it is spent on goods which the periphery cannot provide).

PCA factors one and two show evidence of the spread effect. The first factor can be regarded as society's ability to consume and the volume of entrepreneurial activity, which would be absent or poorly represented in areas where backwash effects are dominant. In the case of KwaZulu-Natal, the backwash effects are most pronounced near the economic core area (Figure 6.2b), especially within ex-KwaZulu homeland areas. The overflow of wealth has ensured that the spread effects are strongest in the magisterial districts in the immediate vicinity of the core (Figure 6.2a).

The landscape mosaic pattern indicators clustered tightly together into five classes (Figure 6.4c) which were then defined on a continuum based on their ability to conserve resources and maintain biodiversity as defined by Ludwig (1999), described in Chapter 2 (Figure 2.5), and by mosaic pattern characteristics outlined by Forman (1995). Class three represents many of the economically active areas, but contain similar landscape mosaic structure as Maputaland and other poor diverse homeland districts, such as Msinga. Classes one and two represent magisterial districts that would be considered to be functioning well for conservation purposes except for the Lower Tugela district which is completely covered in sugarcane, which mimics natural grassland pattern. Several of the magisterial districts consisting of ex-KwaZulu homeland areas have landscape pattern compositions that are moderate to weak in functionality. These districts had higher proportions of high intensity and low intensity transformed land than the other ex-homeland areas. Results from a contingency table analysis were used to compare the landscape pattern against the socio-economic regions and co-evolved regions. The hypothesis being that the landscape patterns and spatial distribution among the magisterial districts are dependent on the past and present socio-economic development. The p value for the Pearson chi-square ($p < 0.0001$, d.f. 35) for the landscape ranked clusters against the co-evolved regions and against the socio-economic regions ($p < 0.0001$, d.f. 42) leads one to believe that the landscape clusters are dependent of the economic clusters (H_0: no interaction between landscape pattern and human economic development). Since the significance tests could be suspect because of sparsely populated cells, Cramer V and contingency coefficients (Systat 8.1, 1998) were calculated to adjust for misleading interpretations. They were, respectively, 0.59 and 0.76 for landscape versus co-evolved regions and, 0.76 and 0.84 for landscape versus socio-economic region, with numbers approaching one conveying dependency among the tested variables. In this case, the socio-economic regions appear to provide a better predictor of magisterial district landscape "health" than the calculated co-evolved regions derived from LCLU data. The measurement of the total mosaic of LCLUs do become confounded in the clustering operation because of pattern similarities found in districts with complete habitat versus habitat replaced with one agriculture cover type or diverse areas mimicking high intensity human-use areas.

6.3.5 Pattern Recognition Results

The CN2 algorithm produced stable results of if-then rules for identifying all the data set clusters against every other data set used in the analysis. Because the pattern search algorithm uses exact rule definitions, based on the data resolution provided to it there is a tendency for the if-then results to appear overly precise in their definition. For example, many of the variables are defined to two decimal places, however this may be spurious precision, and thus the results should be interpreted in a more generalized manner. Tables 6.4 through 6.7 provide the if-then rule complexes for each cluster region, many of the regions required up to four sets of rules for definition. This pattern recognition algorithm makes it clear that by its procedures many of the "homogeneous" clusters have internal variation that cannot be defined by one rule set and instead provide evidence towards local minima requiring separate definitions within many of the cluster groups for either data set. This is more than likely an artifact of the processing of the regional clusters based on the classification of linearly derived factor and correspondence analysis scores, which will integrate correlated variables into one dimension. The pattern recognition algorithm uses the original raw values to develop rules for another data sets regional clusters, therefore loosing any previous indicator variable relationships between data set groups.

Table 6.4 illustrates if-then rules for the landscape pattern indicators that identify the socio-economic regions. The pattern in the cluster definitions shows that classes one and two can be defined by shape and nearest neighbor indicators, class three by patchiness, classes four through seven by patch size and feature richness, and class eight by patch shape complexity and landscape diversity. Table 6.5 provides further evidence of Western style development's detrimental effects on the environment. Class one is telling, essentially to have near-pristine grassland landscapes the people living there should remain without basic standards of living (e.g., running water, electricity, sanitation, etc.), and therefore stymied development and stagnant poverty. In contrast, classes six and seven are identified by human population density, especially the amount of men that infiltrate the economic core, leaving their families behind in the rural areas, which explains the presence of the low male to female ratios in classes three and four (see example systems model outlined in Chapter 2). Tables 6.5 and 6.6 provide the rules derived from the socio-economic-environmental and landscape pattern indicators for defining the co-evolved regions. In Table 6.6 class three is extremely variable showing the extreme differences in development paths taken within various areas of the former KwaZulu and Transkei homeland territories. Class one shows the 'cut off from society' and wilderness character of the Maputaland

Table 6.4: If-then rules of landscape pattern indicators describing clusters developed by PCA classification of the socio-economic-environmental indicators.[†]

Class	Rule set 1	Rule set 2	Rule set 3
1	MPS < 518 MNND > 1949		
2	MPS > 251 PSSD < 1404	NNCV < 184	
3	NP < 71		
4	PSSD < 2506 MAPDC > 438	186.00 < NP < 198	
5	MAPDC > 657	MPS > 391 TCA_P < 78%	
6	LPI < 24 NCA < 1053 MAPDC < 438 CR > 12	LPI < 34 MCA_P > 34% CR > 15	
7	MPS < 553 PSCV > 866	PSSD < 3135 PCACV > 762	
8	PSSD > 2507 FD > 1.28 MAPDC > 398 SHDI < 1.83	MSI > 1.73 MNND < 1058	FD < 1.27 MCA_P > 34%

[†] Variable definitions are found in Chapter 1, Table 1.5.

Table 6.5: If-then rules of socio-economic-environment indicators describing clusters developed by PCA classification of the landscape mosaic pattern indicators.[†]

Class	Rule set 1	Rule set 2	Rule set 3
1	SHCK_BCK > 26% GRS_PER > 50%	RATIO_MF > 1.0	
2	T_PER > 0.4% HOSTEL < 45 PERCAPINC < 1726	T_PER > 21% PERCAPINC < 2504	
3	TRADHOME < 24824 ROOM > 255 SERVE_I > 83% SE_INDEX < 134	M_PER > 1.4% RETIRE > 63 UPGRADE > 80%	PARK_PER > 5% DEVELOP < 75%
4	HOMELESS < 13 DRY_PER > 14%	UT_PER < 54% SERVE_I >99%	NR_INDST > 2961 RETIRE > 1129
5	POPDEN > 27		

[†] Variable definitions are found in Appendix A.

Table 6.6: If-then rules of socio-economic-environment indicators describing clusters developed by DCA classification of the LCLU abundance data.†

Class	Rule set 1	Rule set 2	Rule set 3	Rule set 4
1	PARK_PER > 7% TELSHAREPR < 0.33	RR_INDST < 127		
2	GRS_PER > 49%	POPDEN < 0.70 PLNT_PER > 19%		
3	RR_INDST > 137 A_LITERACY < 81% LOWI_PER > 25%	UT_PER > 51% RATIO_MF < 0.83 FOR_PER > 26%	POPTOTAL > 220366 WET_PER > 3%	POPTOTAL > 193529 DEPEND < 80.50
4	DRY_PER > 18%	RR_INDST > 5823		
5	PROXH2O > 92%			

† Variable definitions are found in Appendix A.

Table 6.7: If-then rules of landscape pattern indicators describing clusters developed by DCA classification of the LCLU abundance data.†

Class	Rule set 1	Rule set 2	Rule set 3
1	LPI < 13	MPFD > 1.08	LPI < 47 MPI > 2645
2	MPS < 553 PSCV > 840	PSCV < 669 FD > 1.29 MPFD < 1.07	
3	MPFD > 1.07 NNCV > 160 SHDI < 1.73	NP < 701 PSSD < 5426 FD > 1.30 MCAPP > 393	169 < NNCV < 174
4	LPI > 17 MPS > 263 DCACV > 451 II > 58	MAPDC > 657	LPI < 52 NNCV < 158
5	PSSD < 1404		

† Variable definitions are found in Chapter 1, Table 1.5.

region with low numbers of available telephone shares and extensive conservation areas. Class five is interesting as it illustrates that the high access to safe running water is the most important indicator defining the economic core. The class rule definitions in Table 6.7 follow the same general pattern as for class definitions in Table 6.4.

6.3.6 Implications for Planning Avian Conservation Persistence

The priority conservation grid cells based on the "ideal" conservation system selection derived in Chapter 4 (Figure 4.7) were overlaid on the magisterial districts to identify districts that had more than a third of at least one cell covering them. Figure 6.6 details the magisterial districts that would be required to implement landscape management plans for sustainable avian conservation. The first thing to note from this comparison is the grouping nature of the grid cells, which seem to be defined by major river basin boundaries. The Drakensberg group is defined by the Mooi and Buffalo River valleys, Maputaland is defined as areas north of the Black and White Mfolozi Rivers, the Midlands group is defined south of the Tugela and Mooi River valleys but north of the Umzimkulu River valley, and the Zululand group is nestled between the Tugela, and White Mfolozi rivers with cells primarily along the entire length of the Mhlatuze River. This result provides further evidence for previous studies conducted by Clancey (1994) and in Chapter 4 on the zoogeographic nature of river valleys as barriers to avian dispersal in South Africa, with special reference to KwaZulu-Natal province.

Table 6.8 illustrates the comparison of magisterial district against the socio-economic condition and landscape mosaic. Six of the magisterial districts requiring conservation action are considered severely underdeveloped African rural areas, and they cover three of the bird conservation regions. Nine of the magisterial districts are classed as sparsely developed-irrigated agriculture and mining, these districts from the PCA analysis appear to be in a stagnant economic development cycle but with healthy landscape mosaic structure for biodiversity (i.e., low landscape diversity and high contagion of natural vegetation cover). Of concern are the third of the magisterial districts that are classified as renewable resource growth regions. These areas represent the "economic frontier" of the province, consisting of environmental and human resource potential for further economic development. These districts contain already poor to fair landscape mosaic patterns, but areas like Eshowe are already showing a trend towards low landscape diversity with high local diversity caused by commercial agricultural development and over grazing. These districts will require immediate integration of landscape conservation and economic development plans to ensure an equitable trade-off between avian diversity conservation, and human developmental needs. Chatsworth and Umlazi represent districts that are fully dysfunctional for long-term avian diversity maintenance; with poor landscape structure representing relict stands of habitat (e.g., McIntyre and Hobbs, 1999).

Many of the districts require that particular physiographic features will be required to be protected. These areas include the central and northern sections of the Drakensberg escarpment, the Lebombo Mountains, and sections of eleven major rivers or their river mouths (Table 6.8). In particular, entire river stretches that must be buffered and considered in an avian conservation plan include the Mhlatuze, Pongola and Mkuze Rivers, with the Mhlatuze River mouth at Richard's bay also requiring attention. Other river sections include the entire upper reaches of

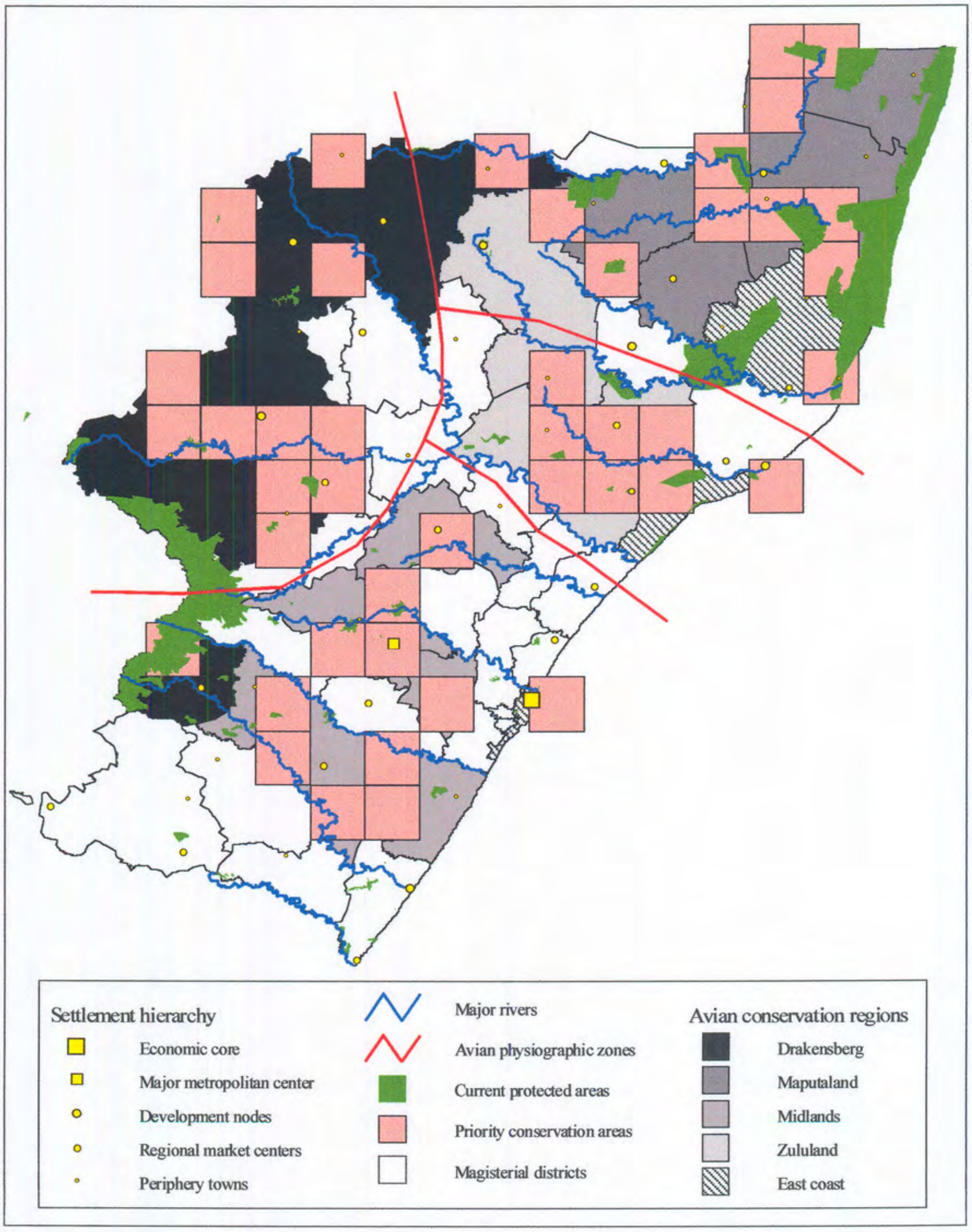

Figure 6.6: Priority avian conservation areas from the "ideal" model developed in Chapter 4, associated magisterial districts, and a general regionalization of the bird conservation areas by physiographic boundaries.

Table 6.8: Magisterial districts requiring landscape conservation plans for avian conservation, with associated socio-economic factors that will need to be addressed for sustainable conservation (also see Table 6.5 and 6.6).

Conservation region	Magisterial district	Socio-economic region	Landscape mosaic	Priority habitats
Drakensberg	Bergville	Low development	3	Grass; forest; thicket[†, ‡]
Drakensberg	Estcourt	Low development	1	Grass; thicket; woodland[‡]
Drakensberg	Dannhauser	Low development	4	Grass; wetland; woodland[‡]
Drakensberg	Kliprivier	Renewable resource	3	Grass; forest; thicket; woodland[†, ‡]
Drakensberg	Newcastle	Low development	1	Grass; forest[†]
Drakensberg	Paulpietersburg	Low development	1	Grassland; forest; wetland[†, ‡]
Drakensberg	Underberg	Low development	1	Grass; shrubland[†]
Drakensberg	Utrecht	Low development	1	Grass; wetland[†]
East Coast	Durban [*]	Economic core	3	Forest; bay mudflats; thicket[‡]
East Coast	Hlabisa	Renewable resource	3	Forest; wetland; woodland[‡]
East Coast	Mtunzini [*]	Renewable resource	3	Forest; thicket; bay mudflats[‡]
Maputaland	Ingwavuma	Underdeveloped	3	Woodland; forest; wetland[§, ‡]
Maputaland	Ngotshe	Renewable resource	3	Woodland; forest; grass; wetland[§, ‡]
Maputaland	Nongoma	Underdeveloped	2	Forest; grassland; woodland[§]
Maputaland	Ubombo	Renewable resource	3	Woodland; forest; wetland[§, ‡]
Midlands	Camperdown	Renewable resource	4	Thicket; grass; woodland
Midlands	Ixopo	Renewable resource	4	Grass; forest; thicket[‡]
Midlands	Lions River	Low development	1	Grass; forest; wetland[‡]
Midlands	Pietermaritzburg	Renewable resource	3	Grass; forest; wetland; thicket[‡]
Midlands	Polela	Underdeveloped	1	Grass; forest; wetland[‡]
Midlands	Umvoti	Renewable resource	3	Grass; forest[‡]
Midlands	Umzinto	Renewable resource	4	Forest; thicket; grass[‡]
Zululand	Babanango	Underdeveloped	2	Grass; thicket[‡]
Zululand	Eshowe	Renewable resource	3	Forest; thicket; grass[‡]
Zululand	Mthonjaneni	Underdeveloped	2	Woodland; thicket; grass[‡]
Zululand	Nkandla	Underdeveloped	2	Grass; forest; thicket[‡]
Zululand	Vryheid	Low development	1	Grass; woodland; forest

[†] The primary conservation area in this magisterial district should be along the escarpment.
[‡] The primary conservation area in this magisterial district should include areas along major rivers or river mouths; see Figure 1.2a.
[§] The primary conservation area in this magisterial district should include the Lebombo Mountains.
[*] Durban and Richards bay are outliers for conservation action as noted in Chapter 4, because of the use of their mudflats and fishing trawler refuse by a large diversity of southern palearctic ocean birds. These bays, however, were important to birds in historical times and should be restored.

the Tugela, Umvoti, and Mgeni Rivers (but includes the Mgeni River mouth), as well as the middle stretches of the Mkomasi and Mzimkhulu Rivers.

As discussed in earlier chapters, the long-term conservation of biological diversity is dependent not only on the establishment of representative protected areas, but also on maintaining hospitable environments and viable populations within managed landscapes (Western, 1989; Hansen et al., 1991; Shafer, 1994). Since the landscape mosaic pattern metrics become inseparable at times when distinguishing between areas of complete or diverse natural habitat and areas of heavy human influence other representations are required. Table 6.9 presents results depicting the state of fragmentation in the non-degraded major vegetation classes in the province. These vegetation types were used earlier in a pattern analysis, which showed evidence of their relationship to ecologically grouped bird diversity patterns (see Chapter 5). Figure 6.7 illustrates the habitat rating results for each vegetation class and the total habitat connectivity within each magisterial district. The habitat connectivity map (Figure 6.7e) clearly displays a similar pattern developed earlier from a detrended correspondence analysis of the LCLU data set and the PCA and classification of the socio-economic-enviromental indicators. The loss of core and connected habitats emanates out from the Durban economic core as far north as Richards bay and then mostly skewed to the south along the coast and in the Midlands region. Earlier evidence from Chapter 5 showed that the bird assemblages along the East coast and Midlands regions were being dominated by generalist species able to exploit the smaller patches left inhospitable for interior core habitat specialist birds. The Nqutu magisterial district is the only outlier in this explanation.

Table 6.9: Magisterial districts requiring landscape conservation plans and the associated vegetation habitat ratings derived from pattern indicators. Habitat connectivity rating is provided using all habitat types to derive measure.

Magisterial district	Woodland	Forest	Thicket	Grassland	Habitat connectivity
Bergville	Poor	Poor	Moderate	Good	Fair
Estcourt	Fair	Poor	Moderate	Good	Good
Dannhauser	Poor	Moderate	Moderate	Poor	Moderate
Kliprivier	Poor	Poor	Fair	Fair	Fair
Newcastle	Poor	Moderate	Poor	Good	Good
Paulpietersburg	Poor	Moderate	Moderate	Fair	Moderate
Underberg	Poor	Poor	Poor	Good	Good
Utrecht	Poor	*None*	Poor	Good	Good
Durban †	*None*	Moderate	Poor	Poor	Poor
Hlabisa	Moderate	Good	Moderate	Poor	Moderate
Mtunzini †	*None*	Good	Moderate	Poor	Moderate
Ingwavuma	Moderate	Moderate	Good	Moderate	Moderate
Ngotshe	Good	Good	Poor	Moderate	Good
Nongoma	Moderate	Poor	Moderate	Moderate	Moderate
Ubombo	Good	Fair	Good	Poor	Fair
Camperdown	Poor	*None*	Moderate	Poor	Moderate
Ixopo	*None*	Fair	Moderate	Moderate	Moderate
Lions River	*None*	Moderate	Poor	Moderate	Moderate
Pietermaritzburg	*None*	Moderate	Moderate	Poor	Moderate
Polela	*None*	Moderate	Poor	Moderate	Moderate
Umvoti	Fair	Poor	Fair	Moderate	Moderate
Umzinto	*None*	Moderate	Good	Poor	Moderate
Babanango	*None*	*None*	Fair	Fair	Good
Eshowe	*None*	Poor	Moderate	Moderate	Moderate
Mthonjaneni	Good	*None*	Moderate	Moderate	Good
Nkandla	*None*	Good	Moderate	Fair	Fair
Vryheid	Good	Poor	Poor	Good	Good

† Durban and Richards bay are outliers for conservation action as noted in Chapter 4, because of the use of their mudflats and fishing trawler refuse by a large diversity of southern palearctic ocean birds. These bays, however, were important to birds in historical times and should be partially restored.

Many African cultures do not distinguish between the natural and human realm, as there is no clear-cut separation (Western, 1989). This contrasts the Western idea of nature and segregating it from humanity in formal parks and reserves, when most of the world's biodiversity is outside parks interacting (negatively and positively) with humans. The human realm occupies 95% of the Earth's surface and will one way or another affect the future of nature far more than the diminutive parks. Overall the formal IUCN protected area categories of strict nature reserve,

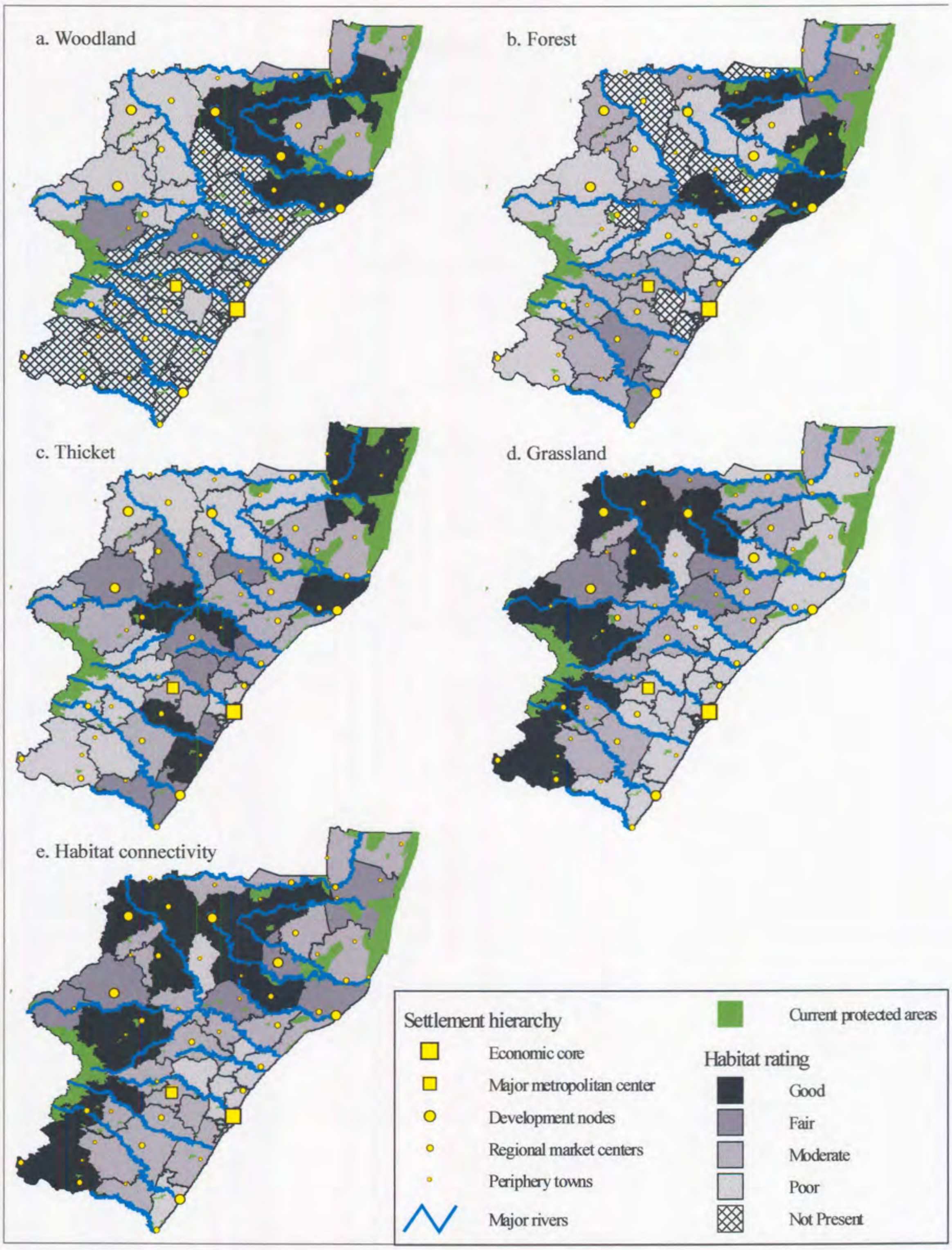

Figure 6.7: The following maps present a rating of the vegetation habitats: (a) to (d) based on patch size and fragmentation, and (e) is the habitat connectivity rating considering all available vegetation types residing in a magisterial district. The districts in a poor to moderate state (e) largely reside along the coast and in the Midlands region. These areas were shown in the analyses of Chapter 5 to be undergoing significant changes in bird assemblage structure because of high intensity transformation.

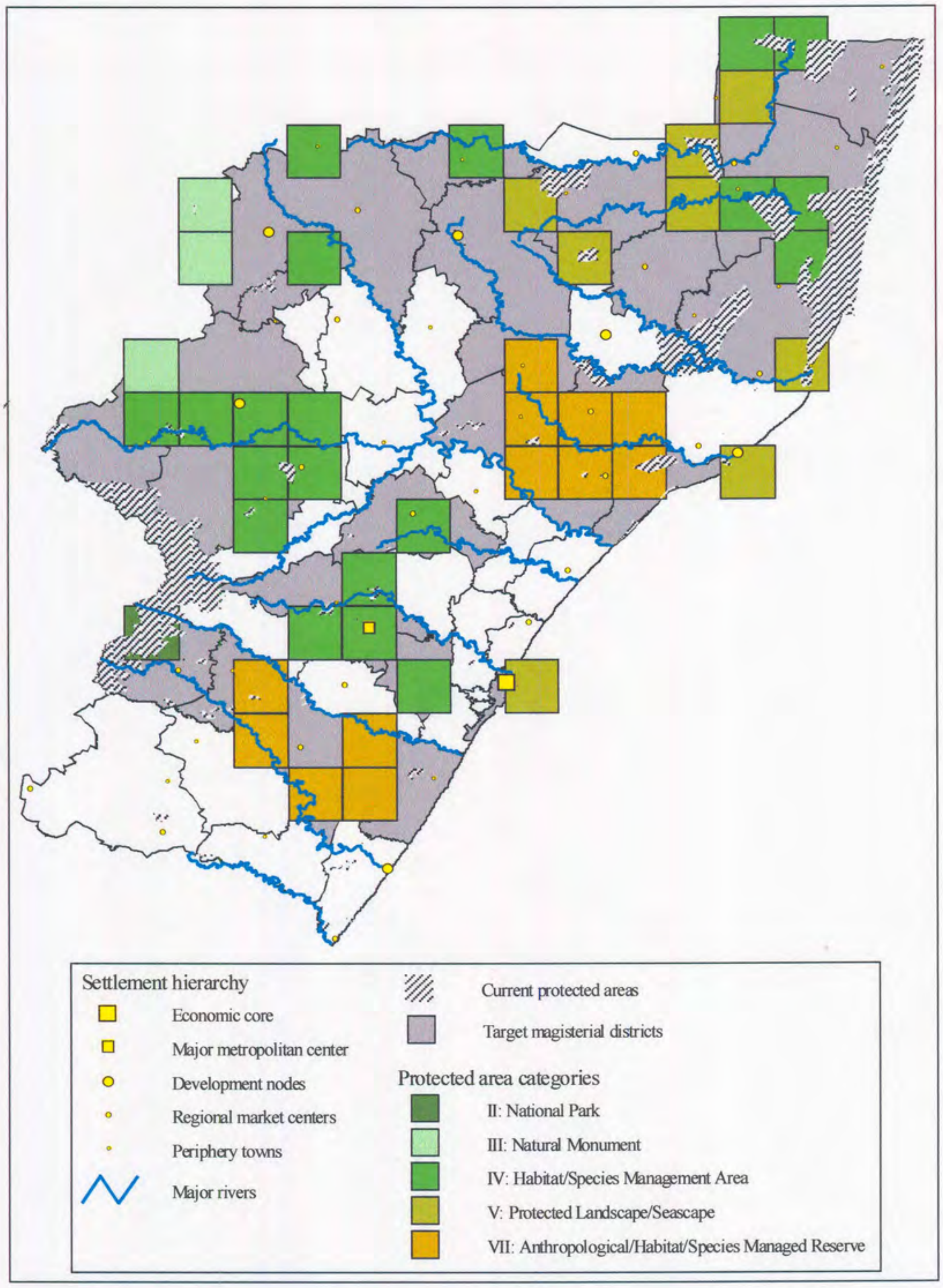

Figure 6.8: Proposed network and management categories of priority avian conservation areas.

wilderness area, and national park will need to be extended to allow for more models of conservation aligned with the co-evolutionary dynamic elucidated for an area. Figure 6.8 proposes a scenario of at least five types of protected area categories (IUCN, 1997, http://www.wcmc.org.uk/protected_areas/data/define.htm) that should be used for avian conservation across KwaZulu-Natal based on the analysis documented here. A new category VII is proposed, which has as its primary objective the maintenance of cultural and traditional attributes in combination with habitat/species management. This new category ensures that the African cultural heritage and co-evolution within particular areas is both rewarded for its positive effects on avian biodiversity preservation and left to be managed for sustainable biodiversity conservation as basic human development needs are met.

6.4 Discussion

The analysis reported in this chapter includes the landscape pattern and socio-economic-environmental indicators that would be available for use in most countries of the world. Therefore, the approach presented here can be extended to other areas, a property that is usually not found in studies of a transdisciplinary nature. This study explores our ability to develop better models for explaining human-conservation interactions that will be required to arrive at sustainable regional biodiversity conservation goals in developing regions of the world. Conservation, in this thesis, is considered a general landscape principle required across the whole region and demanding greater importance for the future sustainability of biodiversity than simply the use of formally protected areas. The shift to integrated landscape conservation management relies on two equally important assumptions. First, by acknowledging that humans are an integral part of any ecosystem (Cronon, 2000) and may be considered a "keystone species" in their own right (sensu O'Neill and Kahn, 2000), and second, that planning and management of the total human modified landscape matrix for biodiversity functionality will ensure biodiversity persistence both within formal protected areas and across a region (e.g., Forman, 1995).

The separate analyses of each data set have suggested a close dependency between socio-economic development, physical environment, and the measured landscape mosaic patterns. It is clear that the properties of the physical environment do significantly affect spatial patterns of human activity, but culture, personality, resource opportunities/constraints, and policy may significantly affect the evolving character of an area. Only the first four principal components were important in explaining the socio-economic-environmental situation of strong modernization and development needs gradients in the study area. Core-periphery structure of economic space provides the best model for explaining the past and present co-evolution of the landscape. Issues of unbalanced economic spatial growth can be explained by resource availability, access to infrastructure and former separate development policies (e.g., Fair and Schmidt, 1974).

In spite of these strong continuous gradients and distortions, the hierarchical and *k*-means clustering classification methods identify several homogeneous regions, which are isolated from one another by stable transition zones. The derived regions from each data set analyzed are explainable and comparable to other regional geographic studies conducted in Africa and to known issues in the province. The overall results can be compared to broadly similar studies by Forde (1968) in Ghana, Soja (1970) in Kenya, Lea (1972) in Swaziland, and Wienand (1973) in Nigeria. The results for Ghana, Kenya, and Nigeria also reached a similar conclusion by uncovering the structure and pattern of modernization and urbanization as the major landscape drivers. In the case of Swaziland (at least in 1972) the rural dimension of land ownership by Africans versus the European population was the main driver, with modernization gradients not dominating at that time.

The identified backwash effects are problematic because they still reflect past separate development policies of the former apartheid South Africa. Attempts to disperse economic activities might be expected to produce a uniform distribution of spread effects in the future (i.e., Reconstruction and Development Plan; Spatial Development Initiatives), but the data used in this study from 1996-97 does not yet show evidence of this. The economic development surface of KwaZulu-Natal (Figure 6.4b) resembles the hypothesis provided by Weinand (1973) for the economic development of Nigeria. Spread and backwash effects appear to decline in parallel throughout the province as distance from the Durban economic core increases. The economic frontier of the province provides evidence for a secondary core area (renewable resources growth regions), but beyond this there lies an extensive 'sparsely developed' irrigated agriculture and mining region within the high grasslands and a very underdeveloped rural African region in the thicket and woodland demarcated areas. This last region not only lacks substantial modern economic activity, but also is unable to provide the infrastructure necessary to attract such activities.

The use of LCLU to derive co-evolved areas of human-cultural influence and productivity turned out to be an important aspect of the space economy description. In this respect, satellite remote sensing derived LCLU patterns and the assumption of human land-use as a unimodal response model across a region derived explainable results. Like most spatial analysis techniques, some degree of caution needs to be exercised over the use of the results and the limitations of this approach need to be noted. The correct use of classified satellite imagery must have accompanying error and accuracy statistics. Fairbanks et al. (2000) noted that one of the key issues related to mapping accuracy, with the development of the South African National Land-Cover (NLC) database, is landscape complexity in terms of the mapping scale used. For example, sheets containing complex patterns and gradients of natural and degraded vegetation types (e.g., 2830 Richards Bay mapsheet, KwaZulu-Natal Province) were significantly harder to map than those containing significantly more (and often smaller) polygons that were based on uniform cover types with clearly definable boundaries (e.g., dryland maize cultivation in Free State Province grasslands). The use and interpretation of ecologically based ordination methods assumes that all features of a study site have been correctly and thoroughly recorded (e.g., Gauch, 1982; Jongman et al., 1995). The NLC had only thirty-one LCLU types defined for mapping (Thompson, 1996; Fairbanks and Thompson, 1996), and these classes were only the ones that could be reliably interpreted from 1:250 000 scale satellite imagery. Therefore, other important land-uses that define regions of the province (e.g., sheep and cattle grazing, horse farms, game farms, etc.) are not recorded and would most likely alter the results.

Socio-economic and biophysical factors interact to yield important landscape changes (Turner, 1989). The landscape mosaic pattern indicators provided important results for analyzing intensively managed landscapes and where the human impacts on the landscape are more noticeable. Of course, the effect of changing the scale of analysis would have an important impact on the results because all measures of landscape pattern are scale dependant (Turner et al., 1989; Haines-Young and Chopping, 1996). Nevertheless, relationships were evident between recorded socio-economic variables and the measured landscape mosaic pattern indicators. Contagion was low in the economically active areas and some ex-homeland areas suggesting that private and communal land is characterized by landscape with much spread out class types and that economically stagnant areas in the highland grasslands consist of landscapes with contiguous patches. An exception to this was found in the coastal magisterial district of Lower Tugela, which is dominated by continuous sugarcane plantations. The landscape structure and its functioning can have serious implications for the health of a landscape and its biodiversity. More survey and temporal analysis work will be needed to fully understand the association between patterns, landscape health, and biodiversity, as investigated in Chapter 5. It is necessary not only to measure diversity, dominance and patch size but also to examine other indexes to evaluate changes in landscape structure. Remote sensing and socio-economic information integrated within a GIS framework can form useful surrogates for monitoring the status and condition of landscapes and therefore have the potential to be useful indicators of environmental health (Frohn et al., 1996; Wood and Skole, 1998; O'Neill et al., 1999; Amissah-Arthur et al., 2000). The case study conducted provides a framework within which to consider issues of fragmentation with other spatial process in the context of land transformation or landscape change. A temporal analysis should be the next step to describe change in the landscapes or model them as a sequence of mosaics.

The required conservation action and socio-economic tension within the province proved to be quite telling. Fifteen of the magisterial districts required as priority bird diversity area are underdeveloped with needy populations. A landscape management system should be developed to provide quality core habitat for the bird diversity, while acknowledging the human impacts and influences happening around the target habitat areas, and addressing the basic human needs required in a region (i.e., access to water, sanitation, and communication services, support to women). The first criterion is to adequately represent all species of the target taxa, and second to represent the associated environmental processes as proposed in Chapter 4. Third, their arrangement on the landscape would have to be based on ideals of persistence, therefore representing appropriate habitat patch characteristics identified in Chapter 5 and protection of indispensable patterns. These top-priority patterns for protection, with no known substitute for their ecological benefits, are wide vegetated corridors protecting the identified major rivers, the natural environmental heterogeneity along the Drakensberg Escarpment, rivers mouths, larger estuary mudflats, connectivity for movement of species among large patches, and small patches and corridors providing heterogeneous bits of nature throughout the economic core and developing areas. Finally, since planning and management will more than likely need to be conducted on communal and private lands for off-reserve management, the socio-economic realities of the areas will need to be addressed to reduced social tension, which may ensure sustainable conservation initiatives. Human "quality of life" development should be allowed to go forward to the extent that they are compatible with the goal of maintaining native species and ecosystem diversity. The development of strategically “designed” future landscape plans should be a requirement to share ideas with communities on pathways to balancing conservation with the regional development needs. In particular, three primary landscape design options should be invoked. First, future development should increase densities in currently developed areas. Second, landscape or regional differences within a magisterial district should be recognized, with subsequent new developments concentrating in areas that are already developed for agriculture or more intensive human activities, while undeveloped or sensitive habitats in the other areas of a district should be conserved. Finally, the former homeland magisterial districts appear to be operating well for bird habitat needs, but the overly dominant effects of degraded lands may changes this situation in the future. These partially impacted lands should be given time to rest and be restored. Future human needs developments that will be required in these districts should follow the first two rules to reduce the extents of human impacts. These recommendations for KwaZulu-Natal province generally follow the "aggregate-with-outliers" principle developed by Forman (1995), and Forman and Collinge (1995). Land is best arranged ecologically by aggregating land-uses, yet maintaining small patches and corridors of nature throughout developed areas, as well as outliers of human activity spatially arranged along major zones between land-uses. Thus, a magisterial district containing a variance in grain size, especially coarse and fine grain, appears to be an important spatial configuration. The first two landscape mosaic classes (Figure 6.4c) adhere to this principle, while the third class reflects districts with increasing fine grained pattern from the increased perforations of the habitat by human land-uses. Magisterial districts in class five reflect homogeneous coarse grain classes of human land-use with minor components of remaining habitat. These pathways of landscape change through human input generally follow the co-evolutionary framework outlined in Chapter 2.

Results from the examination of KwaZulu-Natal's socio-economic-environmental, LCLU and landscape mosaic pattern characteristics provide support for the examination of cultural system development paths in conservation analysis. Along with economic geography models, culture should also be assigned a central role in any theory purporting to characterize the process of land-use intensification among rural African communities. Unfortunately, the analysis conducted here is limited by the absence of a temporal component, which could allow a predictive element. As an example of the interactions between these factors, regional economic shifts can bring population redistribution, which in turn, affects biodiversity through attendant land-use change. The spatial and statistical models will need to be applied again with a temporal data set of factors to develop possible alternative land-use "futures" resulting from various human-environment interactions.

6.5 Summary

Physical location and transportation costs often determine the profitability of an economic activity. In turn, that economic activity is the primary determiner of landscape pattern and change. There is tremendous opportunity for conservation science and landscape ecology to take advantage of the well-developed theories of human and economic geography (Thoman et al., 1962; Bradford and Kent, 1986; Healey and Ilbery, 1990). Other applicable areas, however not included in this study, include central place theory (e.g., Christaller, 1933; Berry and Pred, 1961), location theory (e.g., Isard, 1956; Hall, 1966; Smith, 1971), and market area analysis (e.g., Lösch, 1954). Location theory, for example, considers the value of various products and the cost of transporting them to a central market. The theory then predicts which product will be grown close to the market and which can be profitably grown at greater distances. These theories should be able to drive models of land-use change and assess producers and consumers ability to optimize their use of resources on the landscape, which can then be used to develop "spatial solutions" to protect biodiversity. The integration of human geography with landscape ecology seems to hold the potential for major breakthroughs in our understanding of landscapes (e.g., Behrens, 1996; O'Neill, 1999) and its application to sustainable biodiversity conservation strategies.

Re-integrating society with the environment and the goals of conservation is by its very nature problematical in as much as several potential solutions always appear in any aspect of societal life (i.e., cultural, religious, political, and economical) and how the environment may be addressed (e.g., Cronon, 2000). History and present experience show that controlling these problems in the context of the modern industrial complex is through mutual discussion and analytical discourse (see Chapter 2, Figure 2.5). An increase in the level of integration among fragmented disciplines (e.g., geography, biology, economics, anthropology, and sociology) to develop and arrive at multiple solutions for human and biodiversity survival within Africa could reduce the tension around the conservation issue. The idea that any one discipline has the correct analytical framework for this task is severely misguided.

A realistic philosophy for conservation must be connected with human survival and the support and participation of local communities (Tisdell, 1995). In North America and Australia where there is still land to spare and the human population growth rate is very low, the wilderness concept has real value (Noss, 1991). However, in Africa where land is in great demand and the population growth rate is high, it may be very unrealistic to set aside a large area of the continent for all time as wilderness areas (e.g., Soulé and Sanjayan, 1998; Musters et al., 2000). The Peace Parks concept, however, may eventually prove this position wrong, but Peace Parks are being designed under the premise of multiple-use areas with conservation principles (http://www.peace-parks.org.za). Nevertheless, the aesthetic appeal of wilderness and biodiversity seems insufficient in itself to justify perpetuating land-use at a level below the optimum, however as outlined any land-use must be planned equitably and ecologically within the overall constraints of the socio-cultural-economic and biotic landscape. When it comes down to the real point there are only two valid arguments to advance in support of biodiversity—its ecological value and its economic value to human "quality of life". The dictum for the developing countries of the world should become 'conservation as if people mattered and development as if nature mattered' (e.g., Adams and McShane, 1996).

7. Conclusions

> A river, with its waterfalls, wetlands and meadows, a lake, a hill, a cliff or individual rocks, a forest, and ancient trees standing singly ... If the inhabitants of a town were wise, they would seek to preserve these things, though at a considerable expense; for such things educate far more than any hired teachers or preachers, or any present recognized system of school education. I do not think them fit to be the founder of a state or even of a town who does not foresee the use of these things...
>
> -HENRY DAVID THOREAU, *Journal*, 1861

The studies documented in this thesis offer a series of conservation approaches and develops a framework for understanding and assessing landscape morphologies derived from human impact on the KwaZulu-Natal province, South Africa using both standard and original analysis strategies. The use of avian biodiversity as a bioindicator for levels of human impact provided a rather telling description of landscape development over the last 25 years. The analyses presented are intended to provide a framework derived from empirical results for subsequent more-detailed and quantitative studies.

Evaluating environmental change requires analysis of various relationships over time, between humans and biota/nature, focussing on their reciprocal impacts. Elucidating the history of the environment and changes which have taken place or which are likely to occur in the future requires knowledge of not only natural processes, but also human activity as well. To date many of the theories and techniques developed to make conservation more efficient miss the point that there is a paradox of management in conservation. The paradox states that the probability of having a significant effect is greater in small areas, whereas the probability of successful long-term management is greater in large areas. For example, we can see the result of protecting a rare butterfly or plant in a local grassland, but at the same time, over human generations the chance of finding the butterfly of plant at that same spot is low, whereas the region is likely to continue in similar form. Therefore, the prescriptive approaches to conservation including reserve selection algorithms, gap analysis, and other computerized approaches have only limited potential for conservation planning (Prendergast et al., 1999). Both landscape-level (i.e., top down) and species-level (i.e., bottom-up) approaches are required for practical conservation. More rather than less knowledge is required to make conservation decisions, which in turn should remain flexible. The role of adaptive environmental management to address local surprise and emergent regional change should be required for management of the total human landscape (e.g., Holling, 1986). This would acknowledge the dimensions of evolution, instability, and change in addressing the biodiversity crisis. Evolution in human systems is a continual, imperfect learning process, spurred by the difference between expectation and experience, but rarely providing enough information for a complete understanding. Consequently, adaptive management becomes a social as well as scientific process.

Like co-evolution, adaptive environmental management is on going. Most people think of the right policy and its proper implementation as setting a system on the right trajectory once and forever. For example, this is the case in reserve selection analysis or gap analysis where an overall strategy for conservation is pushed on a public as the final solution to conserve biodiversity. Or management procedures are proposed that offer a final and lasting solution to an environmental problem. Adaptive environmental management helps get people out of this mode, it also does not make the distinctions between scientific, expert and experiential knowledge that are typically made. So, like the co-evolutionary approach, shared learning among disciplines, modelers and technologists contributes to the adaptive approach required for total human landscape conservation, while the co-evolutionary approach adds in more of a social dimension required to understand tensions and emergent change.

A better understanding of biodiversity risk for models of conservation assessment and prioritization was presented. A theoretical foundation for the relationships between categories of social, economic and environmental indicator variables in models for biodiversity risk assessment were developed to enhance the complex biodiversity conservation debate. The analytical framework proposed could be used to gauge the sustainability of existing and future biodiversity conservation areas while remaining open to its own evolution when new knowledge is acquired. An underlying assumption of the approach is that a co-evolutionary relationship exists between social, cultural, economic and environmental systems, and that they cannot be addressed in a reductionist and deterministic manner. Current ecosystem management and biodiversity conservation deals with symptoms of environmental degradation rather than its causes. Co-evolutionary theory integrated into the larger analytical framework and principles of landscape ecology was used to demonstrate the development of landscapes and their effects on avian diversity. Landscape ecology has emerged as a discipline whose primary focus is the analysis of the ecological effects of environmental heterogeneity and pattern on ecological process. The fusion of co-evolutionary theory and landscape ecology makes for an exciting scientific synthesis in which to explain anthropogenic pressure on the landscape and ultimately to bring into question the sustainability of biodiversity conservation within regions of the world's developing nations.

The on-going development of socio-economic systems contrasted the Western model of development based on consumption with the rural African system. Avian diversity proved to be a fairly convincing indicator of landscape health, and illustrated what might happen to bird diversity and assemblage structure if development policy directs the former KwaZulu homeland areas to the same socio-economic "Western" consumption system as found in the "White" dominanted economic core. Consumption growth and the on-going development of socio-economic systems distance people from the environmental systems they are impacting (Norgaard, 1994). The methods focused on both trends and patterns of variance in a multivariate data matrix to identify co-evolved regions allowing identification of dominant trends as well as underlying tensions within a defined area. Potential sources of human insecurity and development patterns at odds with positive biodiversity survival can be identified within the co-evolved landscapes. These sources can then be targeted for political action and be used to inform public debate.

Many factors contribute to the avian composition and change of a region, and it cannot be expected that all relevant information can be anticipated or even fully represented in a GIS database. However, by examining those regions not well explained by the current efforts, future research can be targeted to better understand unique or localized effects on avian diversity. The methodologies used in this thesis should be supported by finer scaled studies with higher accuracy data. Landscape-level study provides a means to quantify and monitor broad-scale changes related to biodiversity and ecosystem processes. Species- or population level analysis can contribute a more mechanistic understanding of the impact of landscape change, while broader scale investigations provide information on broad-scale patterns that can enhance or constrain the conservation of biological diversity.

The work presented here is planned as the beginning of an ongoing research effort, and opens pathways to a much larger array of future research directions. The author recognizes that this research effort represents only a limited set of conditions within the synthesis of diverse information that will be required to develop realistic expectations for the task of sustainable biodiversity conservation. How extensible are the various approaches? What level of accuracy is required? How much error is allowed in databases from the socio-economic and ecological sectors? What is the optimal mix of computational and interpretative capabilities for producing high quality socio-economic, ecological, and conservation information? The problems call for interdisciplinary research to produce information useful to the development of conservation strategies, land characterization, extent of anthropogenic stress, and climate change models.

The best hope for all species is linked to a single uncompromisable human goal- the improvement of human welfare. Our future, and that of wildlife, is not an inevitability, but rather a matter of foresight, choice and action (Western, 1989) in directing the landscape changes to come in a sustainable manner through ecologically responsible spatial planning. These choices and action can only come from an approach based on co-evolutionary thought and shared learning among disciplines, system modelers and appropriate technology. As an understanding of relevant scales and types of information evolves and the power of synergistic relationships between available data is harnessed, the development of a regional management strategy to support conservation across the total human landscape may become a possibility.

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Appendix A

The following table describes the socio-economic and environmental variables used in Chapter 6. References to sources are also provided.

Sources

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Table A-1: Variable names and descriptions for socio-economic and environmental variables.

Acronym	**Description**
1996 Census data	
POPTOTAL	Population census
POPDEN	Population density
MALE96	Male population
FEMALE96	Female population
RATIO_MF	Ratio of males to females
AGE_0_4	Total number of children in the 0 - 4 years of age class
AGE_0_5	Total number of children in the 0 - 5 years of age class
AGE_5_14	Total number of school age children in the 5 - 14 years of age class
AGE_15_44	Total number of people in the 15 - 44 years prime working age class
AG_15_64	Total number of people in the 15 - 64 years complete working age class
AG_65_99	Total number of people in the 65 - 99 years retirement age class
NO_SCHL	Total number of children (5 - 14 years) not in school
IN_SCHL	Total number of children (5 - 14 years) in school
NO_DEGRE	Total number of people with no highschool diploma
YES_DEGR	Total number of people with a highschool diploma
CHLDNWRK	Total number of children (5 - 14 years) working
EMPLOYED	Total number of people (15 - 64 years) formally employed
UNMPLOY	Total number of people (15 - 64 years) not employed
DEP_RAT	Dependency ratio (children 0 - 14 years / total number employed)
POVERTY	Total number of people living in poverty (less than R18 000 per annum)
ABV_POVR	Total number of people living above poverty line (greater than R 18 000 per annum)
POV_RAT	Ratio of those in poverty to those living above poverty line
RR_INDST	Total number of people employed in renewable resource industries (e.g., agriculture, forestry, etc.)
NR_INDST	Total number of people employed in non-renewable resource industries (e.g., mining and quarrying)
MANUFAC	Total number of people employed in the commercial manufacturing sector
ENERGY	Total number of people employed in the energy production sector
CONSTRUC	Total number of people employed in the building construction sector
TRADE	Total number of people employed in the wholesale and retail trade sector
TRAN_COM	Total number of people employed in the transport and communications sector
BUS_SERV	Total number of people employed in the business services sector (e.g., insurance, banks, real estate)
SOC_SERV	Total number of people employed in the social services sector
PRIVATE	Total number of people employed in private households
EXT_ORG	Total number of people employed in exterritorial organizations
REP_FORG	Total number of people employed in representative foreign governments (e.g., diplomatic, NGO)
IND_NEC	Total number of people employed in industry NEC or unspecified
NO_APP	Total number of people employed in non-applicable industries by definition in census
NA_INST	Total number of people employed in non-applicable institutions by definition in census
HOUSE	Total number of people living in a formal Western style modern house
TRADHOME	Total number of people living in a African traditional house (e.g., made from natural materials)
FLAT	Total number of people living in flats in blocks (e.g., apartments)
TOWN	Total number of people living in townhouses or duplexes (e.g., condominiums)
RETIRE	Total number of people living in retirement villages or holiday retirement homes
ROOM	Total number of people living in a room of a shared house or flat
SHCK_BCK	Total number of people living in a informal dwelling/shack on private property (e.g., backyard or farm)
SHCK_EW	Total number of people living in a informal dwelling/shack illegally or on town council land

FLATLET	Total number of people living in a room or flatlet on shared property
CARAVAN	Total number of people living in a caravan or tent
HOMELESS	Total number of people living homeless
HOSTEL	Total number of people living in a workers hostel or institution (e.g., mining, mental hospital, prison)
1996-97 HSRC data	
SERVE_I	Service index is a composite index based on the following variables: ratio of population to police stations, post offices and hospital beds; ratio of road length to district area; ratio of 6 - 17 year olds to school; the percentage of dwellings that are fully serviced, informal, electrified formal, electrified informal, and number of telephone shares
SE_INDEX	Socio-economic index is a composite index based on the following variables: poverty gap, pupil:teacher ratio, dependency ratio, total number of households, and the population density
SAT_ENV	Satisfaction with the general environment and attractiveness of the area (%)
SAT_HOUSE	Satisfaction with the household's position (especially in a community context) (%)
SAT_ECON	Satisfaction with the economic situation (%)
SAT_SERVICE	Satisfaction with local facilities and services (%)
BASICS	Access to or possession of basic items (running water, electricity, flush toilet, and fridge in home) (%)
DEVELOP	Need for improving the general development situation (%)
BNEEDS	Need for addressing people's basic needs (provide clean water, healthy environment, health care, nutrition and job creation) (%)
UPGRADE	Need for upgrading of infrastructure (%)
SAT_LIFE	Satisfaction with life on the whole (%)
DEPEND	Need for improving administrative dependability and equity (%)
PROXH2O	Proximity to safe water (%)
ELECTRIC	Availability of electricity in homes (%)
REFUSE	Access to refuse removal and waste disposal services (%)
FTOILET	Proportion of households with access to a flush toilet (measure of sanitation) (%)
A_LITERACY	Adult literacy rate (total number of people with a minimum of five years schooling) (%)
F_LITERACY	Functional literacy rate (ability to read or write, but ability may not have been attained formally) (%)
PERCAPINC	Total per capita income
TOTPOLSTA	Total number of police stations
TOTPOSTOF	Total number of post offices
BEDSTOT	Total number of hospital beds
TELSHAREPR	Total telephone shares
Fairbanks et al. 2000	
FOR_PER	Percentage of land covered by forest and woodland
GRS_PER	Percentage of land covered by grassland
WET_PER	Percentage of land covered by waterbodies and wetlands
LOWI_PER	Percentage of land covered by subsistence agriculture
PLNT_PER	Percentage of land covered by exotic woodlots and commercial plantations
DRY_PER	Percentage of land covered by commercial dryland agriculture
IRR_PER	Percentage of land covered by commercial irrigated agriculture
URB_PER	Percentage of land covered by urban-residential or industrial land-use
UT_PER	Percentage land untransformed (e.g., "natural" state)
M_PER	Percentage land under low intensity transformation
T_PER	Percentage land under high intensity transformation
1998 KZNNCS †	
PARK_PER	Percentage land under conservation protection

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† KwaZulu-Natal Nature Conservation Services

Appendix B

The following manuscript is in revision for *Diversity and Distributions*. This small study outlines the method used to rank vegetation priority areas used in Chapter 3.

South African Vegetation Priority Conservation Areas: 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 underrepresented in formal national and provincial protected areas. The assessment highlights broad vegetation types that are currently threatened by human impacts or a lack of protection. Most vegetation types contain large tracts of natural vegetation, with little degradation and transformation. 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 goal. In addition to this current vulnerability assessment the ecological effect of the national road network is also evaluated. This provides an indication of the remaining untransformed area threatened by the road-effect zones in each vegetation type and can be used as a measure of potential threat facing that vegetation type due to future impacts and land use changes. An average of 5.5% of the area of each vegetation type is exposed to road-effects. Many of the grasslands, fynbos and thicket vegetation types face not only current land use threats, but may also be exposed to future threats due to a large road-effect zone. This investigation identifies areas where limited conservation resources should be concentrated by identifying vegetation types with high levels of current and potential anthropogenic land use and inadequate conservation efforts.

Keywords: Coarse-filter, biodiversity conservation, land-cover, vegetation types, road-effects

(A) INTRODUCTION

South Africa contains a wealth of biodiversity within its borders, unequalled by other temperate regions. With almost 50% of the world's biodiversity falling within tropical forests (Myers, 1997), of which South Africa has none (Midgley *et al.*, 1997), the country's contribution to global biodiversity is unexpectedly large. Inventoried species total over 250 mammals, 790 birds, 303 reptiles, 95 amphibians, 94 freshwater fish and 23420 flowering plants (Cowling, 1989; Groombridge, 1994; WRI, 1994; van Jaarsveld, 2000). Thus one begins to understand how South Africa earned its place in the top 25 most biodiverse nations in the world (WCMC, 1992; Conservation International, 1998). In addition to this ranking 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, and one of the 25 hotspots of global biodiversity (Myers *et al.*, 2000). These hotspots are areas of importance to conservation because of high levels of species richness, endemism and threat (Myers *et al.*, 1990; 2000). The Cape Floristic Region is one of the few hotspots to fall entirely within one country. It contains 8200 plant species of which 5682 are endemic and has already lost approximately 30.3% of its primary vegetation (Fairbanks *et al.*, 2000; Myers *et al.*, 2000). The Succulent Karoo is another hotspot falling partly within the boundaries of South Africa (Lombard *et al.*, 1999; 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. These include inadequate taxonomical knowledge of the groups employed, biased sampling efforts and lack of congruency between taxa (van Jaarsveld *et al*, 1998; Maddock & du Plessis, 1999, Fairbanks & Benn, 2000; Reyers *et al.*, 2000).

(B) 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). 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 (see Scott *et al.*, 1993). Other hierarchical methods have included species assemblages, land facets, or landscapes (Pressey; 1994; 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.

(A) METHODS

(B) 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, along with a map of protected areas in South Africa, were overlaid in a geographic information system (GIS) to determine the extent of natural, degraded, transformed and protected area within each of the 68 vegetation types identified in Low and Rebelo (1996). In addition to this the NLC database could be used to identify the major broad categories of current threat (e.g. cultivation, forestry) facing these respective vegetation types.

(B) Patterns of roads

In addition to these current 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; (6) alteration of the chemical environment; 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. Thus while the National Land-cover database provides a reasonable estimate of areas with high current vulnerability to biodiversity loss due to existing anthropogenic land transformation, road-effect zones can be used to provide an estimate of the potential threat to regional biodiversity through changing land uses and increased future 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). Unsolicited data, which demonstrated that more than 80% of the transformed area of KwaZulu-Natal Province occurs within 2 km of a road, with approximately 61% of the untransformed areas occurring within the same distance, was also used (unpublished data D. Fairbanks & G. Benn). 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 in a standard geographic information system operation to the distance related to its class (Figure 1d). The roads in protected areas were excluded from this analysis as the road-effect in national parks is of little concern. 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.

(A) RESULTS

(B) Current 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 an average of 76.7% natural vegetation cover across all vegetation types. The vegetation types contain an average of 5.6% degraded surface area, 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 an average of 17.3% 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). The grasslands biome as well as a few areas in the savanna biome are moderately degraded (Figure 2c).

The average amount of vegetation type currently under protection is 9.6% with only 18 vegetation types conforming to the IUCN's nominal recommendation of 10% protected area coverage (Table 3). Only a few regions in the savanna and fynbos biomes receive adequate levels of protection (Figure 2d).

Table 4 provides a list of vegetation types ordered according to their current vulnerability status. This was calculated by ranking each vegetation type from one to 68 according to the amount of area that was degraded, transformed and protected. Vegetation types were ranked from one (lowest) to 68 (highest) according to the amount of land degraded or transformed, and from 68 (lowest) to one (highest) according to the amount of protected area coverage. Thus a vegetation type with large amounts of land degraded or transformed and a low level of protection would be ranked high (close to 68) for all three columns in Table 4. The average of these three columns could then be used as an indication of the current vulnerability status of that vegetation type. Types with high average ranks face a high risk of biodiversity loss due to a combination of extensively degraded and transformed areas with a low protection status.

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, Moist Cold Highveld Grassland, Eastern Thorn Bushveld, Subarid Thorn Bushveld, Moist Upland Grassland and Kalahari Plains Thorn Bushveld all contain large areas of degraded vegetation. These same vegetation types (except the Kalahari Plains Thorn Bushveld) along with the Sand Plain Fynbos, Short Mistbelt Grassland, Laterite Fynbos and Coastal Bushveld-Grassland contain extensive areas of commercial, semi-commercial and subsistence dryland cultivation (Table 5). The Short Mistbelt Grassland and Coastal Bushveld-Grassland contain large areas of exotic forestry plantations and 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).

The Shrubby Kalahari Dune Bushveld, Upland Succulent Karoo, Lebombo Arid Mountain Bushveld, Thorny Kalahari Dune Bushveld and Mopane Shrubveld are all areas of less concern to biodiversity conservation due to a combination of low levels of land transformation and degradation within these vegetation types and high levels of protection (Table 3). The majority of these vegetation types fall above the IUCN's recommended 10% protected area coverage, with the exception of the Upland Succulent Karoo at 4.2% (Table 3). The Mopane Shrubveld and Thorny Kalahari Dune Bushveld include 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).

(B) 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 (Table 3). Top conservation priority vegetation types identified based on Low and Rebelo's (1996) estimates in Table 3 highlight the Moist Clay Highveld Grassland, Dry Clay Highveld Grassland, Moist Cool Highveld Grassland, Kalahari Plateau Bushveld, Dry Sandy Highveld Grassland, Karroid Kalahari Bushveld, Moist Cold Highveld Grassland, West Coast Renosterveld, Natal Central Bushveld and Clay Thorn Bushveld as areas of conservation concern due to high land transformation and low levels of protection. The Mountain Fynbos, Mopane Bushveld, Lebombo Arid Mountain Bushveld, Mopane Shrubveld and Thorny Kalahari Dune Bushveld are estimated to be areas of low priority for conservation as they are well protected and little transformed (Table 3).

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 and in Low and Rebelo's (1996) estimates, Table 3 illustrates the differences found between them. 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, $p < 0.01$). It must however be noted 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).

(B) Road-effect zones

The road-effect zone impacts on an average of 5.5% of the remaining natural land-cover in all vegetation types (Table 3), with 5 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).

(B) Potential vulnerability of vegetation types

Figure 3 is a graphic representation of the current vulnerability status of the vegetation types (Table 4), as well as their potential vulnerability status, measured as the ranked potential threat facing the vegetation types due to the sizes of their road-effect zones (Table 3). This figure demonstrates the fact that many of the grasslands, fynbos and thicket vegetation types face not only current land use threats, but also may be exposed to future threats due to a large road-effect zones. 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). As articulated by Stoms (2000), many aspects of roads affect biodiversity: road width, traffic volume, traffic speed, vehicle miles travelled, road network structure or its spatial configuration, management of the right-of-way, noise levels, light disturbance, and chemical pollution. 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.

(A) 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 *et al.*, 2000). It has also been shown that premier flagship conservation areas in South Africa are not likely to meet their conservation goals (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.

(A) ACKNOWLEDGEMENTS

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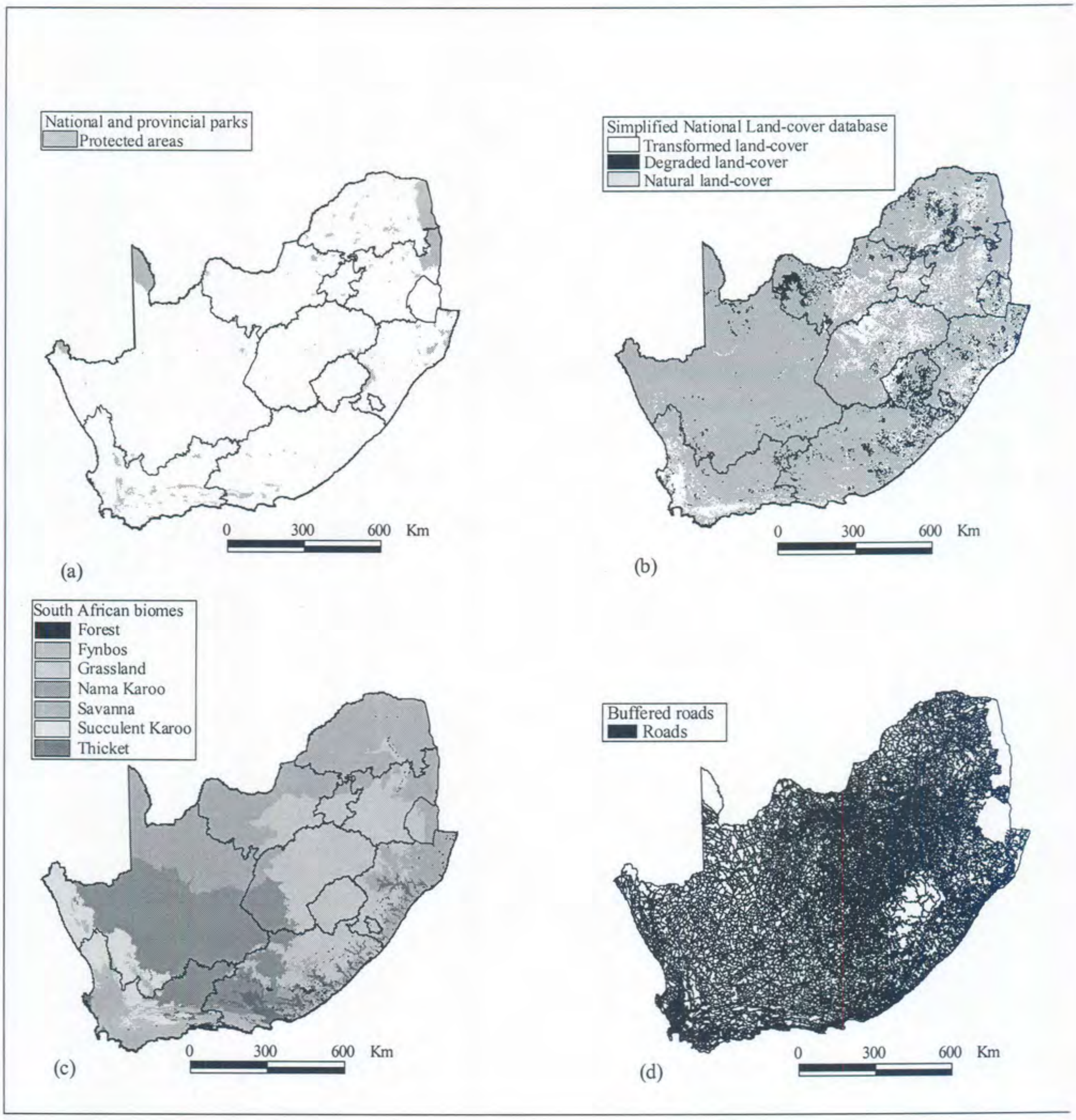

Figure 1: Maps of: (a) South African national and provincial protected areas (DEAT, 1996); (b) transformed, degraded and natural land-cover; (c) biomes (Low & Rebelo, 1996); and (d) road network buffered according to Stoms (2000).

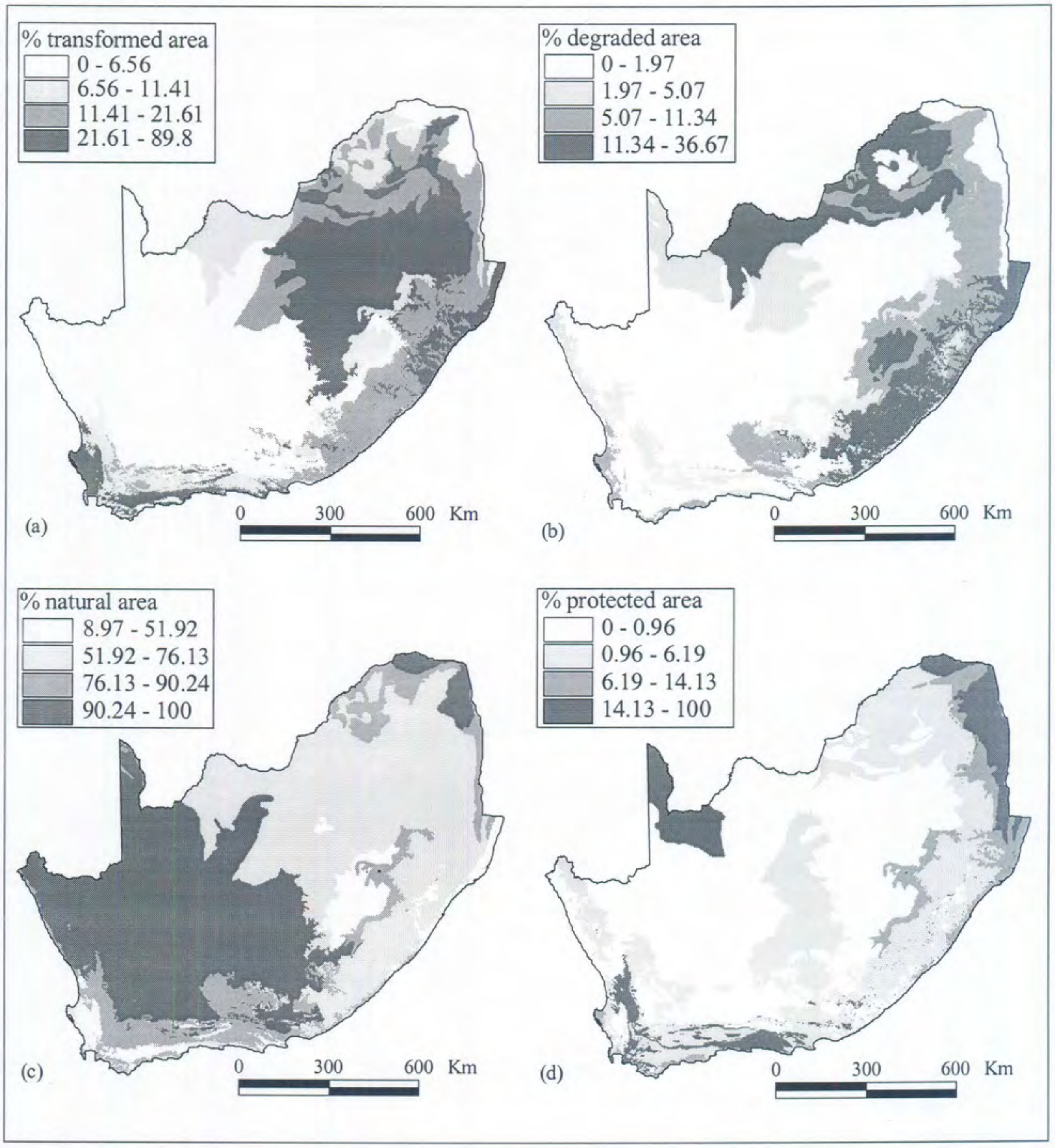

Figure 2: Diagrammatic representation of levels of percentage (a) transformed, (b) degraded, (c) natural and (d) protected vegetation cover within each of Low and Rebelo's (1996) vegetation types.

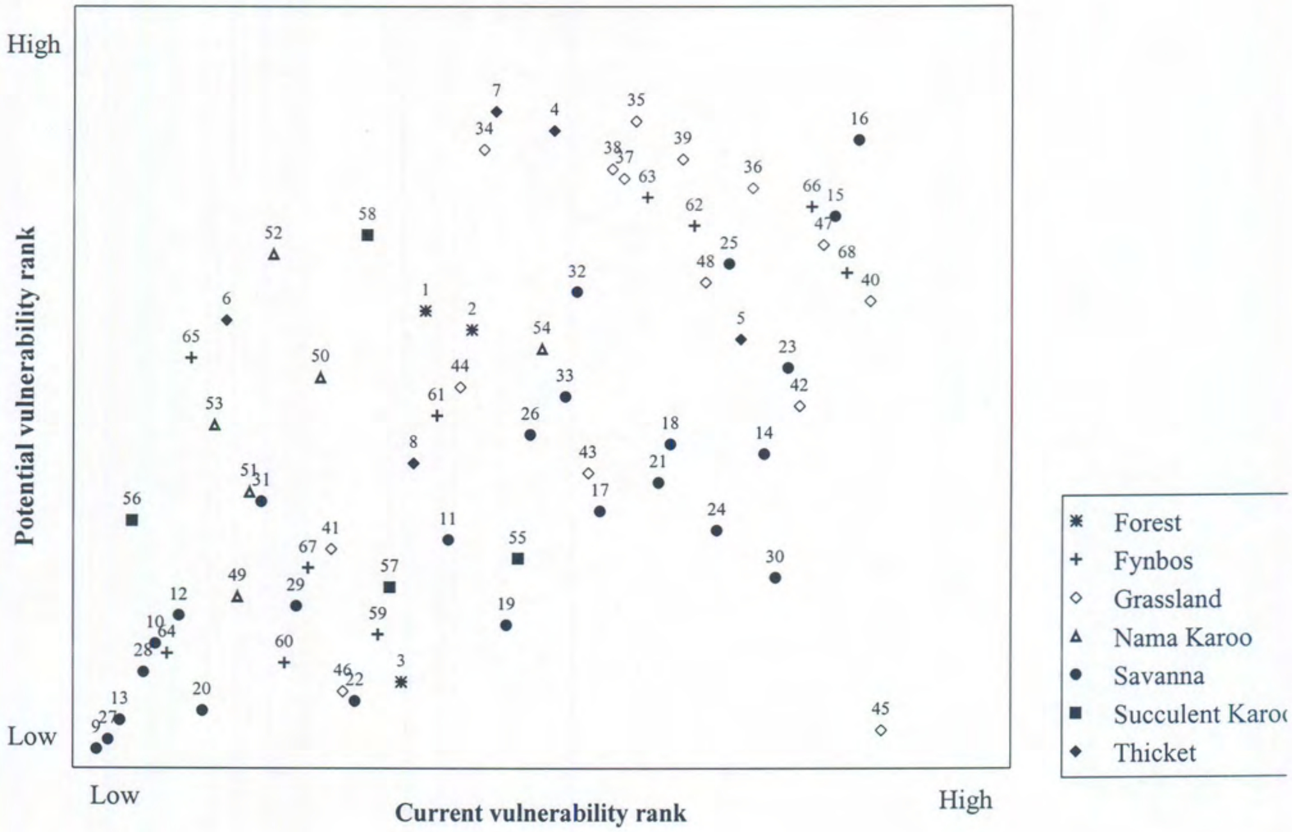

Figure 3: Graph of current and potential vulnerabilities of Low and Rebelo's (1996) vegetation types per biome. Current vulnerability measured as vulnerability rank in Table 4, potential vulnerability measured as ranked road-effect zone per vegetation type (Table 3). The vegetation codes are available in Table 3.

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

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

Table 3: Percentage natural, degraded, transformed and protected area of each of the vegetation types, as well as th percentage of each vegetation type exposed to road-effect zones.
(Values in brackets indicate estimates from Low and Rebelo (1996))

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

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)	**100.0** (100.0)	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

Table 4: Vulnerability ranks of vegetation types according to percentage degraded, transformed and protected area.

Rank	Vegetation type	Degraded rank	Transformed rank	Protected rank	Average rank
1	Afro Mountain Grassland	68	37	65	56.67
2	Moist Cold Highveld Grassland	56	63	43	54.00
3	Eastern Thorn Bushveld	62	43	52	52.33
4	Sand Plain Fynbos	49	65	38	50.67
5	Subarid Thorn Bushveld	60	28	64	50.67
6	Short Mistbelt Grassland	41	64	42	49.00
7	Laterite Fynbos	22	56	67	48.33
8	Moist Upland Grassland	66	49	29	48.00
9	Coastal Bushveld-Grassland	65	62	15	47.33
10	Kalahari Plains Thorn Bushveld	67	26	49	47.33
11	Clay Thorn Bushveld	44	57	40	47.00
12	Dry Clay Highveld Grassland	4	67	68	46.33
13	Valley Thicket	61	41	34	45.33
14	Natal Central Bushveld	54	46	36	45.33
15	Coast-Hinterland Bushveld	47	58	30	45.00
16	Coastal Grassland	42	38	55	45.00
17	West Coast Renosterveld	21	68	45	44.67
18	Moist Cool Highveld Grassland	26	61	47	44.67
19	Mixed Bushveld	63	44	26	44.33
20	Sour Lowveld Bushveld	52	60	20	44.00
21	South & South-west Coast Renosterveld	29	66	35	43.33
22	Moist Clay Highveld Grassland	11	53	66	43.33
23	Dry Sandy Highveld Grassland	17	59	51	42.33
24	Moist Sandy Highveld Grassland	14	54	58	42.00
25	Sweet Bushveld	58	33	32	41.00
26	North-eastern Mountain Grassland	45	50	27	40.67
27	Kimberley Thorn Bushveld	40	47	31	39.33
28	Kalahari Plateau Bushveld	36	20	62	39.33
29	Dune Thicket	48	51	17	38.67
30	Central Lower Nama Karoo	51	10	53	38.00
31	Natal Lowveld Bushveld	57	42	13	37.33
32	Strandveld Succulent Karoo	30	32	50	37.33
33	Mixed Lowveld Bushveld	53	48	8	36.33
34	Mesic Succulent Thicket	43	40	25	36.00
35	Rocky Highveld Grassland	6	55	44	35.00
36	Afromontane Forest	35	52	11	32.67
37	South-eastern Mountain Grassland	38	11	48	32.33
38	Soutpansberg Arid Mountain Bushveld	55	23	18	32.00
39	Central Mountain Renosterveld	28	45	22	31.67
40	Coastal Forest	24	31	37	30.67
41	Spekboom Succulent Thicket	39	14	39	30.67
42	Sand Forest	64	22	4	30.00
43	Lowland Succulent Karoo	33	16	41	30.00
44	North-western Mountain Renosterveld	3	24	63	30.00
45	Little Succulent Karoo	34	27	28	29.67
46	Subhumid Lowveld Bushveld	59	18	9	28.67
47	Alti Mountain Grassland	50	19	16	28.33
48	Wet Cold Highveld Grassland	32	34	19	28.33
49	Upper Nama Karoo	20	6	59	28.33

50	Limestone Fynbos	46	21	14	27.00
51	Karroid Kalahari Bushveld	23	4	54	27.00
52	Escarpment Mountain Renosterveld	10	9	61	26.67
53	Eastern Mixed Nama Karoo	27	17	33	25.67
54	Kalahari Mountain Bushveld	8	8	60	25.33
55	Orange River Nama Karoo	5	12	56	24.33
56	Bushmanland Nama Karoo	9	5	57	23.67
57	Xeric Succulent Thicket	31	15	23	23.00
58	Great Nama Karoo	16	7	46	23.00
59	Sweet Lowveld Bushveld	25	39	3	22.33
60	Grassy Fynbos	18	35	12	21.67
61	Waterberg Moist Mountain Bushveld	15	29	21	21.67
62	Mountain Fynbos	12	36	7	18.33
63	Mopane Bushveld	19	25	6	16.67
64	Shrubby Kalahari Dune Bushveld	37	3	10	16.67
65	Upland Succulent Karoo	13	13	24	16.67
66	Lebombo Arid Mountain Bushveld	7	30	5	14.00
67	Thorny Kalahari Dune Bushveld	2	2	2	2.00
68	Mopane Shrubveld	1	1	1	1.00

Vegetation types were ranked from 1 = lowest to 68 = highest for area degraded and transformed and from 1 = highest and 68 = lowest for protected area coverage

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

Description	Afro Mountain Grassland *Rank (1)*	Moist Cold Highveld Grassland *Rank (2)*	Eastern Thorn Bushveld *Rank (3)*	Sand Plain Fynbos *Rank (4)*	Subarid Thorn Bushveld *Rank (5)*	Short Mistbelt Grassland *Rank (6)*
Natural land-cover	*51.9*	*46.5*	*69.8*	*34.5*	*78.6*	*39.3*
Forest plantations		0.1	0.5	0.4	0.5	**30.9**
Waterbodies	0.0	0.2	0.0	0.1	0.3	0.2
Dongas and sheet erosion scars	0.0	0.1	0.0	0.1	0.7	0.0
Degraded: forest and woodland	0.0	0.0	0.0	0.0	0.0	0.0
Degraded: thicket and bushland (etc)	0.0	0.0	2.3	0.6	1.3	0.6
Degraded: unimproved grassland	**36.7**	**11.0**	**11.5**	0.0	**10.1**	3.7
Degraded: shrubland and low fynbos	0.0	0.0	0.0	7.7	0.3	0.0
Cultivated: permanent - commercial irrigated	0.0	0.0	0.1	5.2	0.1	0.0
Cultivated: permanent - commercial dryland	0.0	0.0	0.7	0.1	0.0	0.0
Cultivated: permanent - commercial sugarcane	0.0	0.0	0.1	0.0	0.0	**10.8**
Cultivated: temporary - commercial irrigated	0.0	0.1	0.3	2.8	0.3	1.7
Cultivated: temporary - commercial dryland	0.0	**19.6**	2.2	**39.5**	0.1	4.7
Cultivated: temporary - semi-commercial / subsistence dryland	**11.4**	**21.3**	**9.2**	0.0	6.3	**7.0**
Urban / built-up land: residential	0.0	0.8	3.2	7.1	1.5	0.8
Urban / built-up land: residential (small holdings: woodland)	0.0	0.0	0.0	0.0	0.0	0.0
Urban / built-up land: residential (small holdings: bushland)	0.0	0.0	0.0	0.0	0.0	0.1
Urban / built-up land: residential (small holdings: shrubland)	0.0	0.0	0.0	1.0	0.0	0.0
Urban / built-up land: residential (small holdings: grassland)	0.0	0.0	0.0	0.0	0.0	0.0
Urban / built-up land: commercial	0.0	0.0	0.1	0.2	0.0	0.0
Urban / built-up land: industrial / transport	0.0	0.0	0.1	0.6	0.0	0.0
Mines & quarries	0.0	0.0	0.0	0.0	0.0	0.0

Table 5: Continued.

Description	Laterite Fynbos *Rank (7)*	Moist Upland Grassland *Rank (8)*	Coastal Bushveld -Grassland *Rank (9)*	Kalahari Plains Thorn Bushveld *Rank (10)*
Natural land-cover	*67.7*	*61.4*	*43.5*	*73.7*
Forest plantations	0.1	3.9	**9.3**	0.0
Waterbodies	0.0	0.1	4.7	0.0
Dongas and sheet erosion scars	0.0	0.0	0.0	0.0
Degraded: forest and woodland	0.0	0.0	0.9	0.0
Degraded: thicket and bushland (etc)	0.0	0.2	7.5	**18.8**
Degraded: unimproved grassland	0.0	**16.7**	2.8	0.0
Degraded: shrubland and low fynbos	1.1	0.0	0.0	0.0
Cultivated: permanent - commercial irrigated	0.0	0.0	0.0	0.0
Cultivated: permanent - commercial dryland	0.0	0.0	0.4	0.0
Cultivated: permanent - commercial sugarcane	0.0	0.2	**15.4**	0.0
Cultivated: temporary - commercial irrigated	0.2	1.3	0.0	0.0
Cultivated: temporary - commercial dryland	**29.9**	1.4	0.0	3.5
Cultivated: temporary - semi-commercial / subsistence dryland	0.0	**12.7**	**10.2**	2.7
Urban / built-up land: residential	0.3	2.0	3.1	0.7
Urban / built-up land: residential (small holdings: woodland)	0.0	0.0	0.0	0.0
Urban / built-up land: residential (small holdings: bushland)	0.0	0.0	0.9	0.0
Urban / built-up land: residential (small holdings: shrubland)	0.0	0.0	0.0	0.0
Urban / built-up land: residential (small holdings: grassland)	0.0	0.0	0.0	0.0
Urban / built-up land: commercial	0.0	0.0	0.1	0.0
Urban / built-up land: industrial / transport	0.0	0.0	0.3	0.0
Mines & quarries	0.0	0.0	0.1	0.1

Appendix C

The following tables describe the CR and ADU species that scored highest and lowest in stepwise canonical correspondence analyses on axes 1 and 2 each for bird assemblage. Associated ecological information for each species is also provided.

Table C-1: CR species that scored highest and lowest in stepwise canonical correspondence analyses on axis 1 for bird assemblages. Associated ecological information is also provided.

SCORE Axis 1	COMMON	SPECIES	ABUNDANCE	DISTRIBUTION	RED DATA	VEG 1	VEG 2	VEG 3	VEG 4
All									
low	Olivetree Warbler	*Hippolais olivetorum*	Uncommon	Non-breeding endemic		Woodland	Degraded woodland		
	Pinkthroated Longclaw	*Macronyx ameliae*	Uncommon		Vulnerable	Grassland	Waterbodies		
	Woodards' Batis	*Batis fratrum*	Locally common	Endemic	Indeterminate	Coastal forest			
	Blackheaded Apalis	*Apalis melanocephala*	Locally common			Forest (A/C)	Thicket		
	Black Coucal	*Centropus bengalensis*	Uncommon		Monitoring	Waterbodies	Grassland		
	Chestnutfronted Helmetshrike	*Prionops scopifrons*	Uncommon		Vulnerable	Woodland	Thicket	Forest	
	Bennett's Woodpecker	*Campethera bennettii*	Locally common			Woodland			
	Yellowbellied Sunbird	*Nectarinia venusta*	Locally common			Forest (A/C)	Woodland	Urban-residential	
	Yellow White-eye	*Zosterops senegalensis*	Rare			Coastal forest	Woodland		
	Greyhooded Kingfisher	*Halcyon leucocephala*	Uncommon		Indeterminate	Woodland			
high	**Drakensberg Siskin**	*Pseudochloroptila symonsi*	Common	Endemic	near-threatened	Shrubland	Grassland		
	Sicklewinged Chat	*Cercomela sinuata*	Common	Endemic		Shrubland	Grassland	Degraded grassland	Degraded shrubland
	Pearlbreasted Swallow	*Hirundo dimidiata*	Common			Woodland	Thicket	Shrubland	Dryland agriculture
	Orangebreasted Rockjumper	*Chaetops aurantius*	Common	Endemic	Near-threatened	Grassland			
	Larklike Bunting	*Emberiza impetuani*	Common	Near-endemic		Shrubland	Grassland	Thicket	Waterbodies
	Thickbilled Lark	*Galerida magnirostris*	Common	Endemic		Shrubland	Grassland	Dryland agriculture	
	Yellowbreasted Pipit	*Hemimacronyx chloris*	Uncommon	Endemic		Grassland			
	Greywing Francolin	*Francolinus africanus*	Common	Endemic		Grassland	Shrubland		
	Blackwinged Pratincole	*Glareola nordmanni*	Locally common			Grassland	Dryland agriculture	Waterbodies	
	Bearded Vulture	*Gypaetus barbatus*	Rare		Monitoring	Grassland			
Summer									
low	**Broadbilled Prion**	*Pachyptila vittata*	Uncommon			Ocean			
	Greatwinged Petrel	*Pterodroma macroptera*	Common		Vulnerable	Ocean			
	Pinkthroated Longclaw	*Macronyx ameliae*	Uncommon		Vulnerable	Grassland	Waterbodies		
	Lesser Gallinule	*Porphyrula alleni*	Locally common			Waterbodies	Woodland		
	Yellow White-eye	*Zosterops senegalensis*	Rare			Coastal forest	Woodland		
	Greater Frigatebird	*Fregata minor*	Rare			Coastal			
	Woodards' Batis	*Batis fratrum*	Locally common	Endemic	Indeterminate	Coastal forest			
	Stierling's Barred Warbler	*Calamonastes stierlingi*	Common			Woodland			

SCORE Axis 1	COMMON	SPECIES	ABUNDANCE	DISTRIBUTION	RED DATA	VEG 1	VEG 2	VEG 3	VEG 4
	Bluecheeked Bee-eater	*Merops persicus*	Locally common			Grassland	Woodland	Waterbodies	
	Natal Nightjar	*Caprimulgus natalensis*	Rare		Vulnerable	Grassland	Waterbodies	Plantations	
high	**Drakensberg Siskin**	*Pseudochloroptila symonsi*	Common	Endemic	Near-threatened	Shrubland	Grassland		
	Sicklewinged Chat	*Cercomela sinuata*	Common	Endemic		Shrubland	Grassland	Degraded grassland	Degraded shrubland
	Orangebreasted Rockjumper	*Chaetops aurantius*	Common	Endemic	Near-threatened	Grassland			
	Yellowbreasted Pipit	*Hemimacronyx chloris*	Uncommon	Endemic		Grassland			
	Whitethroated Canary	*Serinus albogularis*	Common	Near endemic		Shrubland	Grassland		
	Greywing Francolin	*Francolinus africanus*	Common	Endemic		Grassland	Shrubland		
	Bearded Vulture	*Gypaetus barbatus*	Rare		Monitoring	Grassland			
	Cape Eagle Owl	*Bubo capensis*	Locally common		Monitoring	Grassland	Shrubland	Urban-residential	
	Black Harrier	*Circus maurus*	Locally common	Endemic	Near-threatened	Grassland	Shrubland	Dryland agriculture	
	Montagu's Harrier	*Circus pygargus*	Rare			Grassland	Dryland agriculture	Woodland	
Winter									
low	Rufousbellied Heron	*Butorides rufiventris*	Rare	Endemic		Waterbodies			
	Natal Nightjar	*Caprimulgus natalensis*	Rare		Vulnerable	Grassland	Waterbodies	Plantations	
	Blackheaded Apalis	*Apalis melanocephala*	Locally common			Forest (A/C)	Thicket		
	Swallowtailed Bee-eater	*Merops hirundineus*	Rare			Woodland			
	Lesser Gallinule	*Porphyrula alleni*	Locally common			Waterbodies	Woodland		
	Arctic Tern	*Sterna paradisaea*	Uncommon			Coastal			
	Greyrumped Swallow	*Pseudhirundo griseopyga*	Common			Woodland	Waterbodies	Dryland agriculture	
	Woodards' Batis	*Batis fratrum*	Locally common	Endemic	Indeterminate	Coastal forest			
	Pinkthroated Longclaw	*Macronyx ameliae*	Uncommon		Vulnerable	Grassland	Waterbodies		
	Ayres' Eagle	*Hieraaetus ayresii*	Rare			Woodland	Plantations		
high	**Drakensberg Siskin**	*Pseudochloroptila symonsi*	Common	Endemic	Near-threatened	Shrubland	Grassland		
	Sicklewinged Chat	*Cercomela sinuata*	Common	Endemic		Shrubland	Grassland	Degraded grassland	Degraded shrubland
	Blackwinged Pratincole	*Glareola nordmanni*	Locally common			Grassland	Dryland agriculture	Waterbodies	
	Rock Pipit	*Anthus crenatus*	Common	Endemic		Grassland	Shrubland		
	Greywing Francolin	*Francolinus africanus*	Common	Endemic		Grassland	Shrubland		
	Pearlbreasted Swallow	*Hirundo dimidiata*	Common			Woodland	Thicket	Shrubland	Dryland agriculture
	Thickbilled Lark	*Galerida magnirostris*	Common	Endemic		Shrubland	Grassland	Dryland agriculture	
	Larklike Bunting	*Emberiza impetuani*	Common	Near-endemic		Shrubland	Grassland	Thicket	Waterbodies
	Bearded Vulture	*Gypaetus barbatus*	Rare		Monitoring	Grassland			
	Orangebreasted Rockjumper	*Chaetops aurantius*	Common	Endemic	Near-threatened	Grassland			

SCORE Axis 1	COMMON	SPECIES	ABUNDANCE	DISTRIBUTION	RED DATA	VEG 1	VEG 2	VEG 3	VEG 4
Passerine									
low	Blackheaded Apalis	*Apalis melanocephala*	Locally common			Forest (A/C)	Thicket		
	Stierling's Barred Warbler	*Calamonastes stierlingi*	Common			Woodland			
	Yellow White-eye	*Zosterops senegalensis*	Rare			Coastal forest	Woodland		
	Pinkthroated Twinspot	*Hypargos margaritatus*	Rare	Endemic	Monitoring	Thicket	Woodland		
	Woodards' Batis	*Batis fratrum*	Locally common	Endemic	Indeterminate	Coastal forest			
	Greyrumped Swallow	*Pseudhirundo griseopyga*	Common			Woodland	Waterbodies	Dryland agriculture	
	Pinkthroated Longclaw	*Macronyx ameliae*	Uncommon		Vulnerable	Grassland	Waterbodies		
	Yellowbellied Sunbird	*Nectarinia venusta*	Locally common			Forest (A/C)	Woodland	Urban-residential	
	Chestnutfronted Helmetshrike	*Prionops scopifrons*	Uncommon		Vulnerable	Woodland	Thicket	Forest	
	Olivetree Warbler	*Hippolais olivetorum*	Uncommon	Non-breeding endemic		Woodland	Degraded woodland		
high	**Sicklewinged Chat**	*Cercomela sinuata*	Common	Endemic		Shrubland	Grassland	Degraded grassland	Degraded shrubland
	Drakensberg Siskin	*Pseudochloroptila symonsi*	Common	Endemic	Near-threatened	Shrubland	Grassland		
	Pearlbreasted Swallow	*Hirundo dimidiata*	Common			Woodland	Thicket	Shrubland	Dryland agriculture
	Larklike Bunting	*Emberiza impetuani*	Common	Near-endemic		Shrubland	Grassland	Thicket	Waterbodies
	Thickbilled Lark	*Galerida magnirostris*	Common	Endemic		Shrubland	Grassland	Dryland agriculture	
	Orangebreasted Rockjumper	*Chaetops aurantius*	Common	Endemic	Near-threatened	Grassland			
	Yellowbreasted Pipit	*Hemimacronyx chloris*	Uncommon	Endemic		Grassland			
	Whitethroated Canary	*Serinus albogularis*	Common	Near endemic		Shrubland	Grassland		
	Redeyed Bulbul	*Pycnonotus nigricans*	Common	Near endemic		Grassland	Shrubland	Woodland	Urban-residential
	Yellow Canary	*Serinus flaviventris*	Common	Near endemic		Shrubland	Grassland		
Non-passerine									
low	**Black Coucal**	*Centropus bengalensis*	Uncommon		Monitoring	Waterbodies	Grassland		
	Roseate Tern	*Sterna dougallii*	Locally common		Endangered	Coastal			
	Sabine's Gull	*Larus sabini*	Rare			Coastal			
	Bluecheeked Bee-eater	*Merops persicus*	Locally common			Grassland	Woodland	Waterbodies	
	Sand Plover	*Charadrius leschenaultii*	Locally common			Coastal	Waterbodies		
	Greater Frigatebird	*Fregata minor*	Rare			Coastal			
	Slenderbilled Prion	*Pachyptila belcheri*	Uncommon			Ocean			
	Natal Nightjar	*Caprimulgus natalensis*	Rare		Vulnerable	Grassland	Waterbodies	Plantations	
	Greatwinged Petrel	*Pterodroma macroptera*	Common		Vulnerable	Ocean			
	Curlew	*Numenius arquata*	Common			Coastal			
high	**Greywing Francolin**	*Francolinus africanus*	Common	Endemic		Grassland	Shrubland		

SCORE Axis 1	COMMON	SPECIES	ABUNDANCE	DISTRIBUTION	RED DATA	VEG 1	VEG 2	VEG 3	VEG 4
	Blackwinged Pratincole	*Glareola nordmanni*	Locally common			Grassland	Dryland agriculture	Waterbodies	
	Bearded Vulture	*Gypaetus barbatus*	Rare		Monitoring	Grassland			
	Montagu's Harrier	*Circus pygargus*	Rare			Grassland	Dryland agriculture	Woodland	
	Pale Chanting Goshawk	*Melierax canorus*	Common	Near endemic		Shrubland	Woodland		
	Ground Woodpecker	*Geocolaptes olivaceus*	Common	Endemic	Near-threatened	Grassland	Shrubland		
	Black Harrier	*Circus maurus*	Locally common	Endemic	Near-threatened	Grassland	Shrubland	Dryland agriculture	
	Cape Eagle Owl	*Bubo capensis*	Locally common		Monitoring	Grassland	Shrubland	Urban-residential	
	Redbreasted Sparrowhawk	*Accipiter rufiventris*	Locally common			Forest	Plantations	Grassland	
	Pennantwinged Nightjar	*Macrodipteryx vexillaria*	Locally common		Indeterminate	Woodland			
Breeding									
low	Blackheaded Apalis	*Apalis melanocephala*	Locally common			Forest (A/C)	Thicket		
	Pinkthroated Longclaw	*Macronyx ameliae*	Uncommon		Vulnerable	Grassland	Waterbodies		
	Woodards' Batis	*Batis fratrum*	Locally common	Endemic	Indeterminate	Coastal forest			
	Yellow White-eye	*Zosterops senegalensis*	Rare			Coastal forest	Woodland		
	Stierling's Barred Warbler	*Calamonastes stierlingi*	Common			Woodland			
	Pinkthroated Twinspot	*Hypargos margaritatus*	Rare	Endemic	Monitoring	Thicket	Woodland		
	Greyrumped Swallow	*Pseudhirundo griseopyga*	Common			Woodland	Waterbodies	Dryland agriculture	
	Southern Banded Snake Eagle	*Circeatus fasciolatus*	Rare		Near-threatened	Coastal forest	Woodland	Thicket	
	Black Coucal	*Centropus bengalensis*	Uncommon		Monitoring	Waterbodies	Grassland		
	Bennett's Woodpecker	*Campethera bennettii*	Locally common			Woodland			
high	Pearlbreasted Swallow	*Hirundo dimidiata*	Common			Woodland	Thicket	Shrubland	Dryland agriculture
	Sicklewinged Chat	*Cercomela sinuata*	Common	Endemic		Shrubland	Grassland	Degraded grassland	Degraded shrubland
	Drakensberg Siskin	*Pseudochloroptila symonsi*	Common	Endemic	Near-threatened	Shrubland	Grassland		
	Pale Chanting Goshawk	*Melierax canorus*	Common	Near endemic		Shrubland	Woodland		
	Orangebreasted Rockjumper	*Chaetops aurantius*	Common	Endemic	Near-threatened	Grassland			
	Redeyed Bulbul	*Pycnonotus nigricans*	Common	Near endemic		Grassland	Shrubland	Woodland	Urban-residential
	Yellowbreasted Pipit	*Hemimacronyx chloris*	Uncommon	Endemic		Grassland			
	Larklike Bunting	*Emberiza impetuani*	Common	Near-endemic		Shrubland	Grassland	Thicket	Waterbodies
	Thickbilled Lark	*Galerida magnirostris*	Common	Endemic		Shrubland	Grassland	Dryland agriculture	
	Greywing Francolin	*Francolinus africanus*	Common	Endemic		Grassland	Shrubland		
Non-breeding low	Cory's Shearwater	*Calonectris diomedea*	Common			Ocean			
	Fleshfooted Shearwater	*Puffinus carneipes*	Common			Ocean			

SCORE Axis 1	COMMON	SPECIES	ABUNDANCE	DISTRIBUTION	RED DATA	VEG 1	VEG 2	VEG 3	VEG 4
	Sooty Shearwater	*Puffinus griseus*	Common			Ocean			
	Wilson's Storm Petrel	*Oceanites oceanicus*	Common			Ocean			
	Whitebellied Storm Petrel	*Fregetta grallaria*	Rare			Ocean			
	Blackbellied Storm Petrel	*Fregetta tropica*	Common			Ocean			
	Collared Flycatcher	*Ficedula albicollis*	Rare			Woodland			
	Bridled Tern	*Sterna anaethetus*	Rare			Coastal			
	European Storm Petrel	*Hydrobates pelagicus*	Common			Coastal			
	Slenderbilled Prion	*Pachyptila belcheri*	Uncommon			Ocean			
high	African Hobby Falcon	*Falco cuvierii*	Uncommon			Woodland			
	Pennantwinged Nightjar	*Macrodipteryx vexillaria*	Locally common		Indeterminate	Woodland			
	Black Tern	*Chlidonias niger*	Rare			Coastal			
	Lesser Kestrel	*Falco naumanni*	Common		Monitoring	Grassland	Dryland agriculture	Thicket	Urban-residential
	Blackwinged Pratincole	*Glareola nordmanni*	Locally common			Grassland	Dryland agriculture	Waterbodies	
	Pectoral Sandpiper	*Calidris melanotos*	Rare			Coastal			
	Montagu's Harrier	*Circus pygargus*	Rare			Grassland	Dryland agriculture	Woodland	
	Western Redfooted Kestrel	*Falco vespertinus*	Uncommon			Grassland	Woodland		
	Abdim's Stork	*Ciconia abdimii*	Common			Grassland	Dryland agriculture	Pasture	
	Eastern Redfooted Kestrel	*Falco amurensis*	Common		Monitoring	Grassland	Dryland agriculture	Urban-residential	
Human									
low	Greatwinged Petrel	*Pterodroma macroptera*	Common		Vulnerable	Ocean			
	Greyrumped Swallow	*Pseudhirundo griseopyga*	Common			Woodland	Waterbodies	Dryland agriculture	
	Pintado Petrel	*Daption capense*	Common			Ocean			
	Ayres' Eagle	*Hieraaetus ayresii*	Rare			Woodland	Plantations		
	Caspian Tern	*Hydroprogne caspia*	Common		Rare	Coastal	Waterbodies		
	Yellowbellied Sunbird	*Nectarinia venusta*	Locally common			Forest (A/C)	Woodland	Urban-residential	
	Olivetree Warbler	*Hippolais olivetorum*	Uncommon	Non-breeding endemic		Woodland	Degraded woodland		
	Whitewinged Tern	*Childonias leucopterus*	Common			Waterbodies			
	Southern Giant Petrel	*Macronectes giganteus*	Common			Ocean			
	Lesser Flamingo	*Phoeniconaias minor*	Locally common		Near-threatened	Waterbodies			
high	**Sicklewinged Chat**	*Cercomela sinuata*	Common	Endemic		Shrubland	Grassland	Degraded grassland	Degraded shrubland
	Pearlbreasted Swallow	*Hirundo dimidiata*	Common			Woodland	Thicket	Shrubland	Dryland agriculture
	Larklike Bunting	*Emberiza impetuani*	Common	Near-endemic		Shrubland	Grassland	Thicket	Waterbodies
	Thickbilled Lark	*Galerida magnirostris*	Common	Endemic		Shrubland	Grassland	Dryland agriculture	

SCORE Axis 1	COMMON	SPECIES	ABUNDANCE	DISTRIBUTION	RED DATA	VEG 1	VEG 2	VEG 3	VEG 4
	Redeyed Bulbul	*Pycnonotus nigricans*	Common	Near endemic		Grassland	Shrubland	Woodland	Urban-residential
	Montagu's Harrier	*Circus pygargus*	Rare			Grassland	Dryland agriculture	Woodland	
	Black Harrier	*Circus maurus*	Locally common	Endemic	Near-threatened	Grassland	Shrubland	Dryland agriculture	
	Cape Eagle Owl	*Bubo capensis*	Locally common		Monitoring	Grassland	Shrubland	Urban-residential	
	Yellowrumped Widow	*Euplectes capensis*	Common			Grassland	Shrubland	Dryland agriculture	
	South African Shelduck	*Tadorna cana*	Locally common	Endemic		Waterbodies	Shrubland	Grassland	
Non-human low	**Black Coucal**	*Centropus bengalensis*	Uncommon		Monitoring	Waterbodies	Grassland		
	Blackheaded Apalis	*Apalis melanocephala*	Locally common			Forest (A/C)	Thicket		
	Pinkthroated Longclaw	*Macronyx ameliae*	Uncommon		Vulnerable	Grassland	Waterbodies		
	Woodards' Batis	*Batis fratrum*	Locally common	Endemic	Indeterminate	Coastal forest			
	Bluecheeked Bee-eater	*Merops persicus*	Locally common			Grassland	Woodland	Waterbodies	
	Broadbilled Roller	*Eurystomus glaucurus*	Locally common			Woodland	Thicket		
	Yellow White-eye	*Zosterops senegalensis*	Rare			Coastal forest	Woodland		
	Sand Plover	*Charadrius leschenaultii*	Locally common			Coastal	Waterbodies		
	Greater Frigatebird	*Fregata minor*	Rare			Coastal			
	Southern Banded Snake Eagle	*Circeatus fasciolatus*	Rare		Near-threatened	Coastal forest	Woodland	Thicket	
high	**Drakensberg Siskin**	*Pseudochloroptila symonsi*	Common	Endemic	Near-threatened	Shrubland	Grassland		
	Orangebreasted Rockjumper	*Chaetops aurantius*	Common	Endemic	Near-threatened	Grassland			
	Yellowbreasted Pipit	*Hemimacronyx chloris*	Uncommon	Endemic		Grassland			
	Blackwinged Pratincole	*Glareola nordmanni*	Locally common			Grassland	Dryland agriculture	Waterbodies	
	Greywing Francolin	*Francolinus africanus*	Common	Endemic		Grassland	Shrubland		
	Bearded Vulture	*Gypaetus barbatus*	Rare		Monitoring	Grassland			
	Pale Chanting Goshawk	*Melierax canorus*	Common	Near endemic		Shrubland	Woodland		
	Whitethroated Canary	*Serinus albogularis*	Common	Near endemic		Shrubland	Grassland		
	Yellow Canary	*Serinus flaviventris*	Common	Near endemic		Shrubland	Grassland		
	Ground Woodpecker	*Geocolaptes olivaceus*	Common	Endemic	Near-threatened	Grassland	Shrubland		

Table B-2: CR species that scored highest and lowest in stepwise canonical correspondence analyses on axis 2 for bird assemblages. Associated ecological information is also provided.

SCORE Axis 2	**COMMON**	**SPECIES**	**ABUNDANCE**	**DISTRIBUTION**	**RED DATA**	**VEG 1**	**VEG 2**	**VEG 3**	**VEG 4**
All									
low	**Redbilled Buffalo Weaver**	*Bubalornis niger*	Nomadic			Woodland	Thicket		
	Dickinson's Kestrel	*Falco dickinsoni*	Rare			Woodland			
	Carmine Bee-eater	*Merops nubicoides*	Common			Woodland			
	Thickbilled Cuckoo	*Pachycoccyx audeberti*	Rare		Monitoring	Thicket	Woodland		
	Rackettailed Roller	*Coracias spatulata*	Uncommon		Vulnerable	Woodland			
	Purple Widowfinch	*Vidua purpurascens*	Locally common		Monitoring	Woodland	Thicket		
	Whitecrowned Shrike	*Eurocephalus anguitimens*	Common	Endemic		Woodland	Thicket		
	Dusky Lark	*Pinarocorys nigricans*	Uncommon			Woodland	Urban-residential		
	Black Tern	*Chlidonias niger*	Rare			Coastal			
	Greyhooded Kingfisher	*Halcyon leucocephala*	Uncommon		Indeterminate	Woodland			
high	Fleshfooted Shearwater	*Puffinus carneipes*	Common			Ocean			
	Cory's Shearwater	*Calonectris diomedea*	Common			Ocean			
	Wilson's Storm Petrel	*Oceanites oceanicus*	Common			Ocean			
	Roseate Tern	*Sterna dougallii*	Locally common		Endangered	Coastal			
	Sabine's Gull	*Larus sabini*	Rare			Coastal			
	European Storm Petrel	*Hydrobates pelagicus*	Common			Coastal			
	Whitebellied Storm Petrel	*Fregetta grallaria*	Rare			Ocean			
	European Starling	*Sturnus vulgaris*	Common	Alien		Urban-residential	Dryland agriculture		
	Bridled Tern	*Sterna anaethetus*	Rare			Coastal			
	Blackbellied Storm Petrel	*Fregetta tropica*	Common			Ocean			
Summer									
low	Rock Pipit	*Anthus crenatus*	Common	Endemic		Grassland	Shrubland		
	Purple Widowfinch	*Vidua purpurascens*	Locally common		Monitoring	Woodland	Thicket		
	Pearlspotted Owl	*Glaucidium perlatum*	Common			Woodland	Thicket		
	Thickbilled Cuckoo	*Pachycoccyx audeberti*	Rare		Monitoring	Thicket	Woodland		
	Rackettailed Roller	*Coracias spatulata*	Uncommon		Vulnerable	Woodland			
	Dickinson's Kestrel	*Falco dickinsoni*	Rare			Woodland			
	Dark Chanting Goshawk	*Melierax metabates*	Locally common			Woodland	Thicket		
	Greyhooded Kingfisher	*Halcyon leucocephala*	Uncommon		Indeterminate	Woodland			

SCORE Axis 2	COMMON	SPECIES	ABUNDANCE	DISTRIBUTION	RED DATA	VEG 1	VEG 2	VEG 3	VEG 4
	Steelblue Widowfinch	*Vidua chalybeata*	Common		Monitoring	Woodland	Dryland agriculture	Urban-residential	
	Grey Hornbill	*Tockus nasutus*	Common			Woodland	Thicket		
high	Grey Wagtail	*Motacilla cinerea*	Rare			Forest	Waterbodies		
	Fleshfooted Shearwater	*Puffinus carneipes*	Common			Ocean			
	Wilson's Storm Petrel	*Oceanites oceanicus*	Common			Ocean			
	Broadbilled Prion	*Pachyptila vittata*	Uncommon			Ocean			
	European Storm Petrel	*Hydrobates pelagicus*	Common			Coastal			
	Softplumaged Petrel	*Pterodroma mollis*	Common			Ocean			
	Sooty Shearwater	*Puffinus griseus*	Common			Ocean			
	Wandering Albatross	*Diomedea exulans*	Uncommon			Ocean			
	Roseate Tern	*Sterna dougallii*	Locally common		Endangered	Coastal			
	Cory's Shearwater	*Calonectris diomedea*	Common			Ocean			
Winter									
low	Redbilled Buffalo Weaver	*Bubalornis niger*	Nomadic			Woodland	Thicket		
	Purple Widowfinch	*Vidua purpurascens*	Locally common		Monitoring	Woodland	Thicket		
	Whitecrowned Shrike	*Eurocephalus anguitimens*	Common	Endemic		Woodland	Thicket		
	Dusky Lark	*Pinarocorys nigricans*	Uncommon			Woodland	Urban-residential		
	Carmine Bee-eater	*Merops nubicoides*	Common			Woodland			
	Greyhooded Kingfisher	*Halcyon leucocephala*	Uncommon		Indeterminate	Woodland			
	Dickinson's Kestrel	*Falco dickinsoni*	Rare			Woodland			
	Redbilled Helmetshrike	*Prionops retzii*	Common		Threatened	Woodland			
	Purple Roller	*Coracias naevia*	Common			Woodland	Thicket		
	Redcrested Korhaan	*Eupodotis ruficrista*	Common	Near endemic	Monitoring	Grassland	Woodland	Shrubland	
high	Cory's Shearwater	*Calonectris diomedea*	Common			Ocean			
	Roseate Tern	*Sterna dougallii*	Locally common		Endangered	Coastal			
	Sabine's Gull	*Larus sabini*	Rare			Coastal			
	Southern Giant Petrel	*Macronectes giganteus*	Common			Ocean			
	Jackass Penguin	*Spheniscus demersus*	Locally common	Endemic	Near-threatened	Coastal			
	Broadbilled Sandpiper	*Limicola falcinellus*	Rare			Coastal			
	Curlew	*Numenius arquata*	Common			Coastal			
	Sand Plover	*Charadrius leschenaultii*	Locally common			Coastal	Waterbodies		
	Subantartic Skua	*Catharacta antartica*	Common			Coastal			
	Wilson's Storm Petrel	*Oceanites oceanicus*	Common			Ocean			

SCORE Axis 2	COMMON	SPECIES	ABUNDANCE	DISTRIBUTION	RED DATA	VEG 1	VEG 2	VEG 3	VEG 4
Passerine									
low	**Redbilled Buffalo Weaver**	*Bubalornis niger*	Nomadic			Woodland	Thicket		
	Yellowbellied Sunbird	*Nectarinia venusta*	Locally common			Forest (A/C)	Woodland	Urban-residential	
	Chestnutfronted Helmetshrike	*Prionops scopifrons*	Uncommon		Vulnerable	Woodland	Thicket	Forest	
	Dusky Lark	*Pinarocorys nigricans*	Uncommon			Woodland	Urban-residential		
	Purple Widowfinch	*Vidua purpurascens*	Locally common		Monitoring	Woodland	Thicket		
	Whitecrowned Shrike	*Eurocephalus anguitimens*	Common	Endemic		Woodland	Thicket		
	Redbilled Helmetshrike	*Prionops retzii*	Common		Threatened	Woodland			
	Steelblue Widowfinch	*Vidua chalybeata*	Common		Monitoring	Woodland	Dryland agriculture	Urban-residential	
	Yellowbellied Eremomela	*Eremomela icteropygialis*	Common			Shrubland	Woodland		
	Marico Sunbird	*Nectarinia mariquensis*	Common			Woodland			
high	Collared Flycatcher	*Ficedula albicollis*	Rare			Woodland			
	European Starling	*Sturnus vulgaris*	Common	Alien		Urban-residential	Dryland agriculture		
	Thrush Nightingale	*Luscinia luscinia*	Uncommon			Thicket	Urban-residential		
	Whinchat	*Saxicola rubetra*	Rare			Grassland	Woodland	Thicket	
	Tree Pipit	*Anthus trivialis*	Rare			Woodland	Forest	Plantations	
	Pied Mannikin	*Spermestes fringilloides*	Rare		Indeterminate	Coastal forest	Urban-residential	Dryland agriculture	
	Spotted Thrush	*Zoothera guttata*	Uncommon		Endangered	Coastal forest			
	House Crow	*Corvus splendens*	Locally common	Alien		Urban-residential			
	Whitethroated Canary	*Serinus albogularis*	Common	Near endemic		Shrubland	Grassland		
	Thickbilled Lark	*Galerida magnirostris*	Common	Endemic		Shrubland	Grassland	Dryland agriculture	
Non-passerine									
low	Black Tern	*Chlidonias niger*	Rare			Coastal			
	Thickbilled Cuckoo	*Pachycoccyx audeberti*	Rare		Monitoring	Thicket	Woodland		
	Dickinson's Kestrel	*Falco dickinsoni*	Rare			Woodland			
	Carmine Bee-eater	*Merops nubicoides*	Common			Woodland			
	Rackettailed Roller	*Coracias spatulata*	Uncommon		Vulnerable	Woodland			
	Greyhooded Kingfisher	*Halcyon leucocephala*	Uncommon		Indeterminate	Woodland			
	Pearlspotted Owl	*Glaucidium perlatum*	Common			Woodland	Thicket		
	Purple Roller	*Coracias naevia*	Common			Woodland	Thicket		
	Redbilled Hornbill	*Tockus erythrorhynchus*	Common			Woodland	Thicket		
	Grey Hornbill	*Tockus nasutus*	Common			Woodland	Thicket		
high	Fleshfooted Shearwater	*Puffinus carneipes*	Common			Ocean			

SCORE Axis 2	COMMON	SPECIES	ABUNDANCE	DISTRIBUTION	RED DATA	VEG 1	VEG 2	VEG 3	VEG 4
	Cory's Shearwater	*Calonectris diomedea*	Common			Ocean			
	Wilson's Storm Petrel	*Oceanites oceanicus*	Common			Ocean			
	European Storm Petrel	*Hydrobates pelagicus*	Common			Coastal			
	Sabine's Gull	*Larus sabini*	Rare			Coastal			
	Roseate Tern	*Sterna dougallii*	Locally common		Endangered	Coastal			
	Blackbellied Storm Petrel	*Fregetta tropica*	Common			Ocean			
	Whitebellied Storm Petrel	*Fregetta grallaria*	Rare			Ocean			
	Bridled Tern	*Sterna anaethetus*	Rare			Coastal			
	Sooty Shearwater	*Puffinus griseus*	Common			Ocean			
Breeding									
low	**Redbilled Buffalo Weaver**	*Bubalornis niger*	Nomadic			Woodland	Thicket		
	Purple Widowfinch	*Vidua purpurascens*	Locally common		Monitoring	Woodland	Thicket		
	Whitecrowned Shrike	*Eurocephalus anguitimens*	Common	Endemic		Woodland	Thicket		
	Dickinson's Kestrel	*Falco dickinsoni*	Rare			Woodland			
	Thickbilled Cuckoo	*Pachycoccyx audeberti*	Rare		Monitoring	Thicket	Woodland		
	Carmine Bee-eater	*Merops nubicoides*	Common			Woodland			
	Rackettailed Roller	*Coracias spatulata*	Uncommon		Vulnerable	Woodland			
	Greyhooded Kingfisher	*Halcyon leucocephala*	Uncommon		Indeterminate	Woodland			
	Steelblue Widowfinch	*Vidua chalybeata*	Common		Monitoring	Woodland	Dryland agriculture	Urban-residential	
	Purple Roller	*Coracias naevia*	Common			Woodland	Thicket		
high	Roseate Tern	*Sterna dougallii*	Locally common		Endangered	Coastal			
	African Black Oystercatcher	*Haematopus moquini*	Common			Coastal			
	European Starling	*Sturnus vulgaris*	Common	Alien		Urban-residential	Dryland agriculture		
	Jackass Penguin	*Spheniscus demersus*	Locally common	Endemic	Near-threatened	Coastal			
	Cape Gannet	*Morus capensis*	Common	Breeding endemic		Coastal			
	Chestnutbanded Plover	*Charadrius pallidus*	Uncommon		Monitoring	Coastal			
	Cape Cormorant	*Phalacrocorax capensis*	Common	Breeding endemic		Ocean			
	Green Barbet	*Stactolaema olivacea*	Locally common	Endemic	Vulnerable	Forest (A/C)			
	Kelp Gull	*Larus dominicanus*	Common			Coastal			
	Swift Tern	*Sterna bergi*	Common			Coastal			
Non-breeding									
low	Black Tern	*Chlidonias niger*	Rare			Coastal			
	Dusky Lark	*Pinarocorys nigricans*	Uncommon			Woodland	Urban-residential		

SCORE Axis 2	COMMON	SPECIES	ABUNDANCE	DISTRIBUTION	RED DATA	VEG 1	VEG 2	VEG 3	VEG 4
	Steppe Eagle	*Aquila nipalensis*	Uncommon			Woodland			
	Lesser Spotted Eagle	*Aquila pomarina*	Uncommon		Monitoring	Woodland			
	Green Sandpiper	*Tringa ochropus*	Rare			Waterbodies			
	European Bee-eater	*Merops apiaster*	Common			Thicket	Woodland	Shrubland	
	Tree Pipit	*Anthus trivialis*	Rare			Woodland	Forest	Plantations	
	Grey Wagtail	*Motacilla cinerea*	Rare			Forest	Waterbodies		
	Olivetree Warbler	*Hippolais olivetorum*	Uncommon	Non-breeding endemic		Woodland	Degraded woodland		
	European Golden Oriole	*Oriolus oriolus*	Uncommon			Woodland	Urban-residential	Plantations	
high	Blackwinged Pratincole	*Glareola nordmanni*	Locally common			Grassland	Dryland agriculture	Waterbodies	
	Montagu's Harrier	*Circus pygargus*	Rare			Grassland	Dryland agriculture	Woodland	
	Lesser Kestrel	*Falco naumanni*	Common		Monitoring	Grassland	Dryland agriculture	Thicket	Urban-residential
	Pallid Harrier	*Circus macrourus*	Rare		Near-threatened	Grassland	Dryland agriculture	Woodland	
	Western Redfooted Kestrel	*Falco vespertinus*	Uncommon			Grassland	Woodland		
	Pennantwinged Nightjar	*Macrodipteryx vexillaria*	Locally common		Indeterminate	Woodland			
	Corncrake	*Crex crex*	Uncommon		Threatened	Grassland	Waterbodies	Dryland agriculture	Pasture
	African Hobby Falcon	*Falco cuvierii*	Uncommon			Woodland			
	Eastern Redfooted Kestrel	*Falco amurensis*	Common		Monitoring	Grassland	Dryland agriculture	Urban-residential	
	Ruff	*Philomachus pugnax*	Common			Waterbodies	Grassland		
Human									
low	Steelblue Widowfinch	*Vidua chalybeata*	Common		Monitoring	Woodland	Dryland agriculture	Urban-residential	
	Striped Cuckoo	*Clamator levaillantii*	Locally common			Woodland	Thicket	Urban-residential	
	Yellowbellied Sunbird	*Nectarinia venusta*	Locally common			Forest (A/C)	Woodland	Urban-residential	
	Chestnutbacked Finchlark	*Eremopterix leucotis*	Common			Grassland	Woodland	Dryland agriculture	
	Grey Lourie	*Corythaixoides concolor*	Common			Woodland	Thicket	Urban-residential	
	Heuglin's Robin	*Cossypha heuglini*	Common			Thicket	Woodland	Urban-residential	
	Lesser Grey Shrike	*Lanius minor*	Common	Non-breeding endemic		Thicket	Woodland	Shrubland	
	Sabota Lark	*Mirafra sabota*	Common	Near endemic		Woodland	Shrubland	Degraded woodland	
	Pinkbilled Lark	*Spizocorys conirostris*	Common	Near endemic		Grassland	Degraded grassland	Dryland agriculture	
	Bushveld Pipit	*Anthus caffer*	Common			Woodland	Degraded woodland		
high	**Fleshfooted Shearwater**	*Puffinus carneipes*	Common			Ocean			
	Wilson's Storm Petrel	*Oceanites oceanicus*	Common			Ocean			
	European Storm Petrel	*Hydrobates pelagicus*	Common			Coastal			
	European Starling	*Sturnus vulgaris*	Common	Alien		Urban-residential	Dryland agriculture		

SCORE Axis 2	COMMON	SPECIES	ABUNDANCE	DISTRIBUTION	RED DATA	VEG 1	VEG 2	VEG 3	VEG 4
	Subantartic Skua	*Catharacta antartica*	Common			Coastal			
	Shy Albatross	*Diomedea cauta*	Common			Ocean			
	Thrush Nightingale	*Luscinia luscinia*	Uncommon			Thicket	Urban-residential		
	Pearlbreasted Swallow	*Hirundo dimidiata*	Common			Woodland	Thicket	Shrubland	Dryland agriculture
	Southern Giant Petrel	*Macronectes giganteus*	Common			Ocean			
	Blackbrowed Albatross	*Diomedea melanophris*	Common			Ocean			
Non-human									
low	**Redbilled Buffalo Weaver**	*Bubalornis niger*	Nomadic			Woodland	Thicket		
	Purple Widowfinch	*Vidua purpurascens*	Locally common		Monitoring	Woodland	Thicket		
	Dickinson's Kestrel	*Falco dickinsoni*	Rare			Woodland			
	Thickbilled Cuckoo	*Pachycoccyx audeberti*	Rare		Monitoring	Thicket	Woodland		
	Carmine Bee-eater	*Merops nubicoides*	Common			Woodland			
	Rackettailed Roller	*Coracias spatulata*	Uncommon		Vulnerable	Woodland			
	Whitecrowned Shrike	*Eurocephalus anguitimens*	Common	Endemic		Woodland	Thicket		
	Black Tern	*Chlidonias niger*	Rare			Coastal			
	Dusky Lark	*Pinarocorys nigricans*	Uncommon			Woodland	Urban-residential		
	Greyhooded Kingfisher	*Halcyon leucocephala*	Uncommon		Indeterminate	Woodland			
high	**Cory's Shearwater**	*Calonectris diomedea*	Common			Ocean			
	Roseate Tern	*Sterna dougallii*	Locally common		Endangered	Coastal			
	Sabine's Gull	*Larus sabini*	Rare			Coastal			
	Bridled Tern	*Sterna anaethetus*	Rare			Coastal			
	Collared Flycatcher	*Ficedula albicollis*	Rare			Woodland			
	Blackbellied Storm Petrel	*Fregetta tropica*	Common			Ocean			
	Whitebellied Storm Petrel	*Fregetta grallaria*	Rare			Ocean			
	Sooty Shearwater	*Puffinus griseus*	Common			Ocean			
	Broadbilled Sandpiper	*Limicola falcinellus*	Rare			Coastal			
	Softplumaged Petrel	*Pterodroma mollis*	Common			Ocean			

Table B-3: ADU species that scored highest and lowest in stepwise canonical correspondence analyses on axis 1 for bird assemblages. Associated ecological information is also provided.

SCORE Axis 1	COMMON	SPECIES	ABUNDANCE	DISTRIBUTION	RED DATA	VEG 1	VEG 2	VEG 3	VEG 4
All									
low	Grey Wagtail	*Motacilla cinerea*	Rare			Forest	Waterbodies		
	Rufousbellied Heron	*Butorides rufiventris*	Rare	Endemic		Waterbodies			
	Pinkthroated Longclaw	*Macronyx ameliae*	Uncommon		Vulnerable	Grassland	Waterbodies		
	Black Coucal	*Centropus bengalensis*	Uncommon		Monitoring	Waterbodies	Grassland		
	Natal Nightjar	*Caprimulgus natalensis*	Rare		Vulnerable	Grassland	Waterbodies	Plantations	
	Woodards' Batis	*Batis fratrum*	Locally common	Endemic	Indeterminate	Coastal forest			
	Crab Plover	*Dromas ardeola*	Rare			Coastal			
	Broadbilled Roller	*Eurystomus glaucurus*	Locally common			Woodland	Thicket		
	Gullbilled Tern	*Gelochelidon nilotica*	Rare			Coastal			
	Broadbilled Sandpiper	*Limicola falcinellus*	Rare			Coastal			
high	Pale Chanting Goshawk	*Melierax canorus*	Common	Near endemic		Shrubland	Woodland		
	Southern Grey Tit	*Parus afer*	Common	Endemic		Shrubland	Grassland		
	Mountain Pipit	*Anthus hoeschi*	Common	Breeding endemic		Grassland	Shrubland		
	Thickbilled Lark	*Galerida magnirostris*	Common	Endemic		Shrubland	Grassland	Dryland agriculture	
	Yellow Canary	*Serinus flaviventris*	Common	Near endemic		Shrubland	Grassland		
	Sicklewinged Chat	*Cercomela sinuata*	Common	Endemic		Shrubland	Grassland	Degraded grassland	Degraded shrubland
	Layard's Titbabbler	*Parisoma layardi*	Common	Endemic		Shrubland			
	Drakensberg Siskin	*Pseudochloroptila symonsi*	Common	Endemic	Near-threatened	Shrubland	Grassland		
	Botha's Lark	*Spizocorys fringillaris*	Uncommon	Endemic	Indeterminate	Grassland	Degraded grassland		
	Blackchested Prinia	*Prinia flavicans*	Common	Near endemic		Shrubland	Thicket	Urban-residential	
Summer									
low	**Broadbilled Prion**	*Pachyptila vittata*	Uncommon			Ocean			
	Rufousbellied Heron	*Butorides rufiventris*	Rare	Endemic		Waterbodies			
	Pinkthroated Longclaw	*Macronyx ameliae*	Uncommon		Vulnerable	Grassland	Waterbodies		
	Black Coucal	*Centropus bengalensis*	Uncommon		Monitoring	Waterbodies	Grassland		
	Natal Nightjar	*Caprimulgus natalensis*	Rare		Vulnerable	Grassland	Waterbodies	Plantations	
	Woodards' Batis	*Batis fratrum*	Locally common	Endemic	Indeterminate	Coastal forest			
	Broadbilled Roller	*Eurystomus glaucurus*	Locally common			Woodland	Thicket		
	Crab Plover	*Dromas ardeola*	Rare			Coastal			
	Yellow White-eye	*Zosterops senegalensis*	Rare			Coastal forest	Woodland		
	Southern Banded Snake Eagle	*Circeatus fasciolatus*	Rare		Near-threatened	Coastal forest	Woodland	Thicket	
high	Thickbilled Lark	*Galerida magnirostris*	Common	Endemic		Shrubland	Grassland	Dryland agriculture	
	Mountain Pipit	*Anthus hoeschi*	Common	Breeding endemic		Grassland	Shrubland		

SCORE Axis 1	COMMON	SPECIES	ABUNDANCE	DISTRIBUTION	RED DATA	VEG 1	VEG 2	VEG 3	VEG 4
	Yellow Canary	*Serinus flaviventris*	Common	Near endemic		Shrubland	Grassland		
	Sicklewinged Chat	*Cercomela sinuata*	Common	Endemic		Shrubland	Grassland	Degraded grassland	Degraded shrubland
	Layard's Titbabbler	*Parisoma layardi*	Common	Endemic		Shrubland			
	Southern Grey Tit	*Parus afer*	Common	Endemic		Shrubland	Grassland		
	Drakensberg Siskin	*Pseudochloroptila symonsi*	Common	Endemic	Near-threatened	Shrubland	Grassland		
	Pale Chanting Goshawk	*Melierax canorus*	Common	Near endemic		Shrubland	Woodland		
	Botha's Lark	*Spizocorys fringillaris*	Uncommon	Endemic	Indeterminate	Grassland	Degraded grassland		
	Blackchested Prinia	*Prinia flavicans*	Common	Near endemic		Shrubland	Thicket	Urban-residential	
Winter									
low	Grey Wagtail	*Motacilla cinerea*	Rare			Forest	Waterbodies		
	Pinkthroated Longclaw	*Macronyx ameliae*	Uncommon		Vulnerable	Grassland	Waterbodies		
	Blackrumped Buttonquail	*Turnix hottentotta*	Rare		Endangered	Grassland	Waterbodies	Shrubland	
	Saddlebilled Stork	*Ephippiorhynchus senegalensis*	Uncommon		Rare	Waterbodies			
	Natal Nightjar	*Caprimulgus natalensis*	Rare		Vulnerable	Grassland	Waterbodies	Plantations	
	European Storm Petrel	*Hydrobates pelagicus*	Common			Coastal			
	Temminck's Courser	*Cursorius temminckii*	Locally common			Grassland	Degraded grassland	Degraded woodland	Dryland agriculture
	Woodards' Batis	*Batis fratrum*	Locally common	Endemic	Indeterminate	Coastal forest			
	Redbilled Helmetshrike	*Prionops retzii*	Common		Threatened	Woodland			
	Knot	*Calidris canutus*	Locally common			Waterbodies	Coastal		
high	Pale Chanting Goshawk	*Melierax canorus*	Common	Near endemic		Shrubland	Woodland		
	Layard's Titbabbler	*Parisoma layardi*	Common	Endemic		Shrubland			
	Southern Grey Tit	*Parus afer*	Common	Endemic		Shrubland	Grassland		
	Sicklewinged Chat	*Cercomela sinuata*	Common	Endemic		Shrubland	Grassland	Degraded grassland	Degraded shrubland
	Thickbilled Lark	*Galerida magnirostris*	Common	Endemic		Shrubland	Grassland	Dryland agriculture	
	Drakensberg Siskin	*Pseudochloroptila symonsi*	Common	Endemic	Near-threatened	Shrubland	Grassland		
	Yellow Canary	*Serinus flaviventris*	Common	Near endemic		Shrubland	Grassland		
	Mountain Pipit	*Anthus hoeschi*	Common	Breeding endemic		Grassland	Shrubland		
	Botha's Lark	*Spizocorys fringillaris*	Uncommon	Endemic	Indeterminate	Grassland	Degraded grassland		
	Blacknecked Grebe	*Podiceps nigricollis*	Locally common			Waterbodies	Grassland	Shrubland	
Passerine									
low	Grey Wagtail	*Motacilla cinerea*	Rare			Forest	Waterbodies		
	Redbilled Helmetshrike	*Prionops retzii*	Common		Threatened	Woodland			
	Whitebreasted Cuckooshrike	*Coracina pectoralis*	Rare			Woodland			
	Pinkthroated Longclaw	*Macronyx ameliae*	Uncommon		Vulnerable	Grassland	Waterbodies		
	Woodards' Batis	*Batis fratrum*	Locally common	Endemic	Indeterminate	Coastal forest			
	Stierling's Barred Warbler	*Calamonastes stierlingi*	Common			Woodland			
	Yellow White-eye	*Zosterops senegalensis*	Rare			Coastal forest	Woodland		

SCORE Axis 1	COMMON	SPECIES	ABUNDANCE	DISTRIBUTION	RED DATA	VEG 1	VEG 2	VEG 3	VEG 4
	Neergaard's Sunbird	*Nectarinia neergaardi*	Rare	Endemic	Near-threatened	Thicket	Coastal forest		
	Pinkthroated Twinspot	*Hypargos margaritatus*	Rare	Endemic	Monitoring	Thicket	Woodland		
	Lemonbreasted Canary	*Serinus citrinipectus*	Rare		Monitoring	Woodland	Grassland	Dryland agriculture	
high	Southern Grey Tit	*Parus afer*	Common	Endemic		Shrubland	Grassland		
	Mountain Pipit	*Anthus hoeschi*	Common	Breeding endemic		Grassland	Shrubland		
	Sicklewinged Chat	*Cercomela sinuata*	Common	Endemic		Shrubland	Grassland	Degraded grassland	Degraded shrubland
	Yellow Canary	*Serinus flaviventris*	Common	Near endemic		Shrubland	Grassland		
	Thickbilled Lark	*Galerida magnirostris*	Common	Endemic		Shrubland	Grassland	Dryland agriculture	
	Layard's Titbabbler	*Parisoma layardi*	Common	Endemic		Shrubland			
	Drakensberg Siskin	*Pseudochloroptila symonsi*	Common	Endemic	Near-threatened	Shrubland	Grassland		
	Redeyed Bulbul	*Pycnonotus nigricans*	Common	Near endemic		Grassland	Shrubland	Woodland	Urban-residential
	Orangebreasted Rockjumper	*Chaetops aurantius*	Common	Endemic	Near-threatened	Grassland			
	Botha's Lark	*Spizocorys fringillaris*	Uncommon	Endemic	Indeterminate	Grassland	Degraded grassland		
Non-passerine									
low	Gullbilled Tern	*Gelochelidon nilotica*	Rare			Coastal			
	Broadbilled Sandpiper	*Limicola falcinellus*	Rare			Coastal			
	Crab Plover	*Dromas ardeola*	Rare			Coastal			
	Black Coucal	*Centropus bengalensis*	Uncommon		Monitoring	Waterbodies	Grassland		
	Natal Nightjar	*Caprimulgus natalensis*	Rare		Vulnerable	Grassland	Waterbodies	Plantations	
	Mongolian Plover	*Charadrius mongolus*	Common			Coastal			
	Rufousbellied Heron	*Butorides rufiventris*	Rare	Endemic		Waterbodies			
	Broadbilled Prion	*Pachyptila vittata*	Uncommon			Ocean			
	Greater Frigatebird	*Fregata minor*	Rare			Coastal			
	Green Barbet	*Stactolaema olivacea*	Locally common	Endemic	Vulnerable	Forest (A/C)			
high	**Pale Chanting Goshawk**	*Melierax canorus*	Common	Near endemic		Shrubland	Woodland		
	Whitewinged Black Korhaan	*Eupodotis afraoides*	Common			Grassland	Thicket		
	Burchell's Courser	*Cursorius rufus*	Uncommon	Endemic	Monitoring	Shrubland	Degraded grassland	Degraded shrubland	Dryland agriculture
	Western Redfooted Kestrel	*Falco vespertinus*	Uncommon			Grassland	Woodland		
	Greywing Francolin	*Francolinus africanus*	Common	Endemic		Grassland	Shrubland		
	Bearded Vulture	*Gypaetus barbatus*	Rare		Monitoring	Grassland			
	Whitewinged Flufftail	*Sarothrura ayresi*	Rare		Endangered	Waterbodies			
	Blackwinged Pratincole	*Glareola nordmanni*	Locally common			Grassland	Dryland agriculture	Waterbodies	
	Greater Kestrel	*Falco rupicoloides*	Locally common			Grassland	Shrubland	Degraded woodland	
	Abdim's Stork	*Ciconia abdimii*	Common			Grassland	Dryland agriculture	Pasture	
Breeding									
low	Rufousbellied Heron	*Butorides rufiventris*	Rare	Endemic		Waterbodies			
	Pinkthroated Longclaw	*Macronyx ameliae*	Uncommon		Vulnerable	Grassland	Waterbodies		

SCORE Axis 1	COMMON	SPECIES	ABUNDANCE	DISTRIBUTION	RED DATA	VEG 1	VEG 2	VEG 3	VEG 4
	Redbilled Helmetshrike	*Prionops retzii*	Common		Threatened	Woodland			
	Woodards' Batis	*Batis fratrum*	Locally common	Endemic	Indeterminate	Coastal forest			
	Black Coucal	*Centropus bengalensis*	Uncommon		Monitoring	Waterbodies	Grassland		
	Broadbilled Roller	*Eurystomus glaucurus*	Locally common			Woodland	Thicket		
	Yellow White-eye	*Zosterops senegalensis*	Rare			Coastal forest	Woodland		
	Lesser Blackwinged Plover	*Vanellus lugubris*	Uncommon		Rare	Woodland	Grassland		
	Stierling's Barred Warbler	*Calamonastes stierlingi*	Common			Woodland			
	Natal Nightjar	*Caprimulgus natalensis*	Rare		Vulnerable	Grassland	Waterbodies	Plantations	
high	Southern Grey Tit	*Parus afer*	Common	Endemic		Shrubland	Grassland		
	Pale Chanting Goshawk	*Melierax canorus*	Common	Near endemic		Shrubland	Woodland		
	Mountain Pipit	*Anthus hoeschi*	Common	Breeding endemic		Grassland	Shrubland		
	Thickbilled Lark	*Galerida magnirostris*	Common	Endemic		Shrubland	Grassland	Dryland agriculture	
	Yellow Canary	*Serinus flaviventris*	Common	Near endemic		Shrubland	Grassland		
	Sicklewinged Chat	*Cercomela sinuata*	Common	Endemic		Shrubland	Grassland	Degraded grassland	Degraded shrubland
	Layard's Titbabbler	*Parisoma layardi*	Common	Endemic		Shrubland			
	Drakensberg Siskin	*Pseudochloroptila symonsi*	Common	Endemic	Near-threatened	Shrubland	Grassland		
	Botha's Lark	*Spizocorys fringillaris*	Uncommon	Endemic	Indeterminate	Grassland	Degraded grassland		
	Redeyed Bulbul	*Pycnonotus nigricans*	Common	Near endemic		Grassland	Shrubland	Woodland	Urban-residential
Non-breeding									
low	**Abdim's Stork**	*Ciconia abdimii*	Common			Grassland	Dryland agriculture	Pasture	
	Blackwinged Pratincole	*Glareola nordmanni*	Locally common			Grassland	Dryland agriculture	Waterbodies	
	Western Redfooted Kestrel	*Falco vespertinus*	Uncommon			Grassland	Woodland		
	Lesser Kestrel	*Falco naumanni*	Common		Monitoring	Grassland	Dryland agriculture	Thicket	Urban-residential
	Pallid Harrier	*Circus macrourus*	Rare		Near-threatened	Grassland	Dryland agriculture	Woodland	
	Whitewinged Flufftail	*Sarothrura ayresi*	Rare		Endangered	Waterbodies			
	Eastern Redfooted Kestrel	*Falco amurensis*	Common		Monitoring	Grassland	Dryland agriculture	Urban-residential	
	White Stork	*Ciconia ciconia*	Common			Grassland	Dryland agriculture	Woodland	Pasture
	Lesser Grey Shrike	*Lanius minor*	Common	Non-breeding endemic		Thicket	Woodland	Shrubland	
	European Marsh Harrier	*Circus aeruginosus*	Rare			Waterbodies			
high	Gullbilled Tern	*Gelochelidon nilotica*	Rare			Coastal			
	Broadbilled Sandpiper	*Limicola falcinellus*	Rare			Coastal			
	Mongolian Plover	*Charadrius mongolus*	Common			Coastal			
	Softplumaged Petrel	*Pterodroma mollis*	Common			Ocean			
	Crab Plover	*Dromas ardeola*	Rare			Coastal			
	Pintado Petrel	*Daption capense*	Common			Ocean			
	Subantartic Skua	*Catharacta antartica*	Common			Coastal			

SCORE Axis 1	COMMON	SPECIES	ABUNDANCE	DISTRIBUTION	RED DATA	VEG 1	VEG 2	VEG 3	VEG 4
	Wandering Albatross	*Diomedea exulans*	Uncommon			Ocean			
	Bartailed Godwit	*Limosa lapponica*	Common			Coastal			
	Blackbrowed Albatross	*Diomedea melanophris*	Common			Ocean			
Human									
low	Lemonbreasted Canary	*Serinus citrinipectus*	Rare		Monitoring	Woodland	Grassland	Dryland agriculture	
	Greyrumped Swallow	*Pseudhirundo griseopyga*	Common			Woodland	Waterbodies	Dryland agriculture	
	European Storm Petrel	*Hydrobates pelagicus*	Common			Coastal			
	Caspian Tern	*Hydroprogne caspia*	Common		Rare	Coastal	Waterbodies		
	Ayres' Eagle	*Hieraaetus ayresii*	Rare			Woodland	Plantations		
	Purplebanded Sunbird	*Nectarinia bifasciata*	Common			Woodland	Thicket	Coastal forest	Urban-residential
	Subantartic Skua	*Catharacta antartica*	Common			Coastal			
	Shy Albatross	*Diomedea cauta*	Common			Ocean			
	Mangrove Kingfisher	*Halcyon senegaloides*	Uncommon		Vulnerable	Coastal forest	Rivers	Urban-residential	
	Lesser Flamingo	*Phoeniconaias minor*	Locally common		Near-threatened	Waterbodies			
high	**Thickbilled Lark**	*Galerida magnirostris*	Common	Endemic		Shrubland	Grassland	Dryland agriculture	
	Sicklewinged Chat	*Cercomela sinuata*	Common	Endemic		Shrubland	Grassland	Degraded grassland	Degraded shrubland
	Blackchested Prinia	*Prinia flavicans*	Common	Near endemic		Shrubland	Thicket	Urban-residential	
	Redeyed Bulbul	*Pycnonotus nigricans*	Common	Near endemic		Grassland	Shrubland	Woodland	Urban-residential
	Burchell's Courser	*Cursorius rufus*	Uncommon	Endemic	Monitoring	Shrubland	Degraded grassland	Degraded shrubland	Dryland agriculture
	Clapper Lark	*Mirafra apiata*	Common	Endemic		Grassland	Shrubland	Dryland agriculture	
	Greater Kestrel	*Falco rupicoloides*	Locally common			Grassland	Shrubland	Degraded woodland	
	Larklike Bunting	*Emberiza impetuani*	Common	Near-endemic		Shrubland	Grassland	Thicket	Waterbodies
	Abdim's Stork	*Ciconia abdimii*	Common			Grassland	Dryland agriculture	Pasture	
	Fairy Flycatcher	*Stenostira scita*	Common	Endemic		Grassland	Thicket	Urban-residential	
Non-human									
low	Grey Wagtail	*Motacilla cinerea*	Rare			Forest	Waterbodies		
	Rufousbellied Heron	*Butorides rufiventris*	Rare	Endemic		Waterbodies			
	Pinkthroated Longclaw	*Macronyx ameliae*	Uncommon		Vulnerable	Grassland	Waterbodies		
	Black Coucal	*Centropus bengalensis*	Uncommon		Monitoring	Waterbodies	Grassland		
	Broadbilled Sandpiper	*Limicola falcinellus*	Rare			Coastal			
	Gullbilled Tern	*Gelochelidon nilotica*	Rare			Coastal			
	Natal Nightjar	*Caprimulgus natalensis*	Rare		Vulnerable	Grassland	Waterbodies	Plantations	
	Crab Plover	*Dromas ardeola*	Rare			Coastal			
	Woodards' Batis	*Batis fratrum*	Locally common	Endemic	Indeterminate	Coastal forest			
	Broadbilled Roller	*Eurystomus glaucurus*	Locally common			Woodland	Thicket		
high	**Pale Chanting Goshawk**	*Melierax canorus*	Common	Near endemic		Shrubland	Woodland		
	Southern Grey Tit	*Parus afer*	Common	Endemic		Shrubland	Grassland		

SCORE Axis 1	COMMON	SPECIES	ABUNDANCE	DISTRIBUTION	RED DATA	VEG 1	VEG 2	VEG 3	VEG 4
	Mountain Pipit	*Anthus hoeschi*	Common	Breeding endemic		Grassland	Shrubland		
	Yellow Canary	*Serinus flaviventris*	Common	Near endemic		Shrubland	Grassland		
	Layard's Titbabbler	*Parisoma layardi*	Common	Endemic		Shrubland			
	Drakensberg Siskin	*Pseudochloroptila symonsi*	Common	Endemic	Near-threatened	Shrubland	Grassland		
	Botha's Lark	*Spizocorys fringillaris*	Uncommon	Endemic	Indeterminate	Grassland	Degraded grassland		
	Rock Pipit	*Anthus crenatus*	Common	Endemic		Grassland	Shrubland		
	Orangebreasted Rockjumper	*Chaetops aurantius*	Common	Endemic	Near-threatened	Grassland			
	Whitewinged Black Korhaan	*Eupodotis afraoides*	Common			Grassland	Thicket		

Table B-4: ADU species that scored highest and lowest in stepwise canonical correspondence analyses on axis 2 for bird assemblages. Associated ecological information is also provided.

SCORE Axis2	COMMON	SPECIES	ABUNDANCE	DISTRIBUTION	RED DATA	VEG 1	VEG 2	VEG 3	VEG 4
All									
low	Burchell's Starling	*Lamprotornis australis*	Common	Endemic		Woodland	Thicket		
	Bennett's Woodpecker	*Campethera bennettii*	Locally common			Woodland			
	Thickbilled Cuckoo	*Pachycoccyx audeberti*	Rare		Monitoring	Thicket	Woodland		
	Pearlspotted Owl	*Glaucidium perlatum*	Common			Woodland	Thicket		
	Redbilled Buffalo Weaver	*Bubalornis niger*	Nomadic			Woodland	Thicket		
	Barred Owl	*Glaucidium capense*	Locally common		Rare	Woodland			
	Swallowtailed Bee-eater	*Merops hirundineus*	Rare			Woodland			
	Purple Widowfinch	*Vidua purpurascens*	Locally common		Monitoring	Woodland	Thicket		
	Whitebreasted Cuckooshrike	*Coracina pectoralis*	Rare			Woodland			
	Redcrested Korhaan	*Eupodotis ruficrista*	Common	Near endemic	Monitoring	Grassland	Woodland	Shrubland	
high	Gullbilled Tern	*Gelochelidon nilotica*	Rare			Coastal			
	Broadbilled Sandpiper	*Limicola falcinellus*	Rare			Coastal			
	Pintado Petrel	*Daption capense*	Common			Ocean			
	Mongolian Plover	*Charadrius mongolus*	Common			Coastal			
	Whitechinned Petrel	*Procellaria aequinoctialis*	Common		Monitoring	Ocean			
	Softplumaged Petrel	*Pterodroma mollis*	Common			Ocean			
	Wilson's Storm Petrel	*Oceanites oceanicus*	Common			Ocean			
	Blackbrowed Albatross	*Diomedea melanophris*	Common			Ocean			
	Pomarine Skua	*Stercorarius pomarinus*	Common			Coastal			
	Cory's Shearwater	*Calonectris diomedea*	Common			Ocean			
Summer									
low	Bennett's Woodpecker	*Campethera bennettii*	Locally common			Woodland			
	Pearlspotted Owl	*Glaucidium perlatum*	Common			Woodland	Thicket		
	Burchell's Starling	*Lamprotornis australis*	Common	Endemic		Woodland	Thicket		
	Ovambo Sparrowhawk	*Accipiter ovampensis*	Rare			Woodland	Plantations		
	Thickbilled Cuckoo	*Pachycoccyx audeberti*	Rare		Monitoring	Thicket	Woodland		
	Redbilled Buffalo Weaver	*Bubalornis niger*	Nomadic			Woodland	Thicket		
	Longtoed Plover	*Vanellus crassirostris*	Rare		Monitoring	Waterbodies			
	Purple Widowfinch	*Vidua purpurascens*	Locally common		Monitoring	Woodland	Thicket		

SCORE Axis2	COMMON	SPECIES	ABUNDANCE	DISTRIBUTION	RED DATA	VEG 1	VEG 2	VEG 3	VEG 4
	Barred Owl	*Glaucidium capense*	Locally common		Rare	Woodland			
	Redcrested Korhaan	*Eupodotis ruficrista*	Common	Near endemic	Monitoring	Grassland	Woodland	Shrubland	
high	Broadbilled Sandpiper	*Limicola falcinellus*	Rare			Coastal			
	Gullbilled Tern	*Gelochelidon nilotica*	Rare			Coastal			
	Pintado Petrel	*Daption capense*	Common			Ocean			
	Mongolian Plover	*Charadrius mongolus*	Common			Coastal			
	Pied Mannikin	*Spermestes fringilloides*	Rare		Indeterminate	Coastal forest	Urban-residential	Dryland agriculture	
	Whitechinned Petrel	*Procellaria aequinoctialis*	Common		Monitoring	Ocean			
	Softplumaged Petrel	*Pterodroma mollis*	Common			Ocean			
	African Black Oystercatcher	*Haematopus moquini*	Common			Coastal			
	Lesser Blackbacked Gull	*Larus fuscus*	Uncommon			Coastal			
	Fleshfooted Shearwater	*Puffinus carneipes*	Common			Ocean			
Winter									
low	Burchell's Starling	*Lamprotornis australis*	Common	Endemic		Woodland	Thicket		
	Pearlspotted Owl	*Glaucidium perlatum*	Common			Woodland	Thicket		
	Longtailed Shrike	*Corvinella melanoleuca*	Common			Thicket	Woodland		
	Swallowtailed Bee-eater	*Merops hirundineus*	Rare			Woodland			
	Redcrested Korhaan	*Eupodotis ruficrista*	Common	Near endemic	Monitoring	Grassland	Woodland	Shrubland	
	Lesser Grey Shrike	*Lanius minor*	Common	Non-breeding endemic		Thicket	Woodland	Shrubland	
	Jameson's Firefinch	*Lagonosticta rhodopareia*	Locally common			Woodland	Thicket		
	Purple Roller	*Coracias naevia*	Common			Woodland	Thicket		
	Burntnecked Eremomela	*Eremomela usticollis*	Common			Woodland			
	Paradise Whydah	*Vidua paradisaea*	Common			Thicket	Woodland		
high	Gullbilled Tern	*Gelochelidon nilotica*	Rare			Coastal			
	Yellow Wagtail	*Motacilla flava*	Uncommon			Waterbodies	Degraded grassland		
	Pintado Petrel	*Daption capense*	Common			Ocean			
	Wilson's Storm Petrel	*Oceanites oceanicus*	Common			Ocean			
	Yellownosed Albatross	*Diomedea chlororhynchos*	Common			Ocean			
	Whitechinned Petrel	*Procellaria aequinoctialis*	Common		Monitoring	Ocean			
	Arctic Skua	*Stercorarius parasiticus*	Common			Coastal			
	Bartailed Godwit	*Limosa lapponica*	Common			Coastal			
	Bittern	*Botaurus stellaris*	Rare		Vulnerable	Waterbodies			
	Curlew	*Numenius arquata*	Common			Coastal			

SCORE Axis2	COMMON	SPECIES	ABUNDANCE	DISTRIBUTION	RED DATA	VEG 1	VEG 2	VEG 3	VEG 4
Passerine									
low	Whitebreasted Cuckooshrike	*Coracina pectoralis*	Rare			Woodland			
	Burchell's Starling	*Lamprotornis australis*	Common	Endemic		Woodland	Thicket		
	Redbilled Buffalo Weaver	*Bubalornis niger*	Nomadic			Woodland	Thicket		
	Purple Widowfinch	*Vidua purpurascens*	Locally common		Monitoring	Woodland	Thicket		
	Longtailed Shrike	*Corvinella melanoleuca*	Common			Thicket	Woodland		
	Redbilled Helmetshrike	*Prionops retzii*	Common		Threatened	Woodland			
	Olivetree Warbler	*Hippolais olivetorum*	Uncommon	Non-breeding endemic		Woodland	Degraded woodland		
	Clapper Lark	*Mirafra apiata*	Common	Endemic		Grassland	Shrubland	Dryland agriculture	
	Redheaded Weaver	*Anaplectes rubriceps*	Common			Woodland			
	Jameson's Firefinch	*Lagonosticta rhodopareia*	Locally common			Woodland	Thicket		
high	**Pied Mannikin**	*Spermestes fringilloides*	Rare		Indeterminate	Coastal forest	Urban-residential	Dryland agriculture	
	House Crow	*Corvus splendens*	Locally common	Alien		Urban-residential			
	Spotted Thrush	*Zoothera guttata*	Uncommon		Endangered	Coastal forest			
	European Starling	*Sturnus vulgaris*	Common	Alien		Urban-residential	Dryland agriculture		
	Golden Weaver	*Ploceus xanthops*	Common			Waterbodies	Thicket		
	Larklike Bunting	*Emberiza impetuani*	Common	Near-endemic		Shrubland	Grassland	Thicket	Waterbodies
	Brown Robin	*Erythropygia signata*	Common	Endemic	Vulnerable	Coastal forest			
	Barratt's Warbler	*Bradypterus barratti*	Common	Endemic		Forest	Plantations	Grassland	
	European Sedge Warbler	*Acrocephalus schoenobaenus*	Rare			Waterbodies			
	Grey Cuckooshrike	*Coracina caesia*	Uncommon			Woodland	Forest (A/C)		
Non-passerine									
low	Bennett's Woodpecker	*Campethera bennettii*	Locally common			Woodland			
	Thickbilled Cuckoo	*Pachycoccyx audeberti*	Rare		Monitoring	Thicket	Woodland		
	Pearlspotted Owl	*Glaucidium perlatum*	Common			Woodland	Thicket		
	Barred Owl	*Glaucidium capense*	Locally common		Rare	Woodland			
	Swallowtailed Bee-eater	*Merops hirundineus*	Rare			Woodland			
	Redcrested Korhaan	*Eupodotis ruficrista*	Common	Near endemic	Monitoring	Grassland	Woodland	Shrubland	
	Purple Roller	*Coracias naevia*	Common			Woodland	Thicket		
	Grey Lourie	*Corythaixoides concolor*	Common			Woodland	Thicket	Urban-residential	
	Whiteheaded Vulture	*Trigonoceps occipitalis*	Uncommon		Rare	Woodland			
	Giant Eagle Owl	*Bubo lacteus*	Uncommon		Monitoring	Woodland			
high	Gullbilled Tern	*Gelochelidon nilotica*	Rare			Coastal			

SCORE Axis2	COMMON	SPECIES	ABUNDANCE	DISTRIBUTION	RED DATA	VEG 1	VEG 2	VEG 3	VEG 4
	Broadbilled Sandpiper	*Limicola falcinellus*	Rare			Coastal			
	Mongolian Plover	*Charadrius mongolus*	Common			Coastal			
	Pintado Petrel	*Daption capense*	Common			Ocean			
	Whitechinned Petrel	*Procellaria aequinoctialis*	Common		Monitoring	Ocean			
	Softplumaged Petrel	*Pterodroma mollis*	Common			Ocean			
	Wilson's Storm Petrel	*Oceanites oceanicus*	Common			Ocean			
	Whitebellied Storm Petrel	*Fregetta grallaria*	Rare			Ocean			
	Blackbellied Storm Petrel	*Fregetta tropica*	Common			Ocean			
	Pomarine Skua	*Stercorarius pomarinus*	Common			Coastal			
Breeding									
low	Burchell's Starling	*Lamprotornis australis*	Common	Endemic		Woodland	Thicket		
	Bennett's Woodpecker	*Campethera bennettii*	Locally common			Woodland			
	Thickbilled Cuckoo	*Pachycoccyx audeberti*	Rare		Monitoring	Thicket	Woodland		
	Pearlspotted Owl	*Glaucidium perlatum*	Common			Woodland	Thicket		
	Redbilled Buffalo Weaver	*Bubalornis niger*	Nomadic			Woodland	Thicket		
	Whitebreasted Cuckooshrike	*Coracina pectoralis*	Rare			Woodland			
	Burchell's Courser	*Cursorius rufus*	Uncommon	Endemic	Monitoring	Shrubland	Degraded grassland	Degraded shrubland	Dryland agriculture
	Swallowtailed Bee-eater	*Merops hirundineus*	Rare			Woodland			
	Barred Owl	*Glaucidium capense*	Locally common		Rare	Woodland			
	Purple Widowfinch	*Vidua purpurascens*	Locally common		Monitoring	Woodland	Thicket		
high	Pied Mannikin	*Spermestes fringilloides*	Rare		Indeterminate	Coastal forest	Urban-residential	Dryland agriculture	
	House Crow	*Corvus splendens*	Locally common	Alien		Urban-residential			
	Knysna Woodpecker	*Campethera notata*	Locally common	Endemic	Near-threatened	Coastal forest	Thicket		
	Mangrove Kingfisher	*Halcyon senegaloides*	Uncommon		Vulnerable	Coastal forest	Rivers	Urban-residential	
	Bittern	*Botaurus stellaris*	Rare		Vulnerable	Waterbodies			
	Green Barbet	*Stactolaema olivacea*	Locally common	Endemic	Vulnerable	Forest (A/C)			
	Spotted Thrush	*Zoothera guttata*	Uncommon		Endangered	Coastal forest			
	Cape Cormorant	*Phalacrocorax capensis*	Common	Breeding endemic		Ocean			
	African Black Oystercatcher	*Haematopus moquini*	Common			Coastal			
	Cape Gannet	*Morus capensis*	Common	Breeding endemic		Coastal			
Non-breeding									
low	**Olivetree Warbler**	*Hippolais olivetorum*	Uncommon	Non-breeding endemic		Woodland	Degraded woodland		
	Steppe Eagle	*Aquila nipalensis*	Uncommon			Woodland			

SCORE Axis2	COMMON	SPECIES	ABUNDANCE	DISTRIBUTION	RED DATA	VEG 1	VEG 2	VEG 3	VEG 4
	Grey Wagtail	*Motacilla cinerea*	Rare			Forest	Waterbodies		
	Bluecheeked Bee-eater	*Merops persicus*	Locally common			Grassland	Woodland	Waterbodies	
	Lesser Spotted Eagle	*Aquila pomarina*	Uncommon		Monitoring	Woodland			
	European Bee-eater	*Merops apiaster*	Common			Thicket	Woodland	Shrubland	
	Redshank	*Tringa totanus*	Rare			Waterbodies	Coastal		
	Dusky Lark	*Pinarocorys nigricans*	Uncommon			Woodland	Urban-residential		
	Lesser Flamingo	*Phoeniconaias minor*	Locally common		Near-threatened	Waterbodies			
	Icterine Warbler	*Hippolais icterina*	Common			Woodland	Plantations	Urban-residential	
high	Subantartic Skua	*Catharacta antartica*	Common			Coastal			
	Wandering Albatross	*Diomedea exulans*	Uncommon			Ocean			
	Pintado Petrel	*Daption capense*	Common			Ocean			
	Whitewinged Flufftail	*Sarothrura ayresi*	Rare		Endangered	Waterbodies			
	Softplumaged Petrel	*Pterodroma mollis*	Common			Ocean			
	Western Redfooted Kestrel	*Falco vespertinus*	Uncommon			Grassland	Woodland		
	Whitechinned Petrel	*Procellaria aequinoctialis*	Common		Monitoring	Ocean			
	Blackbrowed Albatross	*Diomedea melanophris*	Common			Ocean			
	Wilson's Storm Petrel	*Oceanites oceanicus*	Common			Ocean			
	Yellownosed Albatross	*Diomedea chlororhynchos*	Common			Ocean			
Human									
low	Burchell's Courser	*Cursorius rufus*	Uncommon	Endemic	Monitoring	Shrubland	Degraded grassland	Degraded shrubland	Dryland agriculture
	Olivetree Warbler	*Hippolais olivetorum*	Uncommon	Non-breeding endemic		Woodland	Degraded woodland		
	Heuglin's Robin	*Cossypha heuglini*	Common			Thicket	Woodland	Urban-residential	
	Striped Cuckoo	*Clamator levaillantii*	Locally common			Woodland	Thicket	Urban-residential	
	Grey Lourie	*Corythaixoides concolor*	Common			Woodland	Thicket	Urban-residential	
	Chestnutbacked Finchlark	*Eremopterix leucotis*	Common			Grassland	Woodland	Dryland agriculture	
	Bushveld Pipit	*Anthus caffer*	Common			Woodland	Degraded woodland		
	Flappet Lark	*Mirafra rufocinnamomea*	Common			Woodland	Degraded woodland	Dryland agriculture	
	White Helmetshrike	*Prionops plumatus*	Common			Woodland	Thicket	Urban-residential	Plantations
	Sabota Lark	*Mirafra sabota*	Common	Near endemic		Woodland	Shrubland	Degraded woodland	
high	Pintado Petrel	*Daption capense*	Common			Ocean			
	Wilson's Storm Petrel	*Oceanites oceanicus*	Common			Ocean			
	Whitechinned Petrel	*Procellaria aequinoctialis*	Common		Monitoring	Ocean			
	Greatwinged Petrel	*Pterodroma macroptera*	Common		Vulnerable	Ocean			

SCORE Axis2	COMMON	SPECIES	ABUNDANCE	DISTRIBUTION	RED DATA	VEG 1	VEG 2	VEG 3	VEG 4
	Pied Mannikin	*Spermestes fringilloides*	Rare		Indeterminate	Coastal forest	Urban-residential	Dryland agriculture	
	Subantartic Skua	*Catharacta antartica*	Common			Coastal			
	Fleshfooted Shearwater	*Puffinus carneipes*	Common			Ocean			
	Blackbrowed Albatross	*Diomedea melanophris*	Common			Ocean			
	Southern Giant Petrel	*Macronectes giganteus*	Common			Ocean			
	House Crow	*Corvus splendens*	Locally common	Alien		Urban-residential			
Non-human low	Bennett's Woodpecker	*Campethera bennettii*	Locally common			Woodland			
	Burchell's Starling	*Lamprotornis australis*	Common	Endemic		Woodland	Thicket		
	Thickbilled Cuckoo	*Pachycoccyx audeberti*	Rare		Monitoring	Thicket	Woodland		
	Pearlspotted Owl	*Glaucidium perlatum*	Common			Woodland	Thicket		
	Redbilled Buffalo Weaver	*Bubalornis niger*	Nomadic			Woodland	Thicket		
	Whitebreasted Cuckooshrike	*Coracina pectoralis*	Rare			Woodland			
	Purple Widowfinch	*Vidua purpurascens*	Locally common		Monitoring	Woodland	Thicket		
	Barred Owl	*Glaucidium capense*	Locally common		Rare	Woodland			
	Swallowtailed Bee-eater	*Merops hirundineus*	Rare			Woodland			
	Redcrested Korhaan	*Eupodotis ruficrista*	Common	Near endemic	Monitoring	Grassland	Woodland	Shrubland	
high	Gullbilled Tern	*Gelochelidon nilotica*	Rare			Coastal			
	Broadbilled Sandpiper	*Limicola falcinellus*	Rare			Coastal			
	Mongolian Plover	*Charadrius mongolus*	Common			Coastal			
	Softplumaged Petrel	*Pterodroma mollis*	Common			Ocean			
	Arctic Skua	*Stercorarius parasiticus*	Common			Coastal			
	Yellownosed Albatross	*Diomedea chlororhynchos*	Common			Ocean			
	Whitebellied Storm Petrel	*Fregetta grallaria*	Rare			Ocean			
	Pomarine Skua	*Stercorarius pomarinus*	Common			Coastal			
	Cory's Shearwater	*Calonectris diomedea*	Common			Ocean			
	Blackbellied Storm Petrel	*Fregetta tropica*	Common			Ocean			

Appendix D

The following table lists the birds that were found in the CR survey but not found in the ADU survey, and birds found in the ADU survey but not found in during the CR survey. ADU birds in bold denote species found in the province before 1970 by Clancey (1964).

Table D-1: Avian species recorded in KwaZulu-Natal during the CR survey but not found in the ADU survey, and species recorded during the ADU survey but not found in the CR survey. ADU birds in bold denote species found in the province before 1970 by Clancey (1964).

DATA	SPECIES	COMMON	ABUNDANCE	DISTRIBUTION	RED DATA
CR	*Spheniscus demersus*	Jackass Penguin	Locally common	Endemic	Globally near-threatened
CR	*Pachyptila belcheri*	Slenderbilled Prion	Uncommon		
CR	*Neophron percnopterus*	Egyptian Vulture	Rare		
CR	*Necrosyrtes monachus*	Hooded Vulture	Rare		Extinct South Africa
CR	*Macheiramphus alcinus*	Bat Hawk	Rare		Vulnerable
CR	*Pernis apivorus*	Honey Buzzard	Rare		
CR	*Buteo augur*	Augur Buzzard	Rare		
CR	*Melierax metabates*	Dark Chanting Goshawk	Locally common		
CR	*Falco cuvierii*	African Hobby Falcon	Uncommon		
CR	*Falco dickinsoni*	Dickinson's Kestrel	Rare		
CR	*Coturnix adansonii*	Blue Quail	Rare		
CR	*Ardeotis kori*	Kori Bustard	Rare		Indeterminate
CR	*Calidris ruficollis*	Rednecked Stint	Rare		Vulnerable
CR	*Larus sabini*	Sabine's Gull	Rare		
CR	*Sterna dougallii*	Roseate Tern	Locally common		
CR	*Sterna anaethetus*	Bridled Tern	Rare		Endangered
CR	*Macrodipteryx vexillaria*	Pennantwinged Nightjar	Locally common		
CR	*Merops nubicoides*	Carmine Bee-eater	Common		Indeterminate
CR	*Coracias spatulata*	Rackettailed Roller	Uncommon		
CR	*Oenanthe pileata*	Capped Wheatear	Common		Vulnerable
CR	*Saxicola rubetra*	Whinchat	Rare		
CR	*Luscinia luscinia*	Thrush Nightingale	Uncommon		
CR	*Sylvia communis*	Whitethroat	Locally common		
CR	*Apalis melanocephala*	Blackheaded Apalis	Locally common		
CR	*Ficedula albicollis*	Collared Flycatcher	Rare		
CR	*Anthus trivialis*	Tree Pipit	Rare		
CR	*Prionops scopifrons*	Chestnutfronted Helmetshrike	Uncommon		
CR	*Eurocephalus anguitimens*	Whitecrowned Shrike	Common	Endemic	Vulnerable
CR	*Nectarinia venusta*	Yellowbellied Sunbird	Locally common		
CR	*Anthreptes reichenowi*	Bluethroated Sunbird	Uncommon		
CR	*Uraeginthus granatinus*	Violeteared Waxbill	Common	Near endemic	Globally near-threatened
CR	*Amadina fasciata*	Cutthroat Finch	Uncommon		
CR	*Serinus albogularis*	Whitethroated Canary	Common	Near endemic	
ADU	*Diomedea chrysostoma*	Greyheaded Albatross	Rare		
ADU	***Accipiter ovampensis***	**Ovambo Sparrowhawk**	Rare		
ADU	*Circus aeruginosus*	European Marsh Harrier	Rare		
ADU	***Sarothrura ayresi***	**Whitewinged Flufftail**	Rare		
ADU	***Rynchops flavirostris***	**African Skimmer**	Rare		
ADU	*Columba livia*	Feral Pigeon	Common	Alien	Globally endangered
ADU	*Cuculus gularis*	African Cuckoo	Locally common		Endangered
ADU	***Glaucidium capense***	**Barred Owl**	Locally common		
ADU	***Campethera notata***	**Knysna Woodpecker**	Locally common	Endemic	
ADU	*Mirafra apiata*	Clapper Lark	Common	Endemic	Rare
ADU	***Mirafra ruddi***	**Rudd's Lark**	Uncommon	Endemic	Globally near threatened
ADU	*Spizocorys fringillaris*	Botha's Lark	Uncommon	Endemic	
ADU	*Coracina pectoralis*	Whitebreasted Cuckooshrike	Rare		
ADU	***Parus afer***	**Southern Grey Tit**	Common	Endemic	Critical
ADU	*Prinia flavicans*	Blackchested Prinia	Common	Near endemic	Indeterminate
ADU	***Lamprotornis australis***	**Burchell's Starling**	Common	Endemic	
ADU	***Buphagus africanus***	**Yellowbilled Oxpecker**	Locally common		
ADU	*Anthus hoeschi*	Mountain Pipit	Common	Breeding endemic	Vulnerable