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 2^{nd} 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

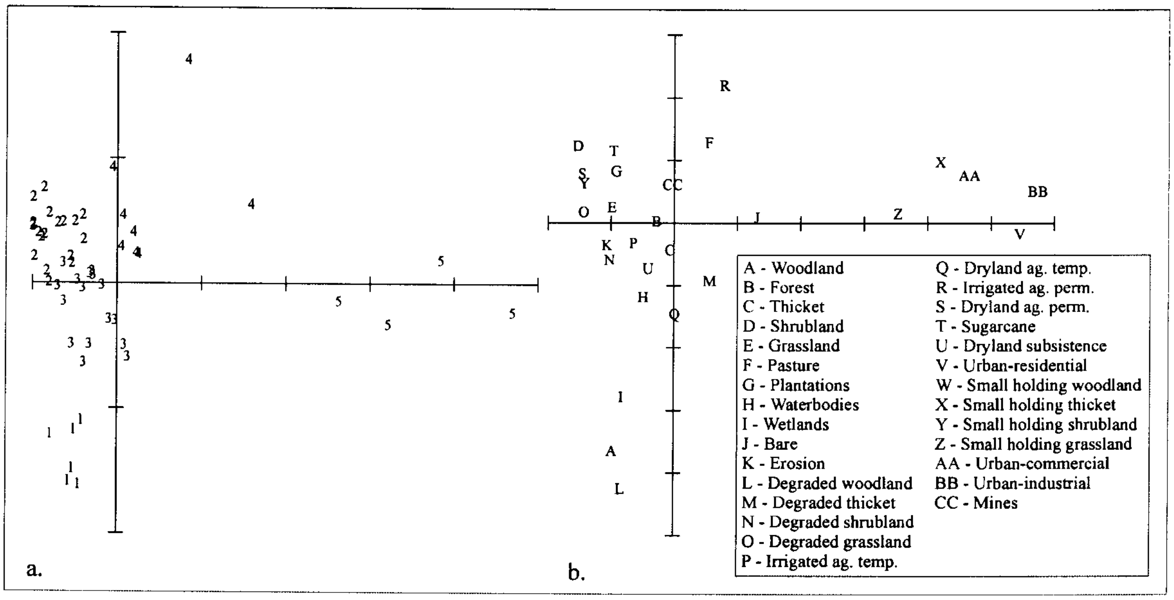

Figure 6.1: Detrended correspondence analysis biplots: (a) two axes of magisterial district data space (numbers match Figure 6.4a); and (b) two axes of feature variable data space.

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

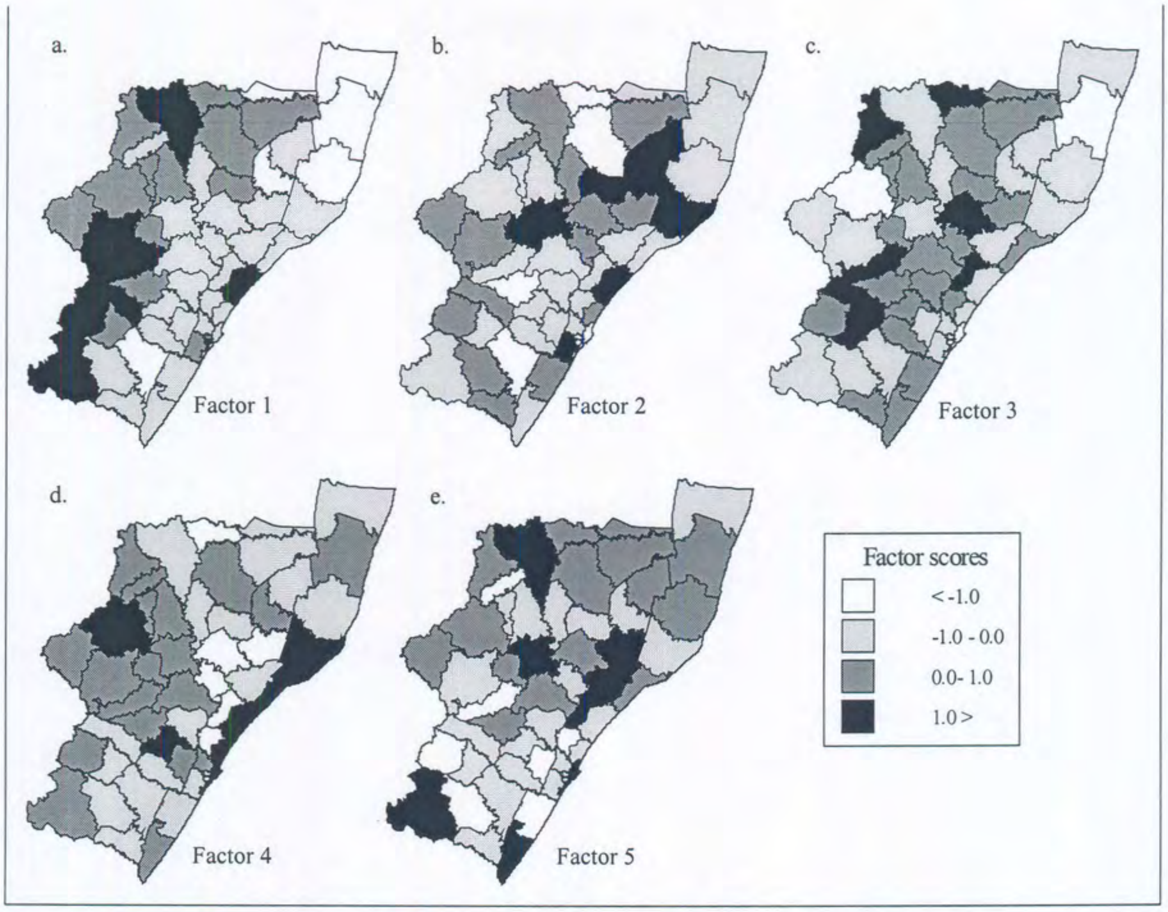

Figure 6.3: Factor patterns of variation derived from principal component analysis of the landscape mosaic pattern indicators.

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.

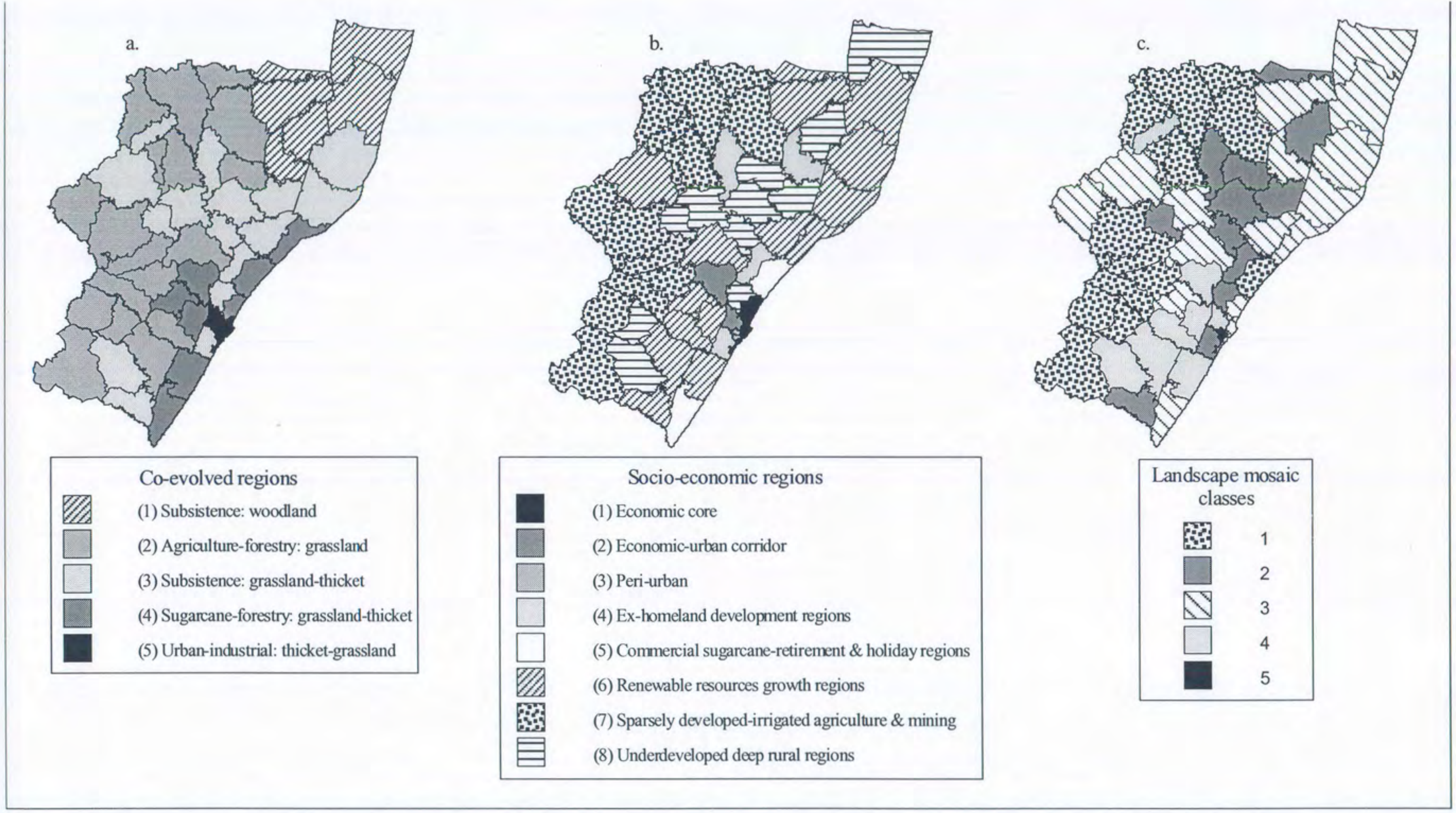

Figure 6.4: Mapping of the clusters produced from hierarchical and *k*-means cluster classification procedures on the dimensions derived for each data set.

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.

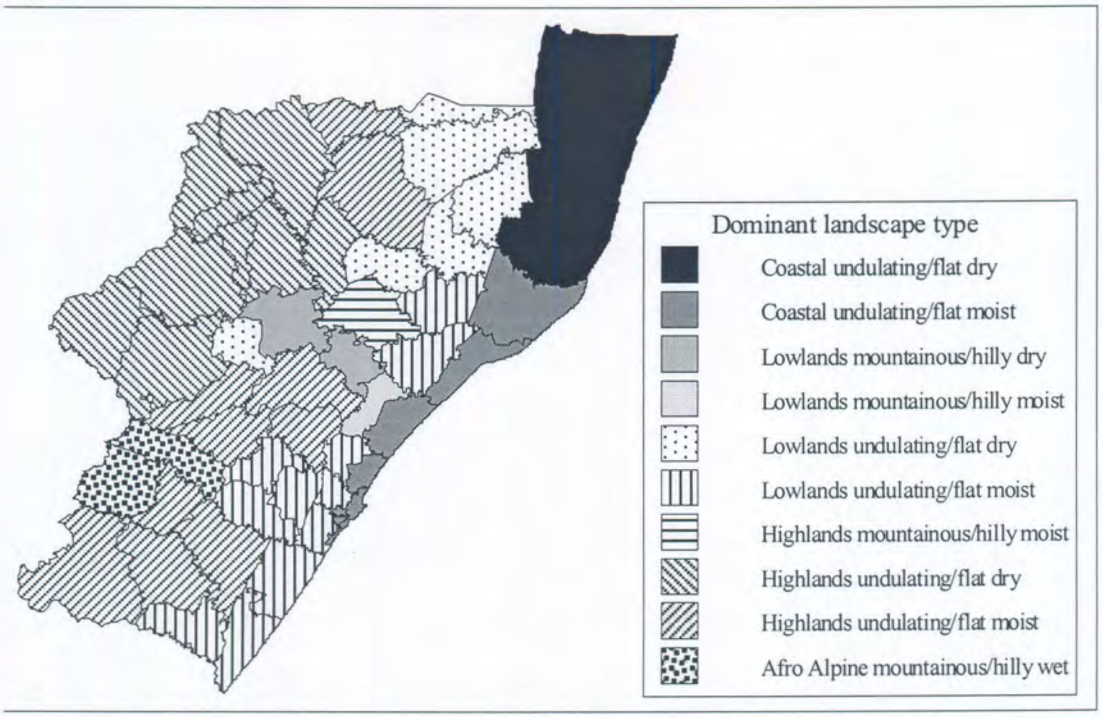

Figure 6.5: The landscape types identified in Chapter 3 are used to identify the dominant class for each magisterial district based on a simple majority.

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

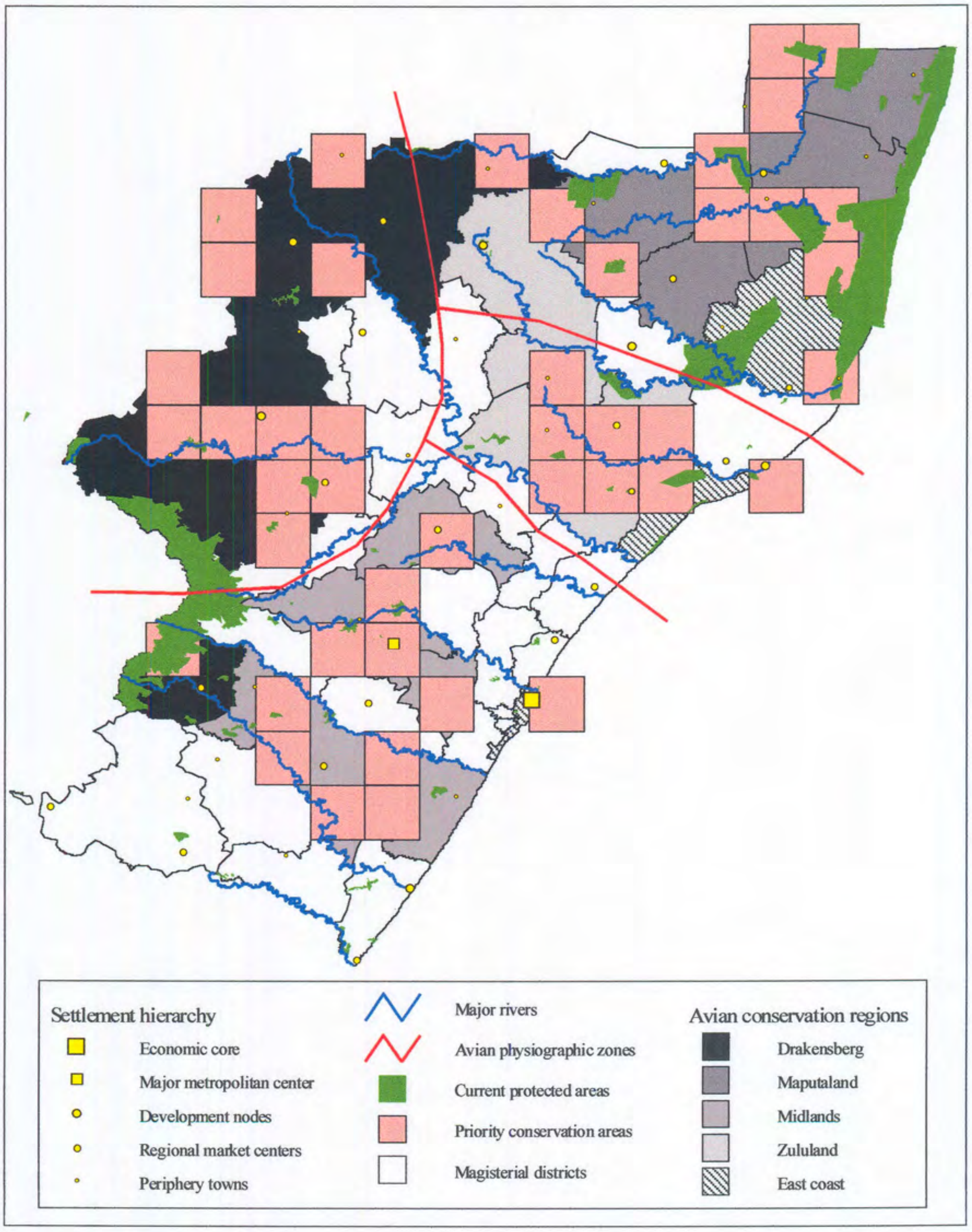

Figure 6.6: Priority avian conservation areas from the "ideal" model developed in Chapter 4, associated magisterial districts, and a general regionalization of the bird conservation areas by physiographic boundaries.

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,

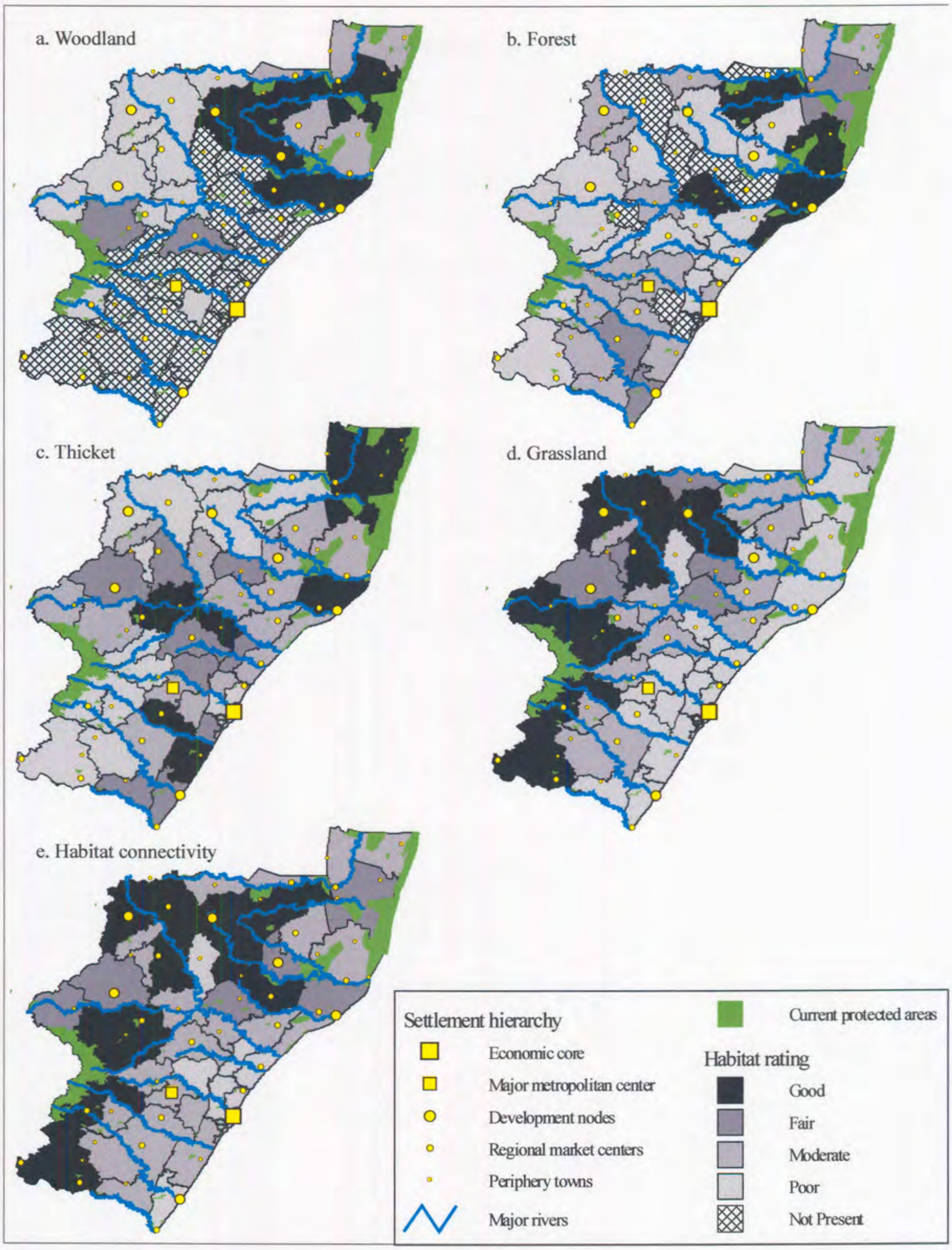

Figure 6.7: The following maps present a rating of the vegetation habitats: (a) to (d) based on patch size and fragmentation, and (e) is the habitat connectivity rating considering all available vegetation types residing in a magisterial district. The districts in a poor to moderate state (e) largely 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.

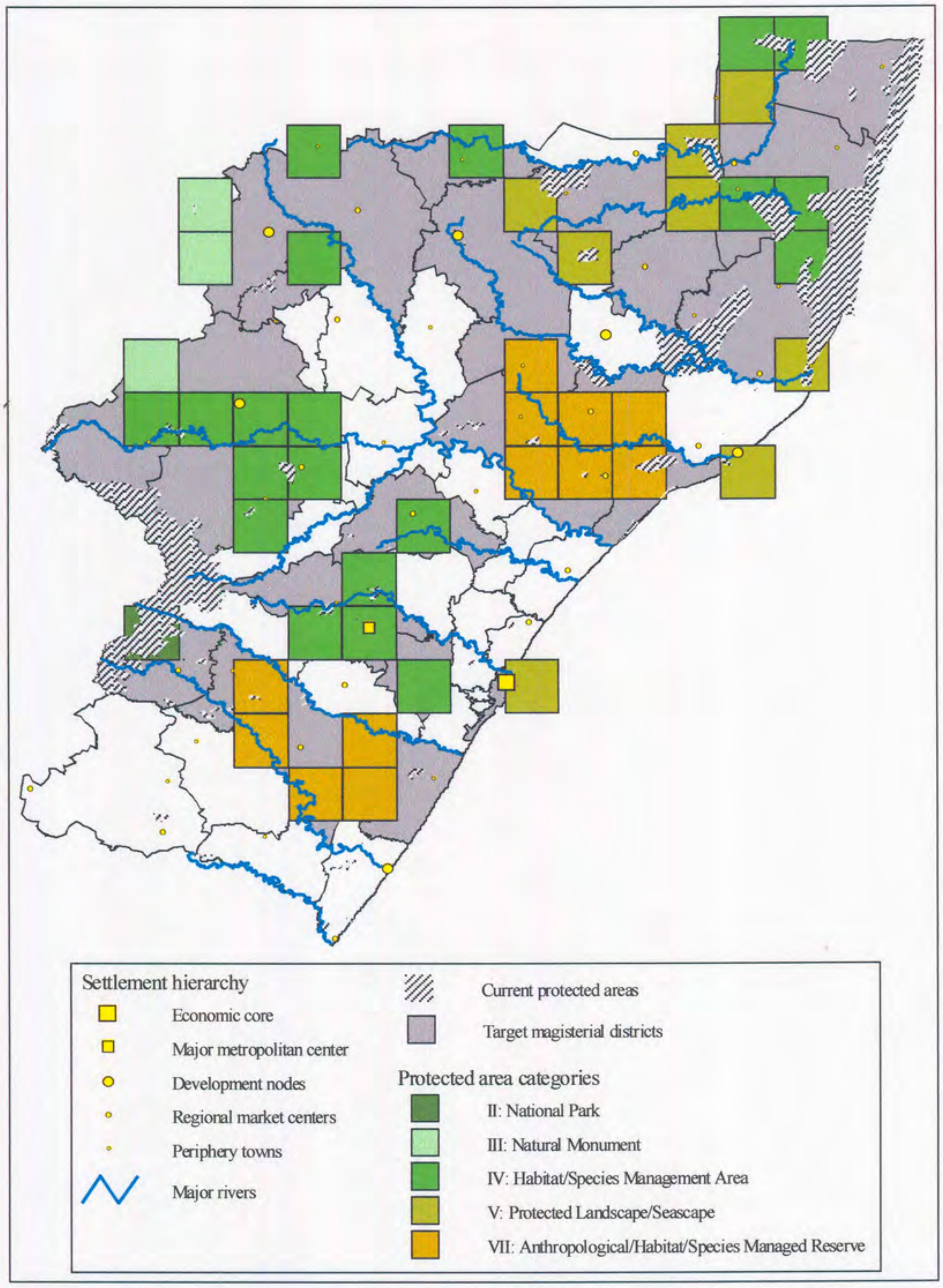

Figure 6.8: Proposed network and management categories of priority avian conservation areas.

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.