TOWARDS A SPATIAL FRAMEWORK FOR TRANSFRONTIER CONSERVATION PLANNING IN THE SADC REGION

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AUTHOR'S DECLARATION

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.

ABSTRACT

The Peace Parks Foundation (PPF) was established in 1997 to facilitate Transfrontier Conservation (TFCA) initiatives in the SADC region and thereby support economic development, conservation of biodiversity, as well as the promotion of regional peace and stability. To this effect, their regional planners require a thorough knowledge of the condition of areas in which the estimated actions will be carried out. To date, the PPF have used base datasets, such as land cover and population densities, in their GIS projects to support their decision making processes. However, they have realised the importance of developing rigorous methods for the extraction and generalization of biodiversity information for informed conservation decisions. The main aim of this study was, therefore, to develop a spatial framework for the generalisation and integration of data to become meaningful information that may be readily interpreted. The resultant framework represents a methodology for, firstly, identifying and, secondly, prioritizing core natural areas or units (CNU). CNUs were modelled to represent large blocks (minimum 100 km^2) of contiguous natural vegetation that are far from major roads and densely populated places. They were, then, ranked into three classes of importance (low, medium and high) according to an ecological value derived for each. This made the framework comprehensive in its considerations of regional biodiversity and robust enough to be used for planning at the SADC scale. By organising data and quantitative approaches logically in a robust, but rigorous, way, spatial frameworks provide the structure for combining specialized knowledge as well as scientific analysis and pragmatic politics in an effective planning process. This could guide plans which are proactive instead of reactive, visionary as well as pragmatic and well founded in research and understanding.

OPSOMMING

Die Peace Parks Foundation (PPF) was gestig in 1997 om oorgrens bewarings-initiatiewe in die SADC streek te fasiliteer en daardeur steun te verleen aan ekonomiese ontwikkeling, die bewaring van biodiversiteit asook die bevordering van vrede en stabiliteit in die streek. Om dit te behaal benodig die betrokke streeksbeplanners 'n grondige kennis van die toestand van die areas waarin die beoogdede aksies uitgevoer sal word. Tot op hede het die PPF basis datastelle, van byvoorbeeld landgebruik en populasie-digtheid, ingespan in hul GIS projekte om besluitnemingsprossese te ondersteun. Daar is egter besef dat dit van hoogste belang is om deeglike metodes te onwikkel vir die onttrekking van biodiversiteits-informasie sodat ingeligte besluitneming moontlik gemaak kan word. Gevolglik was die hoof oogmerk van hierdie studie om 'n ruimtelike verwysingsraamwerk te ontwikkel wat data kan veralgemeen en integreer tot betekenisvolle inligting wat geredelik interpreteerbaar is. Die daaruit-vloeiende raamwerk stel 'n metodologie voor wat Kern Natuurlike Areas (KNA) eerstens kan identifiseer en tweedens kan prioritiseer. Hierdie KNA is gemodelleer om groot blokke (minstens 100km^2) van aaneenlopende natuurlike plantegroei, ver van hoofpaaie en dig bevolkte gebiede, voor te stel. Hulle is hieropvolgend gesorteer in drie range van belangrikheid (laag, medium en hoog) na gelang van 'n ekologiese waarde wat vir elk afgelei is. Hierdeur is die raamwerk, in terme van voldoende oorwegings teenoor streeks-biodiversiteit, omvattend gemaak en terselfdertyd robuus vir beplanning op die SADC skaal. Deur data en kwalitatiewe benaderings logies en in 'n deeglike en robuuste wyse te organiseer, bied ruimtelike verwysingsraamwerke die struktuur om gespesialiseerde kennis met wetenskaplike analise en pragmatiese politiek te kombineer in 'n effektiewe beplanningsproses. Hierdeur kan planne geformuleer word wat proaktief is instede van reaktief, visionêr sowel as pragmaties, en terselfdertyd goed gefundeer bly op navorsing en begrip.

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CHAPTER 1 THE GLOBALIZATION OF CONSERVATION EFFORTS

Two decades ago, the World Conservation Union (IUCN) defined conservation as the wise use of a country's land, water and wildlife resources (1980 as cited by Stevenson 1992). Since then, people have realised that the built and natural environments are inevitably linked, as the former impinges upon the biota, while the latter provides essential resources for sustaining livelihoods (Hall-Martin & Modise 2002; Mackey 2003). However, conservation, or the wise use of natural resources[1], remains one of the great challenges facing humanity today, as the spatial extent of suitable land is decreasing and with it the primary resource for biodiversity protection (Lacher 1998). Conservation has become a land use option that must compete with other land uses, such as urban expansion, for the same geographic space (Liu & Ashton 1998; Carsjens & van der Kaap 2002).

To address these competing interests, the international community started to debate the integration of environmental values and economic growth for the first time on a global scale at the United Nations Conference on Environment and Development held in Rio de Janeiro in 1992. The consensus was captured in the formulation of Agenda 21, and today the management of human and natural resources have come to be closely associated (Mackey 2003). Scientists have accordingly (re)defined conservation as the "wise use and careful management of resources, so as to obtain the maximum possible social benefits from them for present and future generations" (Tyler-Miller 1988 as cited by Koslowski & Vass-Bowen 1997).

Of particular relevance to the African context is the issue of how protected areas can contribute to economic development, poverty alleviation and, increasingly, to the way that nations and communities can work together (Steiner 2003). To this end, the IUCN has been promoting the advantages of conservation areas that cross international boundaries (Pabst 2001). One major argument in favour of cross-border parks is that by consisting of two or more national parks, they encompass typically large areas, and large areas have a greater the range of habitats available for the preservation of vulnerable species than small areas (Hall-Martin 2002). Another argument holds that ecosystem boundaries do not necessary coincide with political ones and by conserving habitat across political boundaries in the form of cross-border parks it becomes

[1] Natural resources are natural capital that can be converted to commodities and used as inputs to create wealth, such as soil, timber, oil, minerals, and other goods taken more or less as they are from the Earth.

possible to protect whole ecosystems, which is an important step towards maintaining healthy environments (Pabst 2001; Steiner 2003).

1.1 INITITIATIVES IN THE SADC REGION

Conservation areas that cross international boundaries have been known by a variety of names, including Transboundary Parks, Peace Parks or Cross-border Areas. This study has adopted the term Transfrontier Conservation Areas (TFCA), which is defined in the Protocol on Wildlife Conservation and Law Enforcement as "...the area or component of a large ecological region that straddles the boundaries of two or more countries, encompassing one or more protected areas, as well as multiple-use resource areas" (Hall-Martin & Modise 2002).

1.1.1 A network of conservation areas

The concept that the environment is a shared resource is well-accepted by many. It is nowhere more evident than in the 1997 opening address of Dr. Z. Pallo Jordan (then South African Minister of Environmental Affairs and Tourism) to the Cape Town Meeting on TFCAs: "...The earth's environment is the common property of all humanity and creation, and what takes place in one country affects not only its neighbours, but many others well beyond its borders" (Sandwith et al. 2001).

Realising not only the stated advantages, but also the fact that TFCAs can play an important role in fostering co-operation and understanding among countries, the Southern African Development Community (SADC) governments have all become signatories to the Protocol on Wildlife Conservation and Law Enforcement (IUCN 2002). This protocol was signed on 18th August 1999 in Maputo, and commits members to promote wildlife as a shared resource through the establishment of TFCAs (Hall-Martin & Modise 2002). The SADC Ministers for Tourism have, accordingly, commissioned a detailed TFCA feasibility study, which was funded by the Peace Parks Foundation and the Development Bank of Southern Africa (Peace Parks Foundation 2001). The objective of the study was to describe the status of Transfrontier initiatives currently under way in Africa in terms of biodiversity conservation, tourism potential and community involvement, as well as the progress made towards formalising these initiatives.

The study revealed that there are 22 existing or potential TFCA sites that are presently supported by the authorities (see Appendix A for a map of the 22 TFCAs). These areas are well dispersed across the SADC region and cover an area of 473 652 km^2 and more than 41% of the total area that is formally protected by the SADC member countries (Hall-Martin & Modise 2002). Spanning various major biomes, the TFCAs together could make a significant contribution to biodiversity conservation as envisaged in the Convention on Biodiversity. Included in the list of 22 sites, is the Okavango-Upper Zambezi area that could potentially become an amalgamation of several individual TFCAs to form a network of major conservation and tourism areas.

1.1.2 The Peace Parks Foundation

The World Wildlife Fund (WWF) South Africa and its chairman Dr. Anton Rupert initiated a non-profit-making body, the Peace Parks Foundation (PPF), which was launched on February 1, 1997. Its declared aim is to facilitate TFCA projects and, in so doing, support economic development, conservation of biodiversity, as well as the promotion of regional peace and stability (Peace Parks Foundation 2003). At present, it is committed to ensure that the first six of the 22 proposed TFCAs are developed in a sustainable manner. These are:

- the Great Limpopo Transfrontier Park (Mozambique/South Africa/Zimbabwe)
- the Lubombo Transfrontier Conservation and Resource Area (Mozambique/South Africa/Swaziland)
- the Limpopo/Shashe TFCA (Botswana/South Africa/Zimbabwe)
- the Maloti/Drakensberg TFCA and Development Area (Kingdom of Lesotho/South Africa)
- the Kgalagadi Transfrontier Park (Botswana/South Africa)
- the |Ai-|Ais/Richtersveld Transfrontier Conservation Park (Namibia/South Africa)

The PPF's main objective is to advocate the concept of transfrontier conservation to political and community leaders, conservation authorities, government departments, donors and many other constituents. Their main tasks, therefore, include (i) the facilitation of political will and support, (ii) project planning and implementation, (iii) financial management of donor funds and (iv) spatial data presentation and manipulation for the creation of ecological and social information to aid in regional planning initiatives such as land-use and zonation planning in and around TFCAs.

1.2 CONSERVATION PLANNING—THEORETICAL CONSIDERATIONS

In recent years, biodiversity conservation has come to embrace both socio-economic as well as whole-ecosystem concerns (Rookwood 1995), a fact highlighted in the previous section. As a result, natural resource managers have adopted more proactive and integrated planning techniques, which incorporate multidisciplinary methodologies (Andreasen et al. 2001; Szaro et al. 1998 as cited by Ball 2002). In doing so, maps have become indispensable tools for displaying information spatially (Doing 1997). This has been a great benefit to decision making processes since it allows managers to address complex issues at a range of spatial and temporal scales (e.g. Walsh, Butler & Malanson 1998; Reich, Turner & Bolstad 1999; Ball 2002).

Ecological systems are composed of many interacting biotic and abiotic components, making them inherently complex (Noss 1990; Andreasen et al. 2001). Wilson (1992) estimated the total number of species comprising the biotic world to be tens of millions. Defining the elements and driving forces in such complex living systems has been a longstanding objective of ecological studies (Mackey 2003). Academics often become caught up in the details of measurement, such as how frequently it should be made, and how much data to accumulate before making inferences and recommendations. However, at some point generalisations[2] about the environment have to be made, because managers and policy makers require information on the status, condition, and trends of biodiversity and ecosystem change in order to make informed decisions.

A traditional approach to measuring biodiversity has been to sample species data (Margules, Nicholls & Pressey 1988; Carroll, Noss & Paquet 2001). It has been argued that some species (typically top predators) can act as 'umbrella' species since they have large spatial requirements and impact on community structure in lower trophic levels (Terborgh et al. 1999 as cited by Kerley et al. 2003). Conserving space for them would, as a result, secure space for all the species below them.

The application of this approach, however, has been limited in studies that cover large areas. Species data are not always available for the entire area under consideration and interpolating the data to a regional extent will introduce spatial bias in the analysis (Mackey 2003). In addition, data sampling across large areas is often too expensive and time consuming to fit within project

2 A definition of 'generalization' presented by Overton et al. (2002) was adopted and denotes the identification of patterns in data by distilling detailed information into reduced forms.

definitions. These shortcomings have become acute, during the past decade, as conservation efforts have shifted increasingly to regional and continental landscapes (Soulè and Terborgh 1999 as cited by Kerley et al. 2003; Anon 2003).

The term 'regional landscape' (ranging in size between roughly 10^2 and 10^7 km^2) represents a spatial complexity of regions, incorporating a mosaic of heterogeneous landforms, vegetation types and land uses (Doing 1997; Urban et al. 1987 as cited by Noss 1990). One way of addressing biodiversity at regional scales has been to develop a system for deriving broad landscape units as surrogates for species data (Hunter, Jacobson & Webb 1988, Noss 1990). This is motivated by the theory that biodiversity is essentially determined by three ecosystems attributes: composition (e.g. species and genetic diversity), structure (physical organization of landscape), and function (e.g. gene flow, disturbance regimes and nutrient cycling) (Franklin et al. 1981 as cited by Noss 1990). The use of a landscape approach to measure biodiversity has gained ground as it has become more and more apparent that biological impoverishment occurs at multiple levels of organization, and that protecting the biological world involves more than just safeguarding species diversity or endangered species (Noss 1990).

Establishing reserves for broad ecosystem units instead of unique habitats for specific species, offer major advantages for the protection of an increasing number of rare and/or endangered species (Belbin 1993; Noss 1999; Margules and Pressey 2000; Olson et al. 2001; Hawkins & Selman 2002). For example, it is useful for protecting species that are poorly known and difficult to survey (Noss 1996). Another advantage is that it is a more cost-effective approach, as landscape structure can be inventoried through satellite imagery, which covers wide areas at frequent time intervals. Through time series analysis of such data, analysts can then monitor and gauge the changing availability of habitats over broad geographic areas (Noss 1990).

This section highlighted the fact that biodiversity can be monitored at multiple levels of organization, and at multiple spatial scales. The scale at which analysis is performed is determined solely by the type of questions asked, because no single level of organization is fundamental and all-encompassing (Noss 1990). The next section elaborates on how spatial biodiversity information has been used by academics and decision makers in conservation planning activities.

1.3 SPATIAL SOLUTIONS TO A COMPLEX PROBLEM

Developing rigorous methods for the extraction and generalization of biodiversity information has become an essential component of conservation planning at regional scales (Hermann & Osinski 1999, Overton et al. 2002). To this end, regional planners require a thorough knowledge of the condition of areas in which the envisaged actions will be carried out (Mackey 2003). Of the many technological and conceptual approaches available, researchers have often concluded that geographic information systems (GIS) and remote sensing (RS) are the most promising tools for providing reliable spatial information to planners (e.g., Michalak 1993; Backhaus & Braun 1998; Gibson & Power 2000; Van Lynden & Mantel 2001; Collado, Chevieco & Camarasa 2002; Nelson & Geoghgan 2002). For example, land use maps have been widely used as a first approximation to the location and quantification of a territory's geographic structure (Tapiador & Casanova 2003). Moreover, GIS techniques have offered the opportunity to work with biodiversity information at a range of spatial scales, and have thereby paved the way to joining scientific research with practical problem solving.

This thesis distinguishes between data and information, such that the term 'data' is used to signify a set of measurements for a feature (Clarke 2001), while the term 'information' is adopted from Van der Merwe (2001) to imply a higher level of interpretation and contextualisation of data. One typically derives information by using a model or conceptual framework to organize data according to a function or specific context (Van der Merwe 2001).

1.3.1 Geographic data

The analysis of environmental phenomena often requires the integration of data from many different sources. For instance, mapping habitat patches available to large mammals in South Africa required the integration of data on geology, topography and climate (Cowling & Heijnis 2000). Similarly, the development of a database for measuring ecosystem health in California involved combining urban growth and development with biodiversity data (Cogan 2003). The data used in conservation planning can also range widely in scale, from being detailed and site-specific to generalised depictions of broad bioregional areas.

It is one thing to develop conservation projects and methods for deriving environmental information, but quite another to obtain the required base data in accurate and usable form. It is this paucity of consistent, biogeographic data that has often constrained coordinated and informed planning in ecosystem management initiatives (Belbin 1993; Overton et al. 2002; Mackey 2003). The reasons for this could be twofold: (i) institutions producing the data follow their own set of procedures, rules and standards for data production, making the integration of different sets impossible without extensive corrections and adjustments, and (ii) the cost of such data adjustments is often so high that they constitute a major disincentive to the use of information in the first place (Prévost & Gilruth 1997). These problems are currently being addressed by the international community, as will become evident in the following paragraphs.

Remotely sensed satellite images have become a viable data source for the routine application to environmental monitoring activities. For example, Reich, Turner and Bolstad (1999) have employed satellite data to initialise and validate broad spatial models. Until recently, the key satellite and sensor systems used for regional to global environmental monitoring were the meteorological satellites—e.g., the National Oceanic and Atmospheric Atministration's (NOAA) advanced very high-resolution radiometer (AVHRR) (Gibson & Power 2000, Friedl et al. 2002; Hastings 2001). Although these sensors provide images at a lower spatial resolution than, say, Landsat or SPOT images (e.g., Campbell 1996), their distinctive characteristics include the fact that data are collected more frequently (daily coverage), the size of the area imaged is larger and both historical and near real time (NRT) imagery are freely available to anyone with or without a receiver (Gibson & Power 2000; Hastings 2001). Over time, it is, therefore, possible to acquire a cloud-free coverage of continental scale (Campbell 1996).

While many useful insights have been gained from AVHRR data analyses, major uncertainties remain in measuring and modelling multi-scale landscape patterns (e.g., Reich, Turner & Bolstad 1999). As a result, the National Aeronautics and Space Administration's (NASA) Earth Observing System (EOS) program was initiated to address significant scientific questions, the answers to which bear directly on vital regional to global environmental policy issues. The entire suite of EOS-related endeavours has been outlined in the volumes of the EOS handbook (Wharton & Myers 1997, Parkinson & Greenstone 2000), while Price et al. (1994) provided a simplified review. In short, the EOS project is a comprehensive space-based observing system, a data and information system, as well as a multidisciplinary and interdisciplinary scientific research program. It is based on a succession of multi-instrument intermediate-sized spacecraft and individual smaller satellites, each with highly sensitive calibrated instruments, to be launched over the next two decades. One of these instruments, the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument, was launched on the Terra platform on 18 December

1999, and a second was launched on the Aqua platform on 4 May 2002. Collectively, the EOS sensors will provide a set of precise measurements on, for example, clouds, precipitation, atmospheric temperature and moisture content, terrestrial snow, sea ice, and sea surface temperature. Based on the 36 spectral bands of MODIS, scientists have developed 42 standard data products describing atmospheric, aquatic, and terrestrial conditions (e.g., Milne & Cohen 1999; Conboy 2003b).

In addition to satellite images and products, a number of international organizations and research institutions have produced worldwide or Africa-wide coverages for a variety of themes, including: the Soil Map of the World from the Food and Agriculture Organization of the United Nations (FAO), the Forest Resources Assessment from FAO, the World Atlas of Desertification (UNEP, 1992), the World Map on the Status of Human Induced Soil Degradation, the hydrogeological map for Africa produced by the African Organization for Cartography and Remote Sensing, composite vegetation indices from NOAA, including a recalibrated coverage for Africa from the US Geological Survey (USGS). Data can also be extracted from the global coverages prepared by the National Geophysical Data Center (Prévost & Gilruth 1997). The EROS Data Center of the USGS has also recently made available data generated by the Famine Early Warning System (FEWS) (FEWS NET 2003).

Finally, in some cases international institutions have been launched to act as coordinating bodies for the regulation and distribution of global information. For example, the EarthMap is a public-private consortium that advances the use of geospatial data and tools for decision-makers (Earthmap 1995 as cited by Prévost & Gilruth 1997). Others include the FAO/UNEP's Global Land Cover Network (GLCC 2003), the Global Spatial Data Infrastructure (GSDI 2003) and the International Steering Committee for Global Mapping (ISCGM 2003). All these institutions have as their objective the improvement of geographic data availability and standardization, with the GLCN focused specifically on global land cover information. The University of Maryland's Global Land Cover Facility (GLCF 2003) hosts and distributes satellite data, ranging from those produced by the Landsat satellites, through MODIS to NOAA AVHRR. Similarly, the Wide Area Satellite Monitoring Information System (WAMIS) has been initiated by the Satellite Application Center (SAC), South Africa, to provide satellite products and services specifically for the SADC region (SAC News 2003).

1.3.2 GIS and environmental modelling

In recent decades, regional conservation planning has focused largely on selecting priority areas for potential reserves and designing reserve networks (e.g., Cock & Baird 1989 as cited by Church, Stoms & Davis 1996; Noss et al. 1999; Davis et al. 1999 as cited by Overton et al. 2002). To this end, several methods have been developed, ranging from simple scoring of sites to iterative heuristic algorithms and mathematical programming techniques (Church et al. 1996; Pressey, Possingham & Day 1997). For example, Margules, Nicholls and Pressey (1988) have used a numerical algorithm to identify a minimum set of wetlands in which a number of species are represented at least once, while Siitonene, Tanskanen and Lehtinen (2002) applied a greedy heuristic algorithm to select old-forest stands that would best complement existing reserves. Bishop et al. (2000) applied GAP analysis to objectively identify areas in Pennsylvania that require protection, while Belbin (1993) used a numerical classification algorithm to map site representativeness across a continuous landscape.

The criteria defined for these studies have included irreplaceability or rarity of species, complementarity, flexibility, representativeness, site quality, taxonomic diversity, threats and costs. Although these methods differ in their structure and aims, common to them all is the attempt to perform spatial planning in an objective, repeatable and efficient way (Pressey, Cowling & Rouget 2003; Church, Storms & Davis 1996). Another aim of conservation planning has been to select reserves that satisfy the goals specified (e.g. number, area or spatial arrangement of features) for the least cost (or area) (Church, Stoms & Davis 1996; Pressey et al. 1997; Margules and Pressey 2000; Siitonen, Tanskanen & Lehtinen 2003).

Driven by concern with regards to the fragmentation of landscapes and continual threats to biodiversity, conservation planners have, however, steered away from focusing on site protection alone (Hawkins & Selman 2002). They have come to adopt off-reserve management approaches which typically incorporate the establishment of networks of natural areas across large regions (Crumpacker 1998); networks that form continuous linear features across a landscape to facilitate ecosystem functions and services (Jongman 1995; Bennett, 1999 as cited by Hawkins & Selman 2002).

The simplest networks are those existing as lists of sites which vary in their ecological and conservation status (Jongman 1995). However, a review of the literature reveals a wide range of practice. For example, many have emphasized the role of multi-objective "greenways" to facilitate animal migration, recreational use, as well as environmental management (e.g. Green Infrastructure 2003). Others have focused on defining "stabilizer zones" as rehabilitation sites for heavily degraded land and also to maximize the viability of animal and bird migration (e.g. Kubes, 1996). The aim of the California biodiversity project was to forecast the development and locations of future biodiversity conflict points across large areas (Cogan 2003). The Maryland Department of Natural Resources has developed the Green Infrastructure Assessment (GIA) project. Using GIS, they have applied principles of landscape ecology to identify an interconnected network of "hubs" and "corridors" that are now the focus of state and local agency conservation initiatives (Weber and Wolf 2000). An important quality of all the reserve (or natural area) networks that have been proposed or developed is their ability to support multiple land use objectives including recreation, visual appreciation, scenic highways and pollution buffering (Dover 2000 as cited by Hawkins & Selman 2002).

Inherent in all these methodologies is the use of spatial analytical techniques for the achievement of high degrees of automation, objectivity, and quick updating capabilities. Diverse data sources have been used, ranging from cartographic vector information to satellite imagery. GIS technology applied to conservation planning, therefore, operates as a decision support tool since it aids in the integration and modelling of a range of data and processes for the representation of the constraints and opportunities available for resource allocation.

1.3.3 Spatial information

In deriving information for conservation decision support, most of the methods described in the previous section required subjective decisions or assumptions at some point or another. It is vital that these decisions be explicitly recognized and stated, otherwise it becomes impossible to derive the same results with a repetition of the process. Lehmann, Overton and Leathwick (2003) argued that the methods used for analyses should meet three criteria. Firstly, they should be general enough to deal with the wide variety of attributes; secondly, they should be rigorous and data-defined to ensure objectivity; and lastly, they should be standardized to produce uniform results. Others have argued in the same vein by claiming that conservation planning should be based on standardized methods to allow for repeated measurement so that trends can be determined and results of experience incorporated (Rookwood 1995; Bell & Morse 2000; Pressey and Cowling 2001).

Overton et al. (2002) have proposed a framework for organizing research methods and data to achieve increased efficiency and standardisation. He labelled such a framework an "information pyramid" which has as its core the integration and generalization of data and knowledge. This makes it especially relevant for the current context and study. The author of this thesis has adopted the term "spatial framework", instead, to reflect the fact that regional conservation planning is inherently a spatial procedure. This section, however, still refers to the term "pyramid" to denote the hierarchical organization of the intended framework.

Based on the discussion by Overton et al. (2002), information pyramids should have four essential characteristics. Firstly, higher levels of the pyramid should be entirely derived from a foundation of underlying data. For a rigorous and objective framework, it is vital to strictly define all data inputs. Secondly, the process of generalization and integration upward should be objective and explicit. Thirdly, multiple pyramids may be based on the same base data as more than one generalization or integration is possible from a set of data. Lastly, all levels of the pyramid should be developed together, including base data, methods and kinds of integration. This is necessary for deriving broad methodologies.

By organising data and quantitative approaches logically in a robust, but rigorous, way, spatial information pyramids provide the structure for combining specialized knowledge as well as scientific analysis and pragmatic politics in an effective planning process. This could guide plans that are proactive instead of reactive, visionary as well as pragmatic and well founded in research and understanding.

1.4 RESEARCH PROBLEM

When historical maps of the distribution of protected areas across regions are studied, it is noticed that reserves have often been established on unproductive land or on areas that were too remote from urban centres to be economically viable. Margules & Pressey (2000) tied this to the fact that, traditionally, reservation of an area was seen as being uneconomical. As a result, many species and habitats are currently not represented in formally protected areas. With the growing awareness of the social, economic and environmental benefits that the conservation of biodiversity entails, such ad hoc planning for the placement of reserves is no longer considered effective. Researchers have, accordingly, proposed methodologies for systematic conservation planning with suggestions that it should be guided by explicit goals and priorities and that decisions should be based on clear choices between potential conservation areas (Margules & Pressey 2000).

The first step, then, towards systematic conservation planning on a regional scale, is the acquisition of accurate and up-to-date data on both the distribution and status of biodiversity. As mentioned previously, biodiversity data could be measured either as sub-sets of species or broad habitat types. Furthermore, comparisons of sites in different areas need to be based on the same kind of information at the same level of detail (Margules & Pressey 2000). For broad, regional analysis, decision makers typically require information such as landscape classification systems that are scientifically robust and easy to understand (Anon 2003).

The development of TFCAs in the SADC region often relies on the assessment of large areas for conservation opportunities and tourism development. As facilitators of TFCAs, the PPF have had to develop the capacity to prepare and disseminate information on a regional scale to decision makers in an effective way. This has frequently been achieved by using maps (Peace Parks Foundation 2001).

However, proposed peace parks are often difficult to access and poorly mapped, yet the current land use and distribution of settlements are critical in the planning of conservation and tourism strategies for these areas. The PPF have, accordingly, turned to using public domain datasets available as global coverages. Until recently, they have used these datasets to map the land cover, infrastructure and population distributions across the entire SADC region. But these representations have often not been informative enough for regional planning. Committed to producing information that is meaningful to conservation, the PPF have expressed their need to develop a standardised methodology for deriving higher order information; information that would represent the biodiversity of the SADC region and thereby aid in conservation planning initiatives.

The main aim of the present study was, therefore, to develop a spatial framework for the generalisation and integration of global-scale data into biodiversity information appropriate for conservation planning across international boundaries in the SADC region. The specific goals were to:

(i) design a framework for robust spatial analysis at a regional scale;
(ii) identify a suite of global datasets to use as base data in the framework;

(iii) derive homogeneous units of Core Natural Units (CNU) through generalisation of landscape features;

(iv) apply ecosystem principles to rank the CNUs according to their ecological value;

(v) derive natural landscape links (or ecological routes) between selected conserved areas.

The remainder of this document is divided into 3 chapters. In the first, the framework and underlying methodologies are outlined, with the results obtained from applying the methodologies to data of the SADC region presented in the second chapter. The last chapter summarises the suitability of the framework for conservation planning as well as future options for development.

CHAPTER 2 A SPATIAL FRAMEWORK FOR MAPPING REGIONAL BIODIVERSITY

The spatial framework presented in this thesis was developed to analyze the distribution of natural resources at a small scale (namely 1:1000 000), which includes the entire SADC region. Processing data and generalizing features at this scale makes it possible for managers to identify specific sites for ensuing studies at a larger scale. In addition, that natural resource analysis at a small scale creates a broad context for pattern analysis and information display.

2.1 THE SADC REGION

The SADC consists of 12 countries on the continent of Africa and the island states of Mauritius and the Seychelles in the Indian Ocean. The continental states of Angola, Botswana, Democratic Republic of Congo (DRC), Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Tanzania, Zambia and Zimbabwe together cover about 9,275,000 km^2 (Figure 1). This is about 31% of the total area of Africa. The population of the SADC countries is about 195 million people, or roughly 24% of the population of Africa (Hall-Martin & Modise 2002).

The political classification of SADC yields 12 countries, while a biological classification by the World Wide Fund for Nature (WWF) of the same area yields 47 terrestrial ecoregions (Figure 2). These ecoregions are marked by differences in geology, soils, climate, and communities of plants and animals. Only rarely do the boundaries of the two classification systems coincide and it is especially at the political border areas that man's negative impact on the natural environment is visible. The study area has a great diversity of habitats and species for which there exist different management policies, strategies and programmes across the international boundaries. This made it essential, at the outset of this study, to embrace an approach that was robust, yet flexible enough to support a wide audience of decision makers.

Figure 1 Political boundaries of the SADC region

Source: Olson et al. 2001

Figure 2 WWF Ecoregion boundaries in the SADC region

The design, outline and specifications of the spatial framework for analysing natural resources in the SADC will receive detailed attention in the next section.

2.2 DEFINING THE SPATIAL FRAMEWORK

A conceptual outline of the spatial framework is presented in Figure 3. The hierarchical presentation of the framework is based on guidelines suggested by Overton et al. (2002), who argued that higher levels of information should be entirely derived from a foundation of base datasets. Moreover, the process of generalization and integration upward should be objective and inputs by planners and experts explicitly stated. The creation of such a hierarchical structure of data, processes and information was an important conceptual exercise in the design of the framework because it clearly presented the upward generalisation of data and integration of specialised knowledge into information products valuable to decision makers. In the present context, the framework provided a means to assess the rigorousness and objectivity of the model processes. Note that this framework is not unidirectional, as there are many feedbacks and reasons for revised decisions about CNUs and other priority areas.

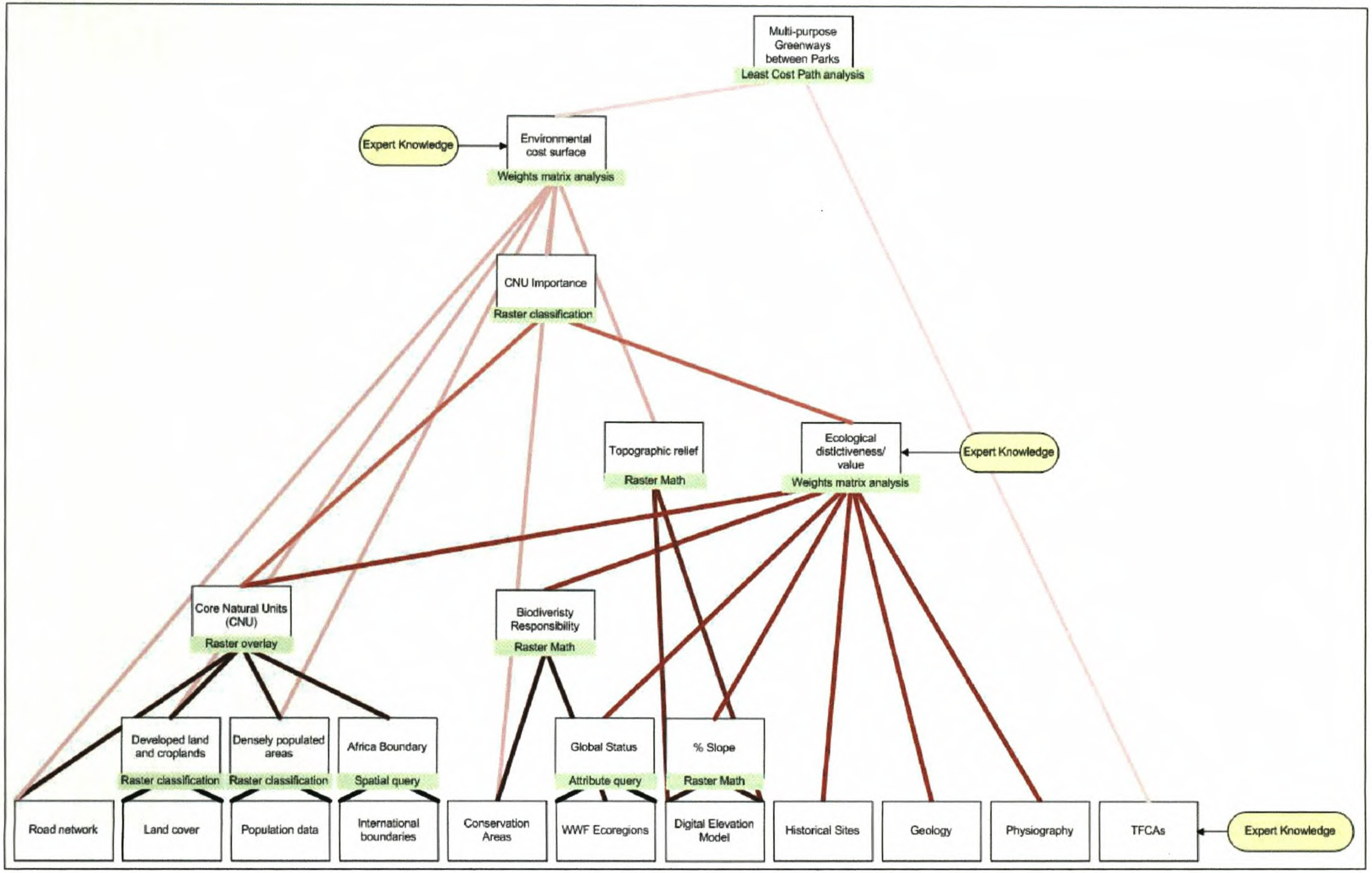

Figure 3 Conceptual outline of the spatial framework illustrating the hierarchical relationship between base data and higher level generalisations

The actual model procedures and anticipated outcomes were adapted from the regional conservation strategy developed for the state of Maryland, USA, namely the Maryland GreenPrint Program (Weber & Wolf 2000). The latter was considered appropriate for the current study as it used regional landscape assessment tools and applied global ecological principles. It was therefore appropriate to transfer their approach to the African context. The framework they presented was simplified in the present context so that it could be applied to model core natural areas for the entire SADC region. Analysts of the GreenPrint Program used the term "hub" to core large natural areas (Weber and Wolf 2000), but the more descriptive term, "core natural unit", was adopted in the present study instead. The framework and its outcomes closely followed guidelines presented by Noss (1992 as referenced by Maryland GreenPrint Program 2001) for conservation planning activities. These were:

- Species that are well distributed across their native range are less susceptible to extinction than species confined to small portions of their range.
- Large blocks of habitat, containing large populations of a target species, are superior to small blocks of habitat containing small populations.
- Blocks of habitat in contiguous blocks are preferable to fragmented habitat.
- Interconnected blocks of habitat are better than isolated blocks; corridors or linkages function more effectively when habitat within them resembles that preferred by target species.
- Blocks of habitat that are roadless or otherwise inaccessible to humans are better than habitat blocks that are accessible by major roads, because such areas are likely to be undeveloped.

In addition, Van Lynden & Mantel (2001) suggested that planning strategies for sustainable land management require accurate and consistent base line data on natural resources as well as on socio-economic aspects. Weinstoerffer & Girardin (2000) suggested that models for deriving landscape-scale indicators must be easy to use, readable and understandable, as well as reflecting the field reality.

The model is a systematic procedure or framework for the generalization of spatial data into meaningful environmental information. To this purpose, two GIS software packages were applied. They were (1) ESRI Arc/INFO workstation 8.1.2 GRID module (ESRI, Redlands, California); and (2) ArcView 3.2 (ESRI, Redlands, California). Figure 4 presents the major analytical steps of the model as a flow diagram. The diagram is strategically numbered and discussed accordingly in detail in sections 2.4 to 2.6.

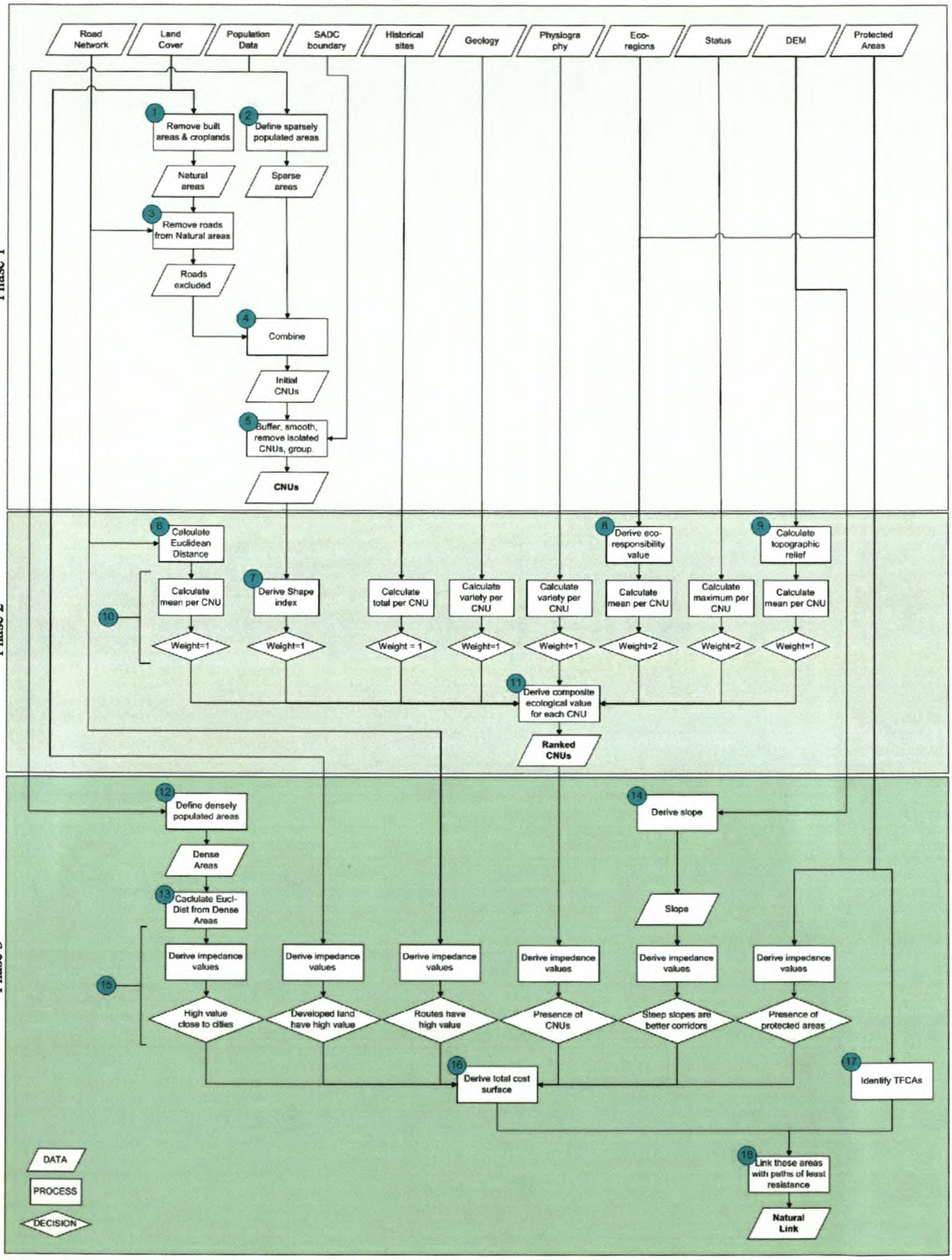

Figure 4 Flow diagram detailing the organizational layout of the data, processes and decisions of the spatial framework

It is important to note that, unlike the Maryland study, the current model was principally a desktop exercise due, firstly, to severe time constraints and, secondly, to the fact that no comparable SADC-wide framework has been implemented as part of the PPF's spatial decision making procedures at the time of research. This study was, therefore, developed as a pilot project on how global datasets could be used in the generation of environmental information for conservation decision support. Furthermore, time constraints prohibited model refinement through a comprehensive peer review process. However, the model and output were reviewed, iteratively, through a series of discussions with the PPF. During this process, choices were made with regards to the type of datasets to be incorporated as well as the parameters to be defined.

2.3 DATA COLLECTION AND PREPARATION

The final set of data that was collected to act as base data for the framework is listed, with associated features, in Table 1. Their corresponding attribute information is presented in Appendix B. This collection of base data was assembled in two steps. Firstly, datasets were chosen based on their availability (i.e. digital georeferenced datasets) as well as suitability to meet the goals defined during the requirements analysis. A suitable dataset was, accordingly, defined as being (i) available on a SADC-wide scale (for the prevention of spatial bias in the analyses) and (ii) based on rigorous and transparent research (so that the credibility of the data could be reviewed).

The majority of datasets were downloaded via the Internet from their host websites either in tiles or as single files (see Table 1 for details on the raw base data selected for inclusion in the analysis). Where necessary, multiple raster tiles were mosaiced together into single tiles. Vector datasets (and raster if not already in correct format) were converted to ArcINFO GRIDs (1000m cell size, nearest neighbor resampling) with geographic bounding coordinates: West 10.701170; East 43.436183; North 5.411187 and South -34.839828. All datasets were (re)projected to Lamberts Azimuthal Equal Area projection (datum: WGS84; central meridian 20°E; latitude of origin 5°N; units meter).

Table 1 Data sources used in SADC's regional spatial framework

Data Layer	Institution	Scale	Time of ground condition	Availability	Comments
Cultural Landmarks	AfricaCD	5 degree graticule	1998	Africa Data CD, is a proprietary product of CDMaps (PTY) Ltd trading as ComputaMaps (http://www.computamaps.com)	Derived from the NIMA Geographic Names Database (GNDB).
Digital Elevation Model	USGS/EROS DATA CENTER (EDC)	Cell size 30 arc-seconds	1996	Anonymous File Transfer Protocol (FTP) account: 152.61.128.6 (edcftp.cr.usgs.gov)	Based on data derived from the Digital Chart of the World (DCW) and Digital Terrain Elevation Data (DTED).
Ecoregions	World Wildlife Fund (WWF) Conservation Science Program	1:3,000,000	1998-1999	Downloaded vector dataset from http://www.worldwildlife.org/ecoregions/dbaserequest.htm See Olson et al. (2001) for further details.	Represents the original distribution of distinct assemblages of species and communities prior to major land use change. It provides a classification framework that builds on existing biogeographic knowledge. In collaboration with over 1000 biogeographers, taxonomists, conservation biologists, and ecologists from around the world.
Geology	AfricaCD	1:5,000,000	1997	Africa Data CD is a proprietary product of CDMaps (PTY) Ltd trading as ComputaMaps (http://www.computamaps.com)	Source: MAPS SHOWING GEOLOGY, OIL AND GAS FIELDS AND GEOLOGICAL PROVINCES OF AFRICA U.S. Geological Survey Open-File Report 97-470A; 1997
Global Status	World Wildlife Fund (WWF) Conservation Science Program: Global 200 Project	1:3,000,000	1998-1999	Downloaded vector dataset from http://www.worldwildlife.org/ecoregions/ dbaserequest.htm	Developed by WWF scientists in collaboration with regional experts around the world. A scientifically based global ranking of the Earth's most biologically outstanding habitats. Provides a critical blueprint for biodiversity conservation at a global scale.
Land cover	International Steering Committee for Global Mapping (ISCGM)	Cell size 1km	1992-1993	Download 46 raster tiles for SADC from http://www.iscgm.org/html4/index.html. ERDAS Imagine 8.0 was used to mosaic the tiles together.	The data set is derived from 1-km Advanced Very High Resolution Radiometer (AVHRR) data spanning a 12-month period (April 1992-March 1993).
Physiography	-	Cell size 1km	-	Peace Parks Foundation GIS laboratory. GIS Manager: Craig Beech Email: cbeech@ppf.org.za	This database was obtained from the PPF GIS lab, processed as a projected ArcINFO GRID.
Population Density	Landscan Global Populations Database	Cell size 1km	1998	Peace Parks Foundation GIS laboratory. GIS Manager: Craig Beech Email: cbeech@ppf.org.za See also Dobson et al. (2000)	This database was obtained from the PPF GIS lab, processed as a projected ArcINFO GRID; originally downloaded from the NCSI Libraries website: http://www.lib.ncsu.edu/stacks/gis/landscan.html
Protected Areas	IUCN & UNEP, The WDPA Consortium	Ranging from 1:100,000 to 1:5,000,000	2003	Download vector database from the WDPA site http://gis.tnc.org/data/IMS/WDPA_viewer/ WDPA_info/WDPA.html	The World Database of Protected Areas is the result of a broad alliance of organizations that have contributed data and effort.
Road Network	ComputaMaps: AfricaCD	1:1,000,000	1995 - 1997	Africa Data CD is a proprietary product of CDMaps (PTY) Ltd trading as ComputaMaps (http://www.computamaps.com)	Based on (i) Vector Map Level 0 (VMAP0™) National Imagery and Mapping Agency; SOAMAFR, SASAUS, EURNASIA; Edition 003; 31 Jan 1997 and (ii) MILITARY SPECIFICATION VECTOR SMART MAP (VMap) Level 0; MIL-V-89039 9 FEBRUARY 1995.
International boundaries	ComputaMaps: AfricaCD	1:1,000,000	1995 - 1997	Same as above.	Same as above.
TFCA's	Peace Parks Foundation	N/A	2002	Peace Parks Foundation. Project Manager: Werner Myburgh Email: wmyburgh@ppf.org.za	TFCAs were identified based on the study performed by Hall-Martin & Modise (2002).

The second step entailed re-examining the data with the goal to minimise redundancy within the model structure and to identify those datasets which best correlated with expert knowledge about certain areas. This was done by comparing sets of CNUs, which were derived from different combinations of datasets. As a consequence of this re-examination the data layers representing cities and built-up areas were replaced by population data. Similarly, datasets denoting major rivers and lakes were removed.

Various land cover datasets were assessed. Notably those presented by programs and institutions such as the Food and Agriculture Organization of the United Nations' Africover initiative, International Steering Committee for Global Mapping (ISCGM), the USGS-NASA Distributed Active Archive Centre, which hosts the Africa Land Cover Characteristics Data Base Version 2.0 (LPDAAC 2003a), and NASA's Earth Observation System (EOS) programme (McClung 2003). The PPF have decided to use the MODIS land cover product, which is produced by a panel of EOS data specialists using images captured by the MODIS sensor on board both the Terra and Aqua satellites. This product is classified according to the 17-class International Geosphere-Bioshpere Project (IGBP) land cover scheme (Belward 1996, Loveland et al. 1999). The latter includes 11 natural vegetation classes (separating needleleaf, broadleaf, and graminoid leaf structures; annually deciduous and evergreen canopy habits; and sparse to dense cover fractions), three developed land classes, one of which is a mosaic with natural vegetation, permanent snow or ice, barren or sparsely vegetated, and water. The MODIS land cover algorithm draws from various information domains, which include directional surface reflectance in seven spectral bands, near-infrared image texture, the Enhanced Vegetation Index (EVI), land-surface temperature, and snow/ice cover. They are assembled for a year of observations for each 1-km pixel using a decision-tree classifier trained from a network of 1500 or more training sites (Parkinson & Greenstone 2000).

The MODIS land cover product, however, could not be used at the time of this study because the first land cover product is yet to be released in its final validated state; it is currently available only as a beta version (LPDAAC 2003b). Therefore, for the purpose of the current study, the ISCGM's global map was used as a temporary replacement since it also applied the IGBP classification scheme and has been derived from a series of AVHRR images spanning the period 1992 to 1993 (Loveland et al. 1999).

Table 2 lists the GRID data files that were derived from the original data listed in Table 1. The GRID names as they are referenced in following sections are recorded in brackets.

Table 2 List of the data files used in the spatial framework

Data and file name	GRID values	Description
Digital Elevation Model (DEM1000)	0 to 5825	Elevation values
Historical sites (HISTSITES)	1	Presence of site in cell
	0	Absence of site in cell
Geology (GEOLOGY)	1 to 45	Geology types
Global200 Status (GLBSTAT)	0 to 3	Status code
Land Cover (LANDCOV)	1 to 27	Land cover codes (see TableB4)
Physiography (PHYSGR)	1 to 16	Physiographic types
Population (POPDENS)	1 to 10	Population density codes (see Table B3)
Protected areas (PROTAREAs)	1	Presence of protected area
Road Network (ROADNET)	0	Areas between roads
	1	Primary routes
	2	Secondary routes
	3	Other
SADC boundary (SADCBND)	1	All cells inside SADC boundary
WWF Ecoregions (WWFECO)	1 to 47	Ecoregions of the World
IUCN Protected areas (Protected.shp)	N/A	Protected areas of the world

The standards identified for the data format, projection and size were important considerations in the preparation of the data, because all future datasets need to comply to these same standards if they are to be used in the framework. If followed strictly, these standards would make is possible to perform time-series change analysis on results derived at different temporal intervals.

The next three sections elaborate on the processes that were developed and applied in generalizing the datasets listed in Table 2 and correlates to the three phases of the framework presented in Figure 4, namely deriving CNUs, prioritizing CNUs and identifying ecological routes. Each section begins with a general discussion of the processes, followed by a step-by-step outline.

2.4 GENERALISED LANDSCAPE UNITS

Phase one of the framework focussed on deriving CNUs from the land cover, population density and roads datasets using raster overlay analysis (Figure 4). They were modelled as blocks of natural areas greater than 1000 km^2, excluding developed land, croplands, roads, as well as densely populated areas. Edges were evened out to eliminate narrow tendrils and coastal areas were excluded using an 8 km shoreline buffer, because CNUs represent solely terrestrial habitat in the present context. At this scale and for the extent of the SADC region, it was decided that 8 km serves as a rough average of the width of a shoreline.

The reasoning behind the exclusion of croplands from the definition of CNUs was that they were considered to be heavily degraded and therefore would require extensive effort and time to be restored to their natural states. For this study, only areas with existing conservation potential were considered, since the objective was to model the distribution of currently pristine (or untransformed) natural areas across the SADC region. In the GreenPrint Program, hubs were modelled to represent entire Protected Areas (PA) or blocks of natural areas outside PAs. The PPF, on the other hand, decided to exclude PAs in the definition of CNUs, since they were interested not so much in the distribution of PAs than the distribution of CNUs within and around PAs constituting the various TFCAs.

The minimum CNU size was determined through an iteration process where CNUs were derived each time substituting different size values. The concluding 1000 km^2 was decided upon as the optimal size to exclude small fragmented areas but, at the same time, ensure a relatively even distribution of CNUs across the study site. It was reasoned that CNUs should function as large refuge areas along "greenways" or natural corridors between TFCAs and should thus not include fragmented areas surrounded by developed land.

The following details the analysis steps followed in the first phase of the framework and corresponds to numbers 1 to 5 of Figure 4. Analysis was performed within the boundaries of SADC, so that data outside the boundaries were always set to NODATA. This was achieved by setting the boundary of analysis with SETMASK SADCBND.

1. <u>Natural Areas</u>

   Create a boolean GRID from the land cover GRID by reclassifying the human settlements, croplands and mixed land (i.e. classes 12 to 14) as 'zero' and the rest (classes 1 to 11, 15 to 17) as 'one'.

   NATR_LC = RECLASS (LANDCOV, LC_REMAP, NODATA, #, #)

2. <u>Sparse Areas</u>

   Create a Boolean GRID from the population density GRID with 'one' denoting sparse population densities of 0-25 per km^2 (i.e. classes 1 to 3) and 'zero', densities of 26 and more (i.e. classes 4 to 10).

   SPARSEPOP = RECLASS (POPDENS, POP_REMAP, NODATA, #, #)

3. Roads Excluded

Remove the road areas where primary routes cross the natural land. It was not necessary to add a buffer around the roads, because at 1km grid cells the roads are already buffered.

NAT_NOROAD = CON (ROADNET == 1, 0, NATR_LC)

4. Combine

Create the first set of CNUs by removing all the natural areas that fall within densely populated areas (i.e. the inverse of SPARSEPOP).

CNU1 = CON (SPARSEPOP == 1, NAT_NOROAD, 0)

5. Buffer, smooth, remove isolated CNUs, group

Buffer CNU1 with an 8km buffer

BND_8KM = FOCALMEAN (SADCBND, RECTANGLE, 8, 8, NODATA)

SETMASK BND_8KM

CNU_8KM = CNU1

Smooth the edges and remove small, isolated CNUs

CNUFSUM1 = FOCALSUM (CNU_8KM, RECTANGLE, 8, 8, DATA) * CNU_8KM

CNUSMTH1 = CON (CNUFSUM1 >= 50, 1, 0)

CNULARGE1 = CON (ZONALAREA (REGIONGROUP(CON (CNUSMTH1 = = 1, 1))) >= 1000000000, 1)

CNUFSUM2 = FOCALSUM (CNULARGE1, RECTANGLE, 8, 8, DATA) * CNULARGE1

CNUSMTH2 = CON (CNUFSUM2 >= 50, 1, 0)

CNULARGE2 = CON (ZONALAREA (REGIONGROUP(CON (CNUSMTH2 = = 1, 1))) >= 1000000000, 1)

CNUFSUM3 = FOCALSUM (CON (ISNULL (CNULARGE2), 0, CNULARGE2), RECTANGLE, 4, 4, DATA) * CON (ISNULL (CNULARGE2), 0, CNULARGE2))

CNUSMTH3 = CON (CNUFSUM3 > 10, 1)

CNUSMTH4 = CON (ZONALAREA (REGIONGROUP (CNUSMTH3)) >= 1000000000, 1)

CNU2 = CON (ISNULL (CNUSMTH4), 0, 1)

Identify the gaps within the large natural areas, and if they correspond to a natural land cover class, then fill them up as natural areas.

CNUGAP = CON (CNU2 = = 1, 0, 1)

```
CNUAREA = ZONALAREA (REGIONGROUP (CON (CNUGAP = = 1, 1)))
CNUGAP2 = CON (CNUAREA <= 725,000,000, 1)
CNUGAP3A = CON (NAT_NOROAD = = 1, CNUGAP2, 0)
CNUGAP3B = CON (CNUGAP3 = = 1, 1, 0)
CNU3 = CON (CNU2 = = 0, CON (CNUGAP4 = = 1, 1), CNU2, CNU2)
```

Group neighbouring pixels, so that CNUs are labelled as groups and not individual pixels.

```
CNU_ZONES = REGIONGROUP (CON (CNU3 = = 1, 1) #, FOUR, CROSS)
```

Phase two of the framework focused on prioritizing CNU groups according to their ecological value. This is discussed in the following section.

2.5 ECOLOGICAL PRIORITISATION OF UNITS

A composite ecological value was derived for each CNU based on a suite of raw and derived parameters. The parameters included distance from roads, shape of CNUs, number of historical sites per CNU, variety of geological and physiographic classes per CNU and the ecoregion responsibility, vulnerability status as well as the average topographic relief of the underlying areas. Analysts involved with the GIA study in Maryland, USA, weighted parameters according to their importance at the final summation stage (Maryland's GreenPrint Program 2001). Where appropriate these were adopted for the current study; if not, a weighted value was assigned based on a survey of ecological literature. In future, these values could be adjusted to reflect the African environment more accurately by incorporating input from various field experts.

A CNU was considered ecologically important in the following cases:

- far from main roads,
- a small boundary to volume ratio,
- a large variety of soil and physiographic zones, denoting a diversity of habitat types,
- high ecoregion responsibility (ecoregions have been widely used as a surrogate measure for biodiversity),
- and rated vulnerable or endangered.

The composite ecological value calculated for each CNU was used to classify them into three groups, based on a percentile breakdown, ranging from low to high ecological importance. Tier one comprised the top 33% of CNUs; tier two, the middle 33%; and tier three, the bottom 33%. This ranking system has been used in the present context to assist in the delineation of "greenways" or natural corridor areas between TFCAs (section 3.4). It may also be adopted to support the prioritisation of areas for conservation action.

The following paragraphs elaborate on steps 6 to 11 of Figure 4.

6. Calculate Euclidean distance

   Set areas between roads equal to NODATA.

   ROADND = CON (ROADNET = = 1, 1)

   ROADIST = EUCDISTANCE (ROADND)

7. Derive shape index

   The shape value for CNUs was calculated using the following equation:

   (0.25 * CNU-perimeter) / √CNU-area.

   CNUSHAPE = (0.25 * ZONALPERIMETER (CNU_ZONES)) div SQRT (ZONALAREA (CNU_ZONES)).

8. Derive eco-responsibility value

   The "ecoregion responsibility" parameter was derived as a percentage value based on the total area of an ecoregion not yet conserved as any of the areas defined by the WDPA Consortium (WDPA03 2003). This, then, provided a measure of the current responsibility decision makers have towards conserving a specific area. Analysts of the California biodiversity project have derived a similar parameter to measure the threat to biodiversity on a regional scale (Cogan 2003).

   ECO_ZONE = ZONALAREA (REGIONGROUP (WWFECO)

   ECO_REM = CON (PROTAREAS == 1, 0, WWFECO)

   ECO_REMZ = ZONALAREA (REGIONGROUP (CON (ECO_REM >= 1, ECO_REM)))

   ECO_RESP = INT ((ECO_REMZ DIV ECO_ZONE) * 100)

9. Calculate topographic relief

Topographic relief was calculated as the standard deviation of elevation within each 1 km^2 grid cell.

TOPORELF = FOCALSTD (DEM1000, RECTANGLE, 3, 3, NODATA)

10. Summarise zones

–Open an application of ArcView 3.2 (ESRI).

–Load the "Surface Analyst" extension.

–Add the following GRID themes to a new view document: ECO_RESP; GEOLOGY; GLBSTAT; HISTSITES; CNU_ZONES; CNUSHAPE; PHYSGR; ROADDIST; TOPORELF.

–Activate CNU_ZONES.

–From the main menu choose, Surface / Summarise zones.

a Choose to summarise each of the themes for the CNU_ZONES theme. This function calculates all the statistics (e.g. mean, maximum, minimum, variety, etc.) for the respective themes per CNU zone. They were not all be necessary and were reduced accordingly in step 11. Export the results each time as a DBF table (CNUgeol.dbf; CNUphys.dbf; CNUrddist.dbf; CNUstat.dbf; CNUtopo.dbf; CNUhist.dbf; CNUeco.dbf)

b Activate PHYSGR. Summarise the number of CNUs per physiographic zone and export results as DBF table (physCNUs.dbf).

11. Derive composite ecological value for each CNU

–Open an application of Microsoft Office Excel.

–Open all the DBF tables derived in step 10(a) in different Excel worksheets. Delete all fields except the following and then list them together according to the corresponding CNU zone (identified by a unique ID number):

- Variety of geology and physiographic zones
- Mean of distance to roads, ecological responsibility and topographic relief
- Total number of historical sites
- Maximum status

–Divide the 'mean distance to road' values by 1000, to get a value as kilometre instead of meter.

– Multiply the maximum status by a weight value of 3. This is the only value that is weighted because a literature survey revealed this to be very important. All the other values contribute equally to the ecological value of each CNU.

– Add these values together and export the total ecological value together with the corresponding CNU zone ID as a DBF file with fields [CNUID] and [eco_rank] (CNUecorank.dbf).

– Open physCNUs.dbf in Excel and delete all other fields so that only the variety of CNUs is listed per physiographic region such the fields [num_CNU] and [physID] remain. Export as DBF file (phys_var_CNUs.dbf).

– Open CNU_phys.dbf in Excel and delete all fields except the majority of physiographic region. Export as DBF file with fields [CNUID] and [maj_phys] (CNU_maj_phys.dbf).

– Open an application of ArcView 3.2 (ESRI).

– Add the GRID theme, CNU_ZONES, to a new View document.

– Add the following tables: phys_var_CNUs.dbf; CNUecorank.dbf; CNU_maj_phys.dbf

– Open the attribute table of CNU_ZONES (CNU_zones.dbf)

– Join the tables to CNU_ZONES' attribute table in the following order:
CNUecorank.dbf to CNU_zones.dbf (based on [CNUID])
CNU_maj_phys.dbf to CNU_zones.dbf (based on [CNUID])
phys_var_CNUs to CNU_zones.dbf (based on [physID])

– Use the field [num_CNU] (i.e. the number of CNUs per physiographic region) to normalise [eco_rank]. Nonparametric ranking was applied because information was lacking to evaluate thresholds or standards for parameters.

– Create a grid with CNUs separated into three tiers. Use the Map Calculator available in Spatial Analysts to derive a grid based on the following calculation:

(((\[CNU_zones.eco_rank] * 3) / [CNU_zones.num_CNU]) + 1).Int

– Reclassify the resultant grid into 3 classes based on "Natural Breaks". Save grid as CNU_RANK.

Once CNUs were rated according to their ecological value, they were used to inform the identification of natural area links between TFCAs. A case study is detailed in the following section.

2.6 MAPPING ECOLOGICAL ROUTES BETWEEN PARKS

This final phase of the model was developed to illustrate how CNUs, and their ecological values, could be applied in landscape planning for the achievement of conservation goals. The objective was to map a natural area corridor, or ecological route, between selected TFCA's. The term 'route' was adopted instead of 'corridor', a well-researched concept within ecological and wildlife studies, to refrain from narrowing the context within which such ecological routes could be viewed. Essentially, they have many potential uses (e.g. ecotourism or wildlife migration routes).

Previously, within the PPF, similar links between TFCAs were derived, but their results were based solely on the knowledge of local experts. Such a methodology is typically ad hoc and often subjective, making it difficult to duplicate the procedures for similar future decisions. It has generally been argued that decision makers should move away from purely subjective decision making. The procedure and outcomes of the model presented here could pave the way for the development of a more quantitative approach to decision making regarding landscape links within the PPF.

ArcINFO 8.1.2 (ESRI, Redlands, California) has a set of algorithms available for defining paths between cells or zones based on the least accumulative cost at each cell location. In the present study, these algorithms were used to derive an ecological route between two selected TFCAs. The cost at any particular location was defined as a composite value based on the slope, distance from closest road, population density, land cover type and presence of CNUs within each cell. Preference was given to steep slopes (since a higher diversity of communities occur where there is topographic relief), a large distance away from roads, sparsely populated areas, undeveloped land and ecologically important CNUs. The total impedance value ranged between 50 and 6230.

An ecological route was mapped between the Okavango-Upper Zambezi TFCA and Kgalagadi Transfrontier Park. These two TFCAs were chosen by the PPF, because they were interested in contrasting the results of this proposed methodology with the distinct corridor they have previously mapped between them. The Okavango-Upper Zambezi TFCA incorporates a major part of the Upper Zambezi basin and the Okavango basin and Delta. It is a biologically rich area with relatively little intrusive infrastructure, no urban areas of any significance, and a wealth of protected areas, or areas where natural resource utilisation is a major form of land use. The Kgalagadi Transfrontier Park (KTP) is the first formal TFCA that was proclaimed in Africa. It is located in the Southern Kalahari, a vast semi-desert area that extends across the international boundary from southern Botswana into the Northern Cape Province of South Africa.

The following paragraphs follow steps 12 to 18 of Figure 4.

12. <u>Define densely populated areas</u>

    Create an inverse grid of SPARSEPOP

    DENSPOP = CON (SPARSEPOP = = 1, 0, 1)

13. <u>Calculate Euclidean distance from dense areas</u>

    Set sparsely populated areas equal to NODATA.

    DENSPOPND = CON (DENSPOP = = 1, 1)

    DENSPOPDST = EUCDISTANCE (DENSPOPND)

14. <u>Derive slope</u>

    DEMSLOPE = SLOPE (DEM1000, PERCENTRISE)

15. <u>Derive cost/benefit values</u>

    LANDCOV, DENSPOPDST, ROADNET, CNU_RANK and DEMSLOPE were reclassified to impedance grids corresponding to the values listed in Tables B2 to B6. The resultant grids were LC_IMP, POP_IMP, ROAD_IMP, CNU_IMP, SLOPE_IMP.

Table 3 Land cover impedance values

Code	Description	Impedance
1	Evergreen Needleleaf Forest	50
2	Evergreen Broadleaf Forest	50
3	Deciduous Needleleaf Forest	50
4	Deciduous Broadleaf Forest	50
5	Mixed Forest	50
6	Closed Shrubland	50
7	Open Shrubland	50
8	Woody Savanna	50
9	Savannas	50
10	Grasslands	50
11	Permanent Wetlands	100
12	Croplands	250
13	Urban and Built-up	NODATA
14	Cropland/Natural vegetation	150
15	Snow and Ice	NODATA
16	Barren of sparsely vegetated	150
17	Water bodies	150

Table 4 Impedance values for the distance from densely populated areas

Distance (m^2)	Impedance
NODATA	0
0 – 2000	1000
2001 – 4000	500
4001 to maximum	200

Table 5 Road impedance values

Code	Description	Impedance
NODATA	NODATA	0
1	Primary	1000
2	Secondary	500
3	Other	200

Table 6 CNU impedance values based on their ecological rank values

Rank value	Impedance
NODATA	0
1	50
2	20
3	10

Table 7 Slope impedance values

Slope	Impedance
0 - 8	100
9 - 15	50
16 - 25	20
25 - 100	10

16. Derive total cost surface

    ArcINFO GRID Math

    TOTALCOST = POP_IMP + LC_IMP + ROAD_IMP - (CNU_IMP + SLOPE_IMP + (PROTAREAS*50))

17. Identify TFCAs

    The TFCAs between which to map the ecological route was identified by PPF decision makers. For the present study, this was an ad hoc decision but should be in future based on the priority of projects within the PPF framework.

- Open an application of ArcView 3.2 (ESRI, Redlands, California).
- Load the 'Surface Analyst' extension.
- Add Protected.shp to a new View document.
- Select a protected area and convert to grid. Name it PROT1.

–Select another protected area, convert it to grid and name it PROT2.

18. Perform least cost path analysis

    COSTSURF1 = COSTDISTANCE (PROT1, TOTALCOST)

    COSTSURF2 = COSTDISTANCE (PROT2, TOTALCOST)

    CORRSURF = CORRIDOR (COSTSURF1, COSTSURF2)

    TFCA_CORR = CON (CORRSURF < 65,000,000, 1)

The results of these three phases are presented in the next chapter. It is recommended that these three phases should be followed by a peer review process whereby field experts qualify the CNUs and their ratings. The importance of this lies with the fact that in this model the CNUs are not solely derived from the base datasets, but require the interpretation of patterns by analysts at two steps (Figure 3). A peer review process would normalize the subjectivity of the model. Such a peer review process was, however, not followed in the present study due to the severe time constraints.

CHAPTER 3 LANDSCAPE UNITS FOR THE SADC REGION

This chapter presents the results that were obtained from the three stages of the model as a series of maps (Figures 5 to 12). These results are strictly data dependent, and could change if the base datasets were updated in future, or replaced by different sets. Note also that at 1km^2, a grid cell already represents a generalisation of a feature's attribute at any location.

3.1 RESULTS OF THE SPATIAL MODEL

The existing protected areas, as defined by the IUCN, are represented across the SADC region in Figure 5. The World Database on Protected Areas (WDPA) consortium (WDPA03 2003) uses a number of classes to characterize protected areas (e.g. IUCN classes 1 to 6 or classes corresponding to one of 8 international conventions or agreements). They were, for the sake of simplification, grouped into the following classes: conservancy; game reserve; national park; nature reserve; private reserve; protected area; and other. The latter is a broad category which denotes safari areas, hunting reserves, wetland parks, etc. Resource planners have suggested that for the long-term conservation of ecosystem processes (e.g. nutrient cycling), countries need to protect 10-25% of their total surface. Many countries in SADC have not reached this goal.

Densely populated areas, defined as those areas containing more than 25 people per km^2, were distributed mainly from North to South on the eastern side of SADC (Figure 6). Nodes of dense human populations also occurred on the western side of the DRC as well as Angola. Central and southwest SADC have large areas with sparse populations. This pattern is repeated in the land cover data (Figure 7), where the croplands and developed land classes correlated with dense human settlements of the population database.

Having been derived from land cover and population density data, it is not surprising that the resultant CNUs (in terms of area) were concentrated in the DRC, Angola, Namibia and Botswana (Figure 8)—a rough inverse to Figures 6 and 7. A total of 193 CNUs were mapped for the SADC region and ranged between 1022 km^2 to 1,639,818 km^2 in size. The most densely distributed CNUs are found in the Central Congo Basin moist forests, Angola Miombo forests as well as in the arid and semi-arid areas of South Africa (e.g. Nama Karoo) and Namibia (e.g. Namib desert). The largest CNUs may be too large for site-specific planning and could be subdivided into smaller areas with a set of refined criteria developed by experts.

Source: The WDPA Consortium 2003

Figure 5 Existing conservation areas in the SADC region

Source: Dobson et al. (2000)

Figure 6 Distribution of densely populated areas within the SADC region

Source: ISCGM 2003

Figure 7 Developed or degraded areas including croplands, human settlements and roads within the SADC region

Figure 8 Core natural landscape units (CNUs) across the SADC region.

The Limpopo Province of South Africa, Zimbabwe and southern Mozambique were virtually devoid of CNUs. This, however, does not correlate with reality as this is the area where the Great Limpopo TFCA is located, with 35,771 km^2 of protected land (Hall-Martin & Modise 2002). The reason for this shortcoming in the CNUs layer may result from the fact that the ISCGM land cover dataset (Table 1) has those areas classified as croplands, whereas in reality they are dominated by grasslands and savanna. This illustrates the importance of choosing an appropriate land cover layer for modelling CNUs. It also illustrates the need to have interaction with expert knowledge at the base data level. Local decision makers and other experts can review and verify the accuracy of small-scale, public domain base data at an early stage, so that inaccuracies can be rectified before modelling begins. Gaining such expert input can be achieved by a number of means, including workshops, across the email, placing a map on the Internet or simply posting a hard copy map to the receiver. This leads to another point and that is the need for systematic objective approaches like this framework to be able to still interface with and accept inputs from subjective sources such as decision makers and expert knowledge. Cowling et al. (2003) elaborate on this point in their paper.

Notably the CNUs' spatial distribution was independent of political boundaries. This could stimulate insights regarding the placement of areas for Park expansions across borders. The ecological responsibility and global status for large areas are presented in Figures 9 and 10 respectively. These were incorporated with other data to derive an ecological (or conservation potential) value for each CNU, which was used to rank CNUs into three levels of importance (low, medium and high). The resultant, ranked, CNUs are presented in Figure 11. Based on these values for each CNU, as well as incorporating continuous values derived for the entire landscape, an ecological route or corridor was mapped between representative TFCAs (Figure 12). This route, essentially, represents a path of least ecological or development resistance. Being based on quantitative methods, the route can be compared to a corridor that has been mapped by decision makers at the PPF for the same two TFCAs, but based on expert knowledge only (Figure 12).

Figure 9 Ecological responsibility of areas across the SADC region

Source: WWF 2000

Figure 10 Global conservation status of terrestrial ecosystems across the SADC region

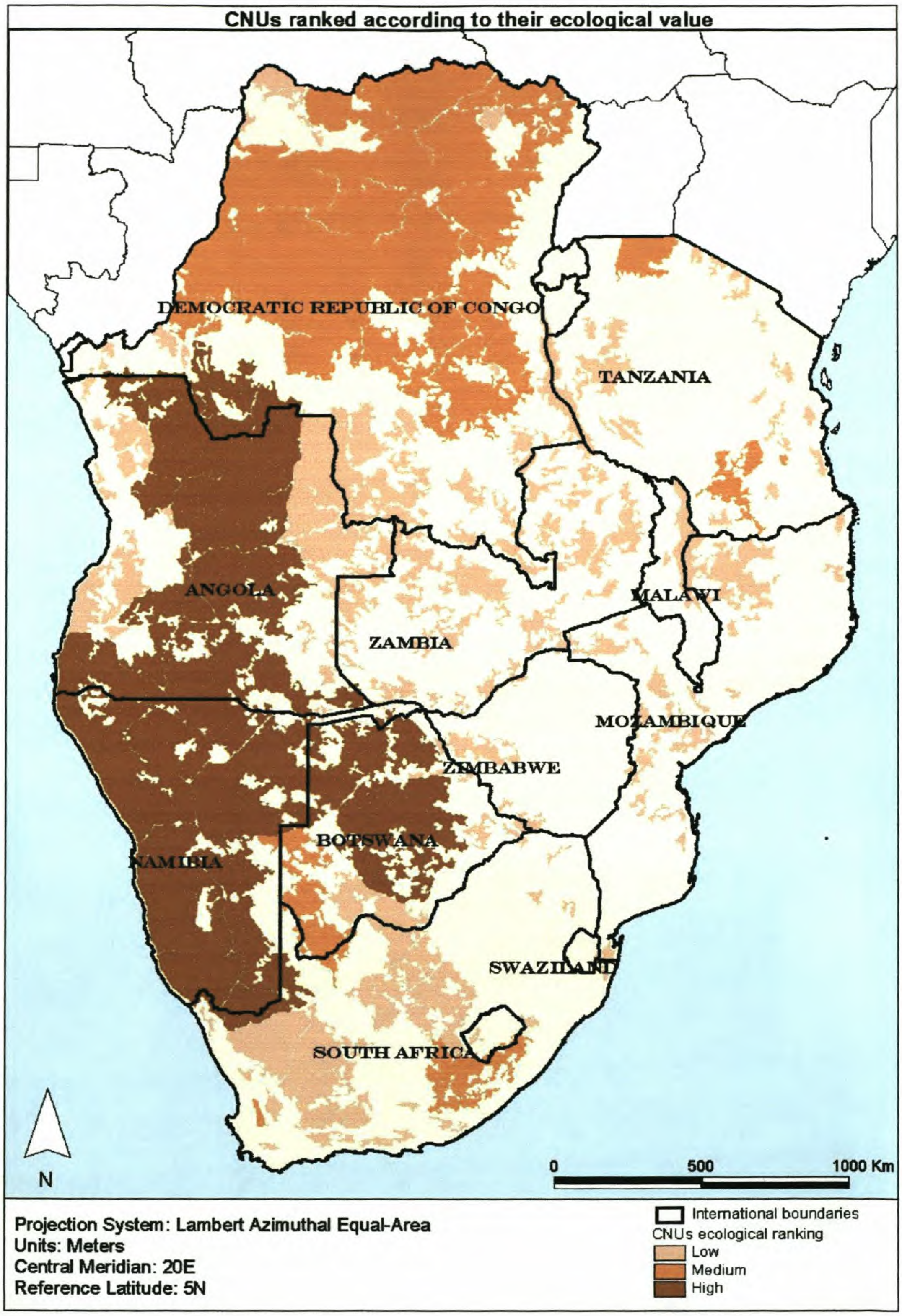

Figure 11 CNUs ranked according to their ecological values

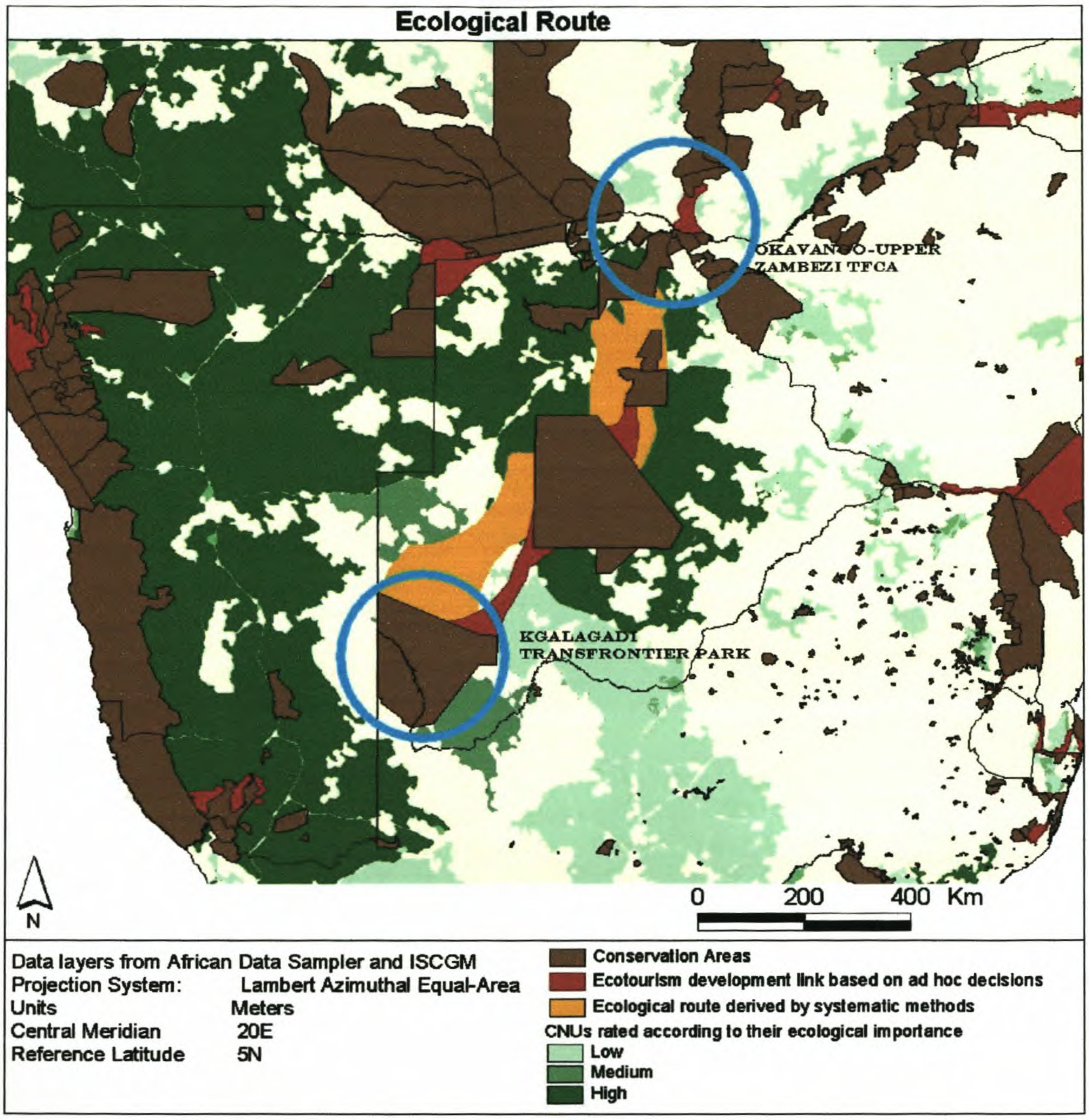

Figure 12 Ecological route between the Okavango-Upper Zambezi TFCA and Kgalagadi Transfrontier Park

3.2 DISCUSSION OF RESULTS

Societies throughout the world have, over time, divided their landscapes by legal lines or boundaries according to land-ownership and political or administrative jurisdictions. These cultural lines have played a significant role in defining the natural pattern of animal movements, for example. There is scarcely a landscape anywhere in the world, which has not been modified as a result of human activity, and this is one reason why societies today are faced with the urgent need to actively protect biodiversity.

In an effort to curtail the continual threats to natural ecosystems and their biodiversity, conservation biologists have suggested that planners and managers should establish reserves not as individual sites, but as networks of (near) continuous areas; ecosystems need to be protected not as fragmented patches of land, but as large areas over which both the biotic and abiotic elements can function. The adoption of such a regional approach to biodiversity conservation has gained momentum as people have come to see that plans prepared at a small scale can provide the context for the detailed decisions of local authorities. The necessity to protect whole ecosystems and their biodiversity has compelled planners to cease making detailed decisions that do not take the bigger picture into account, in favour of a broad, integrated approach.

3.2.1 Conservation planning with core natural areas

The current spatial framework was developed as a scientifically-defensible methodology for quantitative landscape analysis and decision making across political boundaries in the SADC region. It stipulates in a series of steps how to derive a set of natural landscape units ranked according to a composite ecological value, and as such provides a means to assess landscape structure at a small scale in terms of the size, connectivity and juxtaposition of large patches of natural areas, with the ecological value derived for each denoting conservation potential. This methodology is substantiated by Stevenson's (1992) paper in which he emphasizes the fact that regional conservation activities could only be appraised scientifically if it is based on the development of indices, or measurable units, that evaluate, objectively, the conservation potential of sites.

The system of CNUs that results from applying the methodology, furthermore, fulfils a number of the characteristics to which Noss (1990) suggested indices of biodiversity should conform. Notably that an indicator should be: (1) distributed over a broad geographical area; (2) capable of providing a continuous assessment over a wide range of stress; and (3) easy and cost-effective to measure. With regards to the first two points, the CNUs derived in this study is distributed continuously over the entire SADC region, making it possible to get a holistic view of the natural environment and condition thereof for each of the SADC countries simultaneously. The third point is realized by the fact that the framework utilizes public domain data sets, making it particularly cost-effective and as a result make it possible to update it periodically at minimum cost and effort so as to monitor a variety of threats to the natural environment.

The concept of deriving landscape scale indicators for resource management and decision making has been widely applied. CNUs derived for the GIA project in Maryland, have been used as indicators of ecologically important land (Maryland's GreenPrint Program 2001). Weinstoerffer and Girardin (2000) developed an indicator to estimate the influence of the pattern and intensity of agriculture on the rural landscape. Cogan (2003), together with the California Biodiversity Project team of analysts, derived a composite landscape indicator for measuring ecosystem health at a county level. This indicator was derived from a suite of data including ecoregions, features of special concern, species habitat assemblages, distance from developed areas, restoration potential and population data. For analysis at a 1:250,000 scale, Cowling and Heijnis (2001) derived a set of landscape (or habitat) units as surrogates for vegetation diversity and based it on geology, homogeneous climate as well as vegetation zones and topographic data.

In their paper, Lombard et al. (2003) discussed the effectiveness of using land classes in conservation planning. They cited a study carried out by Reyers et al. (2002), which covered an area of over 122,000km^2. For this region, Reyers et al. (2002 as cited by Lombard et al. 2003) demonstrated the scale-dependency of biodiversity indices, such as the fact that planning to conserve sites based only on broadly defined landscape indices can exclude more species than finely defined ones and, conversely, that species-based approaches can miss entire habitats. This is just one of many studies which has demonstrated the necessary trade-offs between meaning and effectiveness when generalising data for complex ecosystem analyses and planning.

As a solution to the debate regarding appropriate data for conservation planning and monitoring, several authors have suggested that species data should be used in conjunction with land classes (Noss 1990; Kirkpatrick & Brown 1994 as cited by Lombard et al. 2003). Landres et al. (1988 as cited by Noss 1990) recommended that both habitat (including corridors, mosaics, and other landscape structures) and species data should be integrated into a comprehensive strategy that uses them as complementary indicators for measuring compositional, structural, and functional biodiversity at multiple levels of organization. Along the same lines, Margules and Pressey (2000) stated that there is, essentially, no ideal surrogate for biodiversity data and that the decision to use either landscape classes or species data often depends on the availability of accurate data as well as resources for analysis and collection of new data (Margules & Pressey 2000). This applied to the current study, as the availability of data that were prepared at a continental scale was the primary reason for deciding to exclude species data from the analyses. However, the author expects that the large CNUs mapped for Namibia, Angola and the DRC (Figure 8) with the current base data (see Table 1 for a comprehensive list), will become more meaningful once species data are integrated with the framework.

CNUs represent the most valuable large ecological patches potentially remaining in the SADC. This makes them important as a data source and could thus be incorporated in a number of research activities, for example: to define conservation targets for large regions, or to indicate the extent to which natural areas are under threat (Gardner et al 1987). In the face of continued population growth and urban expansion, it is important that efforts are made to maintain CNUs as open spaces or to regulate the type of development in the surrounding areas as a means of controlling biodiversity loss across the SADC.

“Ecology is a science, and like all science any predictions (hypotheses or models) are compared to the hard reality of what actually happens” (Bell & Morse 2000). The next step in the framework is, therefore, to compare the results with areas on the ground. If specific instances of CNUs and their conservation potential do not correspond to reality, then this should be built into future predictions of the framework. With input from field workers, local governments and other organizations, it is anticipated that the proposed framework will continue to be refined.

3.2.2 Ecological routes and sustainable development

A strategic methodology for deriving landscape links (or ecological routes) between TFCAs was developed to compliment current decision making processes at the PPF and also to illustrate how CNUs can be used as information source in planning activities. The method was based on the knowledge that corridors should be strategically located (in this instance linking TFCAs), continuous and sufficiently wide to provide enough interior conditions for the protection from edge effects and invasive exotics (Ecotrust 2003). Moreover, the method was made robust enough in its considerations so that it could be applied to any of the TFCAs in the SADC region. Figure 12 denotes an ecological corridor linking the Upper Zambesi/Okavango TFCA with the Kgalagadi Transfrontier Park and compares this corridor with the one derived from expert knowledge solely. A detailed analysis of the ecological implications of applying the two planning techniques is beyond the scope of this paper, but it should be noted that they are not mutually exclusive and both techniques could be used in off-reserve land use planning. For example, conservation biologists can use these results as a backdrop for planning for animal and seed migrations or compositions of particular abiotic and biotic elements. The protection of CNUs and ecological routes can potentially safeguard water and soil quality, aquifer recharge, stream baseflow, and provide human recreation and business opportunities for foreign and local communities.

Corridors in Maryland's Green Infrastructure network were derived as linear features, at least 1,100 feet wide, linking CNUs together (Maryland GreenPrint Program 2001). In general, they mapped corridors to follow prominent features like forests, ridges lines and streams with wide riparian buffers and healthy aquatic conditions. The Baltimore County greenway plan gave highest priority to preserving large forest patches with low edge-to-interior ratios, and delineated corridors between them based on satellite data. The Southern Appalachian Forest Coalition (1998) connected large, high quality core habitats with riparian or roadless corridors.

In a broad sense, the methodology presented can be used as a framework for identifying systems of protected areas to maintain viable populations of all native species as well as ecological and evolutionary processes (e.g. disturbance regimes, hydrologic processes, nutrient cycles, and biotic interactions) all with the involvement of local communities. In the end, conservation achievements will be measured as the difference made to the intensity and diversity of human-induced disturbance pressures. This model thus improves the practice of sustainable development by providing a means to improve the condition of the natural heritage.

3.3 A SPATIAL FRAMEWORK FOR CONSERVATION DECISION SUPPORT

The spatial framework presented in this paper should not be seen as a vehicle by which to achieve a final solution regarding the placement of reserves or corridors, since it was neither designed to answer detailed questions for specific areas nor to anticipate all the changes in circumstances which could occur over time. Instead, the CNUs and ecological routes should form part of a larger decision making process which integrates biological surveys, statistical modelling, policy developments, legislation, and political tactics with GIS analyses (Rookwood 1995; Pressey & Cowling 2001). In such an integrated process, the framework could help to build political consensus and public support in an open and accountable manner, and assist in defining and building support for broad directions regarding conservation goals. In other words, the spatial framework could serve as an information backdrop in decision making that enhances—not replaces—expertise and judgement of managers (Pressey & Cowling 2001).

Examples of the integration of such information frameworks in research activities for conservation decisions are still rare (Overton et al. 2002). Overton et al. (2002) described the usual situation to be one of disorganized and disparate data collection combined with uncoordinated methods for data generalisation and information extraction. When generalizations of ecosystem patterns do exist, they are often subjective and not based on objectively defined data sources and methodologies. The advantages of explicitly operating within information frameworks are numerous, as mentioned by Overton et al. (2002), and include the following: (i) it helps to direct the gathering of data to satisfy predefined goals, (ii) missing components in the analysis process, whether it be data or methods, are more easily identified and, (iii) research efforts are focussed on understanding important relationships between different components. In so doing, information frameworks draw upon the advances in quantitative ecosystem analysis and thereby provide the basis for informed conservation management.

The specific framework developed in this study for the SADC region served as an example of the type of data and methods one can apply to derive objective, generalised landscape units. Its immediate value for transfrontier conservation planning activities at the PPF is that it formed a basis for organising data into a logical framework and thereby gain a number of important measurement and reporting tools, such as spatially explicit reporting on conservation gains, losses and the difference made across the landscape, and conservation cost-effectiveness analysis (Overton et al. 2002). Ultimately, it will assist in performing quantitative measurements of environmental conditions for robust, integrated decision making.

This makes the spatial framework especially practical, because it made efficient use of limited resources (e.g., data) for deriving environmental information; information that could be used to inform conservation decisions and thereby help to make these decisions defensible and flexible in the face of competing land uses, as well as providing the accountability for decisions to be critically reviewed. Finally, it must be added that a good part of the usefulness of the methodology described lies in its updating capacity. Once the tasks to be developed are established, and with the experience acquired during the stage of realization, it is possible to produce new maps by just modifying the base data and parameters. In this way, it is possible to obtain new products with a rotation cycle much shorter than was possible with traditional techniques, and with superior properties as far as quality and objectivity are concerned (Tapiodor & Casanova 2003).

CHAPTER 4 CONCLUSION AND RECOMMENDATIONS

4.1 CONCLUSION

This paper presented a spatial information framework that is centered on portraying ecosystems at a small scale. By addressing landscape elements at a regional scale, it could become an essential building block for sustainable development initiatives, such as the establishments of TFCAs in Africa. It was based on the rationale that planners, resource managers and decision-makers are constantly faced with the task of providing answers to a host of problems that are related to improving the well-being of communities and human populations. The conservation of natural ecosystems has become an important consideration in addressing issues of community upliftment and economic growth in conjunction with biodiversity protection. Towards this aim, the PPF was founded to facilitate the establishment of TFCAs across the SADC region. GIS technology has come to play an integral part in the performance of these tasks by providing tools to present data in a spatially explicit manner.

The methodology that was developed in this study is presented as a framework for the melding of information into useful products, especially for regional conservation planning. By operating at a broad scale and integrating biophysical and cultural systems into its considerations, the spatial framework becomes a tool by which to assist in the management of change in the landscape so as to conserve biodiversity, and thereby contribute to a more sustainable future. It is modelled on the principles that sustainability should be viewed in a holistic sense (including economic, social and ecological components); that methods and data employed for assessment should be open and accessible to all; that broad participation is required; and that allowance should be made for repeated measurement in order to determine trends and incorporate the results of experience.

One of the conclusions implicit in this framework is the necessity of an interdisciplinary, but complementary, team that should contribute to the development of outcomes that are realistic. The most important issue will be to integrate scientific data with public values. Furthermore, because of limitations in data resolution, maps of the model's outputs are meaningful only at a 1:1 000 000 scale or smaller. For site-specific planning, maps should be photo and field verified, and boundaries defined using aerial photographs and property maps.

4.2 FUTURE RESEARCH OPPORTUNITIES

The model could be complemented, in future, by incorporating additional datasets or by combining it with techniques that form part of the larger body of knowledge related to ecological monitoring and decision making. For example, once a system for conservation has been proposed based on a network of CNUs, a process called GAP analysis can be used to verify to which degree native animal and plant communities are represented in the network as a whole (USGS 2003).

To survey the abundance of a species and existing spatial coverages of environmental variables (e.g. climate, landform) for a regional distribution of CNUs, a modelling technique called generalised regression analysis and spatial prediction (GRASP) can be applied (Lehmann, Overton & Leathwick 2003). Multiple regression techniques (e.g. GAM) can then be used to establish the statistical relationship between the species abundance and the environmental variables of the CNUs.

By repeating the model at different spatial scales, planners would get an idea of the spatial scales over which sustainability could be achieved. The intensity of threats to natural areas can be quantified by comparing model outcomes using data collected at different times. Overton (2002) described a methodology for measuring conservation achievement, which entails comparing the difference in predicted site value (e.g. using the ecological value derived for CNUs) with and without conservation management.

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APPENDIX A

Table A.1 A list of the 22 proposed TFCAs with the respective countries involved.

TFCA	Partner Countries
|Ai-|Ais/Richtersveld Transfrontier Park	Namibia; South Africa
Chimanimani TFCA	Mozambique; Zimbabwe
Great Limpopo Transfrontier Park	Mozambique/South Africa; Zimbabwe
Iona-Skeleton Coast TFCA	Angola; Namibia
Kagera TFCA	Rwanda;Tanzania
Kasungu-Lukusuzi TFCA	Malawi; Zambia
Kgalagadi Transfrontier Park	Botswana; South Africa
Lichinga-Liwonde TFCA	Malawi; Mozambique
Limpopo-Shashe TFCA	Botswana; South Africa; Zimbabwe
Liuwa Plain-Mussuma TFCA	Angola; Zambia
Lower Zambezi-Mana Pools TFCA	Zambia; Zimbabwe
Lubombo Conservancy –Goba Transfrontier Conservation And Resource Area	Mozambique; Swaziland
Maiombe Forest TFCA	Angola; Congo Republic; Democratic Republic Of Congo
Maloti-Drakensberg Transfrontier Conservation And Development Area	Lesotho; South Africa
Mnazi Bay-Quirimbas Transfrontier Marine Conservation Area	Mozambique; Tanzania
Ndumo Tembe-Futi Transfrontier Conservation And Resource Area	Mozambique; South Africa
Niassa-Selous TFCA	Mozambique; Tanzania
Nyika TFCA	Malawi; Zambia
Okavango-Upper Zambezi Transfrontier Conservation Zone	Angola; Botswana; Namibia; Zambia; Zimbabwe
Songimvelo-Malolotja TFCA	South Africa; Swaziland
The Lubombo TFCA Complex	Mozambique; South Africa; Swaziland
Vwaza-Lundazi TFCA	Malawi; Zambia
Zimoza Transboundary Natural Resource Management (Tbnrm) Project	Mozambique; Zambia; Zimbabwe

(Source: Hall-Martin & Modise 2002)

APPENDIX B

This section presents a series of tables listing the grid and vector files that were used as base data in the spatial framework (Table B1), as well as their corresponding attribute descriptions (Table B2 to B6) where applicable. Please refer to Table 1 in the main text for a description on the source of the data presented here.

Table B.1 Global status codes and descriptions

Code	GLOBAL200 Status
1	Critical or Endangered
2	Vulnerable
3	Relatively Stable or Intact

Table B.2 Population codes and corresponding density values

Code	Population Density
0-1	0 to 2
2	3 to 5
3	6 to 25
4	26 to 50
5	51 to 100
6	101 to 500
7	501 to 2500
8	2501 to 5000
9	5001 to 25 000
10	25 001 to 200 000

Table B.3 WWF Ecoregion codes and descriptions

Code	Description
1	Namib desert
2	Maputaland-Pondoland bushland and thickets
3	Zambezian flooded grasslands
4	Zambezian coastal flooded savanna
5	Eastern Congolian swamp forests
6	Northeastern Congolian lowland forests
7	Albertine Rift montane forests
8	Northern Zanzibar-Inhambane coastal forest mosaic
9	Eastern Arc forests
10	Atlantic Equatorial coastal forests
11	Northern Congolian forest-savanna mosaic
12	Southern Zanzibar-Inhambane coastal forest mosaic
13	Southern Congolian forest-savanna mosaic
14	Zambezian Cryptosepalum dry forests
15	Southern Africa bushveld
16	Itigi-Sumbu thicket
17	Nama Karoo
18	Angolan scarp savanna and woodlands
19	Zambezian Baikiaea woodlands
20	Western Congolian forest-savanna mosaic

Table B.3 (cont) WWF Ecoregion codes and descriptions

21	Central Zambezian Miombo woodlands
22	Western Zambezian grasslands
23	Lowland fynbos and renosterveld
24	Southern Acacia-Commiphora bushlands and thickets
25	Kalahari xeric savanna
26	Southern Miombo woodlands
27	Northern Acacia-Commiphora bushlands and thickets
28	Montane fynbos and renosterveld
29	Succulent Karoo
30	Southern Rift montane forest-grassland mosaic
31	Kaokoveld desert
32	Ruwenzori-Virunga montane moorlands
33	East African mangroves
34	East African halophytics
35	East African montane moorlands
36	Zambezian halophytics
37	Eastern Zimbabwe montane forest-grassland mosaic
38	Highveld grasslands
39	Angolan Mopane woodlands
40	Namibian savanna woodlands
41	Western Congolian swamp forests
42	Kalahari Acacia-Baikiaea woodlands
43	Victoria Basin forest-savanna mosaic
44	Angolan Miombo woodlands
45	Central Congolian lowland forests
46	Lake
47	Albany thickets

Table B.4 Geology codes and descriptions

Code	Description
1	Quaternary (undivided)
2	Holocene
3	Pleistocene
4	Quaternary-Tertiary
5	Tertiary
6	Mesozoic
7	Tertiary-Cretaceous
8	Cretaceous
9	Lower Creteceous
10	Cretaceous-Jurassic
11	Jurassic
12	Lower Jurassic
13	Jurassic-Triassic
14	Triassic
15	Upper/Middle Devonian
16	Permian-Carboniferous
17	Lower Triassic
18	Mesozoic-Paleozoic
19	Devonian-Silurian
20	Ordovician
21	Camrian
22	Silurian-Ordovician
23	Ordovician-Camrian

Table B.4 Geology codes and descriptions

24	Cretaceous-Carboniferous
25	Jurassic-Carboniferous
26	Paleozoic
27	Permian
28	Triassic-Permian
29	Carboniferous
30	Carboniferous-Devonian
31	Devonian
32	Silurian
33	Precambrian
34	Paleozoic-Precambrian
35	Paleozoic
36	Quaternary Igneous
37	Tertiary Igneous
38	Mesozoic Igneous
39	Mz-Pz Igneous
40	Paleozoic Igneous
41	Kimberlites
42	Salt Domes
43	Water (River 0r Lake)
44	Sea
45	Areas outside of African Continent

Table B.5 Physiography codes and descriptions

Code	Description
1	Escarpments
2	Flat Depression
3	Flat Plain
4	Flat Plateau
5	Flat Valley
6	Flat wet plain
7	Flat wet valley
8	High Mountains
9	Moderately steep hills, ridges and mountains
10	Rolling high hills and escarpments
11	Rolling Hills
12	Undulating dunes and depressions
13	Undulating Plains
14	Undulating Plateaus
15	Undulating Valleys
16	Water

Table B.6 IGBP land cover codes and descriptions

Code	Class	Description
1	Evergreen Needleleaf Forest	Lands dominated by trees with a % canopy cover > 60% and height exceeding 2 m. Almost all trees remain green all year. Canopy is never without foliage.
2	Evergreen Broadleaf Forest	Lands dominated by trees with a % canopy cover > 60% and height exceeding 2 m. Almost all trees remain green all year. Canopy is never without foliage.

Table B.6 (cont) IGBP land cover codes and descriptions

3	Deciduous Needleleaf Forest	Lands dominated by trees with a % canopy cover > 60% and height exceeding 2 m. Consists of seasonal needleleaf tree communities with an annual cycle of leaf-on and leaf-off periods.
4	Deciduous Broadleaf Forest	Lands dominated by trees with a % canopy cover > 60% and height exceeding 2 m. Consists of seasonal needleleaf tree communities with an annual cycle of leaf-on and leaf-off periods.
5	Mixed Forest	Lands dominated by trees with a % canopy cover > 60% and height exceeding 2 m. Consists of tree communities with interspersed mixtures or mosaics of the other four forest cover types. None of the forest types exceeds 60 % of the landscape
6	Closed Shrubland	Lands with woody vegetation less that 2 m tall and with shrub canopy cover over 60%. The shrub foliage can be either evergreen or deciduous.
7	Open Shrubland	Lands with woody vegetation less that 2 m tall and with shrub canopy cover between 10-60%. The shrub foliage can be either evergreen or deciduous.
8	Woody Savanna	Lands with herbaceous and other understory systems, and with forest canopy cover between 30-60%. The forest cover height exceeds 2m.
9	Savannas	Lands with herbaceous and other understory systems, and with forest canopy cover between 10-30%. The forest cover height exceeds 2m.
10	Grasslands	Lands with herbaceous types of cover. Tree and shrub cover is less than 10%
11	Permanent Wetlands	Lands with a permanent mixture of water and herbaceous or woody vegetation that cover extensive areas. The vegetation can be present in either salt, brackish, or fresh water
12	Croplands	Lands covered with temporary crops followed by harvest and a bare soil period (e.g. single and multiple cropping systems). Note that perennial woody crops will by classified as the appropriate forest or shrub land cover
13	Urban and Built-up	Land covered by buildings and other man-made structures
14	Cropland/Natural vegetation Mosaic	Lands with a mosaic of croplands. Forests, shrublands, and grasslands in which no one component comprises more than 60% of the landscape
15	Snow and Ice	Lands under snow and/or ice cover throughout the year
16	Barren of sparsely vegetated	Lands with exposed soil, sand, rocks, or snow and never has more than 10% vegetated cover during any time of the year
17	Water bodies	Ocean, seas, lakes, reservoirs, and rivers. Can be either fresh or salt water bodies