

APPLICATION OF MULTI-CRITERIA ANALYSIS IN LAND USE DECISIONS

by

Peter Kuyler

Submitted in accordance with the requirements for
the degree of

Doctor of Philosophy

**Centre for Environmental Management
Faculty of Natural and Agricultural Sciences
University of the Free State
Bloemfontein**

May 2006

Promoter:

Dr P.J. du Preez

Department of Botany, University of the Free State, Bloemfontein

Co-promoter:

Dr P.S. Goodman

Ezemvelo KwaZulu-Natal Wildlife, Pietermaritzburg

ACKNOWLEDGEMENTS

I wish to express my sincere appreciation for the support received from the following persons:

My promoter, Dr Johann du Preez and co-promoter, Dr Pete Goodman for their valuable guidance, motivation and stimulating comments throughout this project;

Prof. Tim O'Connor for his valuable advice, practical input and inspiring comments on this project;

Dr Timothy Fasheun, Ms Sbu Hlela and the staff of the KwaZulu-Natal Department of Agriculture and Environmental Affairs for their support throughout this project;

All those who participated in the workshops and interviews for their valuable contribution to this project;

My mother for her continuous encouragement and support of my studies;

My sister, Patricia-Anne, and my niece Lara for their interest and support; and

Finally, Edith and Leeza for all their love, understanding and encouragement during the many months I worked on this project.

ABSTRACT

Global land use trends have resulted in extensive transformation and loss of biodiversity in natural landscapes. In South Africa these trends are apparent in the Grassland Biome. Although it has a very high level of biodiversity and provides essential ecosystem services for economic development, only 2% is formally protected and it is one of the most threatened biomes in the country. With over 60% transformed and less than 1% formally protected, the Mistbelt Grassland of KwaZulu-Natal is a priority for urgent conservation attention. The continued transformation of natural landscapes due to economic pressures and the limited opportunity for an increase in protected areas where production and development needs must be met, presents a challenge to biodiversity conservation.

This study was motivated by the need for a strategic focus in the evaluation of the impacts of land use on the biodiversity integrity of landscapes in order to facilitate integrated environmental management and guide land use decisions that would promote conservation of biodiversity and sustainable development. A methodology for this evaluation is proposed that exploits the hierarchical approach to characterizing biodiversity and employs multi-criteria analysis in the form of the Analytic Hierarchy Process and decision-making by experts.

Separate evaluations of the impacts of land use on biodiversity integrity in the Mistbelt Grassland of KwaZulu-Natal and the moist sub-biome of the Grassland Biome were conducted to examine the application of the methodology at the vegetation-type and biome levels. Accordingly, five land uses and fourteen biodiversity indicators were selected for the Mistbelt Grassland study, and ten land uses and fifty-two indicators for the Grassland Biome study. Indicators for the integrity of landscape composition, structure and function were selected. The overall relative weights for land uses were obtained from rankings of the impacts of each land use on indicator criteria. Relative impacts of land uses on

landscape composition, function and structure were consistent and provided an unambiguous statement of the overall impact on biodiversity integrity. The greatest impact of land use was associated with that on landscape structure and was the result of the extent of transformation and fragmentation. The integrity of grassland habitat is important for landscape composition, while nutrient leakage and fire regime are considered important for landscape function.

Urban settlements were considered to have the greatest negative impact on biodiversity, while timber plantations, croplands and rural settlements also had a high impact. Pastures and livestock ranching were associated with low impacts. Against the benchmark of conservation, activities like game ranching, livestock ranching and tourism accounted for slight impacts on biodiversity integrity and are recommended for the maintenance of landscape biodiversity. While timber plantations, dairy farming, rural settlements and croplands were considered to make little contribution to the maintenance of biodiversity, their spatial orientation was considered to be critical for the maintenance of regional connectivity and the biodiversity integrity of the greater landscape.

In accordance with the methodology employed and insights obtained in the evaluation of land use impacts on biodiversity integrity, the Land Use Evaluation Model is proposed as an integrated environmental management tool. Within a single integrated, cost-effective evaluation procedure that allows for input by key stakeholders, the hierarchy of decisions in the Analytic Hierarchy Process can be expanded to accommodate a limitless number of indicator criteria to rank the impacts of alternative development plans or projects on the social, economic and biodiversity components of the environment. An examination was made of the Land Use Evaluation Model in strategic environmental assessments and its role in facilitating environmental impact assessment and the integrated development planning processes.

Key terms: land use impacts; transformation; landscape ecology; biodiversity conservation; Analytic Hierarchy Process; integrated environmental management; Land Use Evaluation Model; strategic environmental assessment.

UITTREKSEL

Verandering in grondgebruik lei, wêreldwyd, tot grootskaalse habitats-transformasie en biodiversiteits-verlies. In Suid-Afrika blyk hierdie tendense duidelik in die Grasveldbloom. Ten spyte daarvan dat hierdie bioom 'n besonder hoë biodiversiteit huisves en noodsaaklike ekosisteedienste onderliggend tot ekonomiese ontwikkeling verskaf, is net 2% hiervan onder amptelike bewaring en word die bioom as uiters bedreig beskou. Veral die Misgordelgrasveld (*Mistbelt Grassland*), met meer as 60% reeds getransformeer en minder as 1% onder amptelike bewaring, verdien prioriteit-status vir dringende bewaring. Die aanhoudende transformasie van natuurlike landskappe om ekonomiese redes en die beperkte geleentheid om meer bewaringsgebiede te bekom, skep 'n buitengewoon groot uitdaging vir die bewaring van biodiversiteit.

Die noodsaaklikheid vir 'n strategiese fokus op die evaluering van grondgebruik en hul impak op landskapbiodiversiteit, asook die soeke na geïntegreerde omgewingsbestuur en besluite oor grondgebruik wat die bewaring van biodiversiteit en volhoubare ontwikkeling bevorder, het as motivering vir hierdie studie gedien. Gevolglik word 'n metode vir die evaluering van grondgebruik wat die hiërargiese benadering tot die beskrywing van biodiversiteit volg en veelkriteria-analise in die vorm van die *Analytic Hierarchy Process* met besluitneming deur kenners insluit, voorgestel.

Onafhanklike evalueerings van die impakte van grondgebruik op die integriteit van biodiversiteit in die Misgordelgrasveld en die Klamgrasveld sub-bioom is gedoen om die gebruik van die metode op die plantegroeitipe- en bioom-vlakke te toets. In totaal is vyf grondgebruike en veertien biodiversiteitsindikatore vir die Misgordelgrasveld-studie, en tien grondgebruike en twee-en-veertig indikatore vir die Grasveldbloom-studie, gekies. Indikatore vir die integriteit van landskapsamestelling, funksionering en struktuur is geïdentifiseer. Die algehele relatiewe waardes vir grondgebruik is bepaal deur die rangering van die impakte van grondgebruik op indikatore. Die relatiewe impakte van grondgebruik op

landskapsamestelling, funksionering en struktuur was deurentyd konstant, met 'n ondubbelsinnige siening rakende die algehele impak op die integriteit van biodiversiteit. Die grootste negatiewe impak van grondgebruik was op landskapstruktuur en te wyte aan transformasie en fragmentering van die landskap. Die integriteit van grasveldhabitat was belangrik vir landskapsamestelling, terwyl die loging van voedingstowwe en die brandpatroon as belangrik vir landskapsfunksionering geag is.

Stedelike vestings was beskou as verantwoordelik vir die grootste negatiewe impakte op biodiversiteit, terwyl die impakte van bosbou plantasies, saailande en landelike vestings ook hoog gelys is. Die impak van aangeplante weidings en veeboerdery is minder hoog geag. Met bewaringsgebiede as maatstaf, is die impakte van wildboerdery, veeboerdery en toerisme op die integriteit van landskappe relatief gering geag en geniet hierdie grondgebruike dus voorkeur sover dit die behoud van biodiversiteit betref. Terwyl bosbouplantasies, melkboerdery, landelike vestings en saailande min bydra tot die behoud van biodiversiteit, word hulle ligging en ruimtelike oriëntasie as uiters belangrik beskou om te verseker dat onversteurde gebiede met mekaar verbind is en sodoende bydra tot die integriteit van biodiversiteit in die groter landskap.

Na aanleiding van insigte wat met die evaluering van die impakte van grondgebruik op die integriteit van biodiversiteit verkry is, word die *Land Use Evaluation Model* as instrument vir geïntegreerde omgewingsbestuur voorgestel. Met 'n enkele geïntegreerde, koste-effektiewe evaluasie-prosedure wat insette deur sleutel aandeelhouers toelaat, kan die hiërargie van besluite in die *Analytic Hierarchy Process* uitgebrei word om 'n groot aantal indikatore in te sluit. Gevolglik word daar voorgestel dat die impakte van alternatiewe ontwikkelingsplanne of -projekte op die sosiale, ekonomiese en biodiversiteitskomponente van die omgewing bepaal kan word. Die toepassing van die *Land Use Evaluation Model* in strategiese omgewingsbepalings, sowel as die model se rol in die fasilitering van omgewingsimpakstudies en die geïntegreerde ontwikkelingsbeplanningsproses, is ook ondersoek.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS	ii
ABSTRACT	iii
UITTREKSEL	vi
LIST OF TABLES	xiv
LIST OF FIGURES	xvii
LIST OF ACRONYMS	xix

CHAPTER 1 INTRODUCTION

1.1. Land use decisions and biodiversity management	1
1.1.1. Global context	1
1.1.2. South African context	3
1.2. Evaluation of land use impacts	5
1.3. Objectives of this study	6

CHAPTER 2 LAND USE IMPACTS ON LANDSCAPE BIODIVERSITY

2.1. Defining and characterizing biodiversity	8
2.1.1. Changing perceptions of biodiversity	8
2.1.2. Defining biodiversity	8
2.1.3. Hierarchical characterization of biodiversity	9
2.2. Landscapes and their transformation	12
2.2.1. Defining a landscape	12
2.2.2. Transformation of natural landscapes	13

2.3. Evaluation and conservation of landscape biodiversity	15
2.3.1. Biodiversity integrity of landscapes	15
2.3.2. Conservation of landscapes	18
2.4. Land use and integrated environmental management	19
2.4.1. The concept of integrated environmental management	19
2.4.2. South African law	21
2.4.3. Strategic environmental assessment	26
2.4.4. Integrated environmental management in KwaZulu-Natal	29
2.5. Multi-criteria analysis	35
2.5.1. Introduction	35
2.5.2. Approaches to multi-criteria analysis	37
2.5.3. The Analytic Hierarchy Process in natural resource management	41

CHAPTER 3
EVALUATION OF LAND USE IMPACTS ON LANDSCAPE
BIODIVERSITY

3.1. General evaluation procedure	44
3.2. Spatial scale of enquiry	44
3.3. Expert opinion	45
3.4. The Analytic Hierarchy Process	45
3.4.1. Hierarchy of decisions	45
3.4.2. General application	46

CHAPTER 4
IMPACT OF LAND USE ON BIODIVERSITY OF THE MISTBELT
GRASSLAND

4.1. Introduction	52
4.1.1. Selection of the study area	52
4.1.2. Description of the study area	53
4.2. Evaluation	56
4.2.1. General approach	56
4.2.2. Workshops	56
4.2.3. Land uses selected	58
4.2.4. Land uses omitted	62
4.2.5. Biodiversity indicators selected	62
4.2.6. The Analytic Hierarchy Process	74
4.3. Results	77
4.3.1. Pilot workshops	77
4.3.2. Formal workshop	80
4.4. Discussion	82
4.4.1. Relations among indicators	82
4.4.2. Impact of land uses on biodiversity	86
4.4.3. Recommendations for land uses	90

CHAPTER 5
IMPACT OF LAND USE ON BIODIVERSITY OF THE MOIST SUB-
BIOME OF THE GRASSLAND BIOME

5.1. Introduction	98
5.1.1. Selection of the study area	98
5.1.2. Description of the study area	99

5.2. Evaluation	101
5.2.1. General approach	101
5.2.2. Interviews	101
5.2.3. Land uses selected	101
5.2.4. Land uses omitted	109
5.2.5. Biodiversity indicators selected	109
5.2.6. The Analytic Hierarchy Process	129
5.3. Results	132
5.4. Discussion	138
5.4.1. Relations among indicators	138
5.4.2. Impact of land uses on biodiversity	144
5.4.3. Recommendations for land uses	150

CHAPTER 6
EVALUATION OF PROPOSED METHODOLOGY AND
APPLICATION FOR LAND USE DECISIONS

6.1. Evaluation of methodology	155
6.1.1. The Analytic Hierarchy Process	155
6.1.2. Level of application	160
6.1.3. Selection of indicators	162
6.1.4. General comments	163
6.2. The Land Use Evaluation Model	165
6.3. Application of the Land Use Evaluation Model	170
6.3.1. Integrated environmental management	170
6.3.2. The strategic environmental assessment	174
6.3.3. The environmental impact assessment	178
6.3.4. Integrated development planning	181

**CHAPTER 7
CONCLUSIONS**

7.1. Achievements of this study	186
7.1.1. Evaluation of land use impacts on biodiversity	186
7.1.2. The Land Use Evaluation Model	190

REFERENCES	194
-------------------	-----

**APPENDIX A
LIST OF PARTICIPANTS**

1. Mistbelt Grassland study	209
2. Grassland Biome study	209

**APPENDIX B
IMPACT OF LAND USE ON BIODIVERSITY OF THE MISTBELT
GRASSLAND**

1. Pilot workshop results	210
1.1. Ranking of biodiversity indicators	210
1.2. Ranking of land uses with respect to indicators	213
1.3. Final ranking of land uses	226
1.3.1. Impact on biodiversity components	226
1.3.2. Overall impact on biodiversity	228
2. Formal workshop results	230
2.1. Ranking of biodiversity indicators	230
2.2. Ranking of land uses with respect to indicators	233

2.3. Final ranking of land uses	247
2.3.1. Impact on biodiversity components	247
2.3.2. Overall impact on biodiversity	249

APPENDIX C

IMPACT OF LAND USE ON BIODIVERSITY OF THE MOIST SUB-BIOME OF THE GRASSLAND BIOME

1. Final ranking of land uses (summary)	251
1.1. Impact on biodiversity components	251
1.2. Overall impact on biodiversity	263

LIST OF TABLES

Table 3.1: The continuous rating scale of the Analytic Hierarchy Process.	47
Table 3.2: A $n \times n$ matrix (M) according to the Analytic Hierarchy Process with pair-wise ranking of criteria (C) as indicators of biodiversity integrity.	48
Table 3.3: A $n \times n$ matrix (M) according to the Analytic Hierarchy Process with pair-wise ranking of the impacts of land use alternatives (A) on a specific indicator of biodiversity integrity ($M=n \times n$ for A_n land uses).	50
Table 3.4: Final ranking to determine overall priority weights (OP_r) for land-use alternatives.	50
Table 4.1: Transformation and conservation status of the Mistbelt Grassland (Midlands Mistbelt Grassland) in KwaZulu-Natal according to 2000 land-cover information.	53
Table 4.2: List of indicators selected for assessing the impact of land use on biodiversity integrity of the Mistbelt Grassland.	63
Table 4.3: Weights for indicators of the integrity of landscape composition, structure and function for the Mistbelt Grassland (pilot workshops).	77
Table 4.4: Weights for the impact of land use on the indicators of landscape composition, function and structure for the Mistbelt Grassland (pilot workshops).	78

Table 4.5: Weights for the impact of land use on the overall biodiversity integrity for the Mistbelt Grassland (pilot workshops).	79
Table 4.6: Weights for indicators of the integrity of landscape composition, structure and function for the Mistbelt Grassland (formal workshop).	80
Table 4.7: Weights for the impact of land use on the indicators of landscape composition, function and structure for the Mistbelt Grassland (formal workshop).	81
Table 4.8: Weights for the impact of land use on the overall biodiversity integrity for the Mistbelt Grassland (formal workshop).	82
Table 5.1: List of indicators selected for assessing the impact of land use on the integrity of landscape composition in the moist sub-biome of the Grassland Biome.	113
Table 5.2: List of indicators selected for assessing the impact of land use on the integrity of landscape structure and function in the moist sub-biome of the Grassland Biome.	114
Table 5.3: Weights of indicators for landscape composition in the moist sub-biome of the Grassland Biome.	132
Table 5.4: Weights of indicators for landscape structure and function in the moist sub-biome of the Grassland Biome.	133
Table 5.5: Weights for the impact of land use on indicators of landscape composition for the moist sub-biome of the Grassland Biome.	134

Table 5.6: Weights for the impact of land use on indicators of landscape structure for the moist sub-biome of the Grassland Biome.	136
Table 5.7: Weights for the impact of land use on indicators of landscape function for the moist sub-biome of the Grassland Biome.	137
Table 5.8: Weights for the impact of land use on the overall biodiversity integrity for the moist sub-biome of the Grassland Biome.	138

LIST OF FIGURES

Figure 4.1: Map of the Mistbelt Grassland of KwaZulu-Natal.	54
Figure 4.2: Relative impact of land use on landscape structure in the Mistbelt Grassland (pilot workshop).	91
Figure 4.3: Relative impact of land use on landscape structure in the Mistbelt Grassland (formal workshop).	91
Figure 4.4: Relative impact of land use on landscape function in the Mistbelt Grassland (pilot workshop).	92
Figure 4.5: Relative impact of land use on landscape function in the Mistbelt Grassland (formal workshop).	92
Figure 4.6: Relative impact of land use on landscape composition in the Mistbelt Grassland (pilot workshop).	93
Figure 4.7: Relative impact of land use on landscape composition in the Mistbelt Grassland (formal workshop).	93
Figure 4.8: Relative impact of land use on overall biodiversity integrity of the Mistbelt Grassland (pilot workshops).	94
Figure 4.9: Relative impact of land use on overall biodiversity integrity of the Mistbelt Grassland (formal workshop).	94
Figure 5.1: Relative impact of land use on landscape structure in the moist sub-biome of the Grassland Biome.	148

Figure 5.2: The relative impact of land use on landscape function in the moist sub-biome of the Grassland Biome.	148
Figure 5.3: The relative impact of land use on landscape composition in the moist sub-biome of the Grassland Biome.	149
Figure 5.4: The relative impact of land use on overall biodiversity integrity for the moist sub-biome of the Grassland Biome.	149
Figure 6.1: Proposed Land Use Evaluation Model for the assessment and management of impacts of land use on biodiversity.	166
Figure 6.2: Land Use Evaluation Model applied to the framework of a strategic environmental assessment	176
Figure 6.3: Land Use Evaluation Model applied to facilitate the environmental impact assessment process.	179
Figure 6.4: Land Use Evaluation Management Model applied to facilitate the integrated development planning process.	182

LIST OF ACRONYMS

AHP	Analytic Hierarchy Process
CBD	Convention on Biological Diversity
DAEA	Department of Agriculture and Environmental Affairs (KwaZulu-Natal)
DEAT	Department of Environmental Affairs and Tourism
ECA	Environment Conservation Act (Act 73 of 1989)
EIA	Environmental Impact Assessment
EIP	Environmental Implementation Plan
EKZNW	Ezemvelo KwaZulu-Natal Wildlife
IDP	Integrated Development Plan
IUCN	International Union for the Conservation of Nature
KZN	KwaZulu-Natal
LUEM	Land Use Evaluation Model
LUMS	Land Use Management System
MCA	Multi-Criteria Analysis
NEMA	National Environmental Management Act (Act 107 of 1998)
PGDS	Provincial Growth and Development Strategy
SANBI	South African National Biodiversity Institute
SDF	Spatial Development Framework
SEA	Strategic Environmental Assessment

CHAPTER 1

INTRODUCTION

1.4. Land use decisions and biodiversity management

1.4.1. Global context

Growing populations of the world as well as unsustainable consumption patterns are placing increasing stress on the natural resources of our planet and severely influencing the ability of its ecosystems to deliver essential services. The unprecedented expansion of human need for resources requires, now more than ever, a proactive approach to decisions regarding land use that would ensure the maintenance of biodiversity integrity and sustainable natural resource utilization for the continued delivery of ecosystem services.

Natural resource management and the management of biodiversity are complex and associated with a multiplicity of management objectives that must be considered in accordance with human needs and legislative requirements. The need for an integrated approach to planning and environmental management has been recognized in Agenda 21 (UN 1999). Accordingly, the integration of research, policy making and practice in environmental planning and management has become widely applied to facilitate sustainable social and economic development (DEAT 1998a). To ensure a “win-win” situation, social and economic development must be sustained by ecological services that are provided through the maintenance of adequate biodiversity integrity.

Article 6 in the United Nations Convention on Biological Diversity (CBD) requires each contracting party to develop national strategies, plans or programmes for the conservation and sustainable use of biological diversity (UNEP 2005).

Contracting parties are expected to, as far as possible and where appropriate, integrate the conservation and sustainable use of biological diversity into their relevant sectoral or cross-sectoral plans, programmes and policies. Article 7 in this Convention furthermore requires parties to *identify processes and categories of activities which are likely to have significant adverse impacts on conservation and sustainable use of biological diversity, and monitor their effects through sampling and other techniques*. Contracting parties must therefore identify activities (including those related to land use) that are likely to have significant adverse impacts on the conservation of biodiversity and implement the necessary monitoring so as to guide mitigation strategies.

In 2002, ten years after the CBD was adopted, signatories developed a Strategic Plan to guide the further implementation of the Convention at national, regional and global levels (UNEP 2005). The key objective of the Strategic Plan is to halt the accelerating loss of biodiversity and secure the continuity of its beneficial uses through conservation and the sustainable use of its components. Obstacles to the implementation of the Convention are also identified in the Strategic Plan and include the lack of mainstreaming and integration of biodiversity issues into sectoral and cross-sectoral programmes and plans in a precautionary and proactive manner, and the lack of the use of tools such as environmental impact assessments to guide the mitigation of impacts and ensure environmental sustainability.

Although the process of integrating biodiversity into mainstream development as prescribed by the CBD may be difficult to describe, Sandwith (2002) explains that situations where it occurs may be characterized by the following:

- the incorporation by signatories of biodiversity concerns into policies governing their sectoral activities;
- the simultaneous achievement of gains in biodiversity and gains in an economic sector (the “win-win” scenario);

- sectoral activities being recognized as based on, or dependent on the sustainable use of biodiversity; and
- situations where sectoral activities result in overall gains for biodiversity that exceed biodiversity losses.

The mainstreaming of biodiversity into socio-economic development however, requires a clear understanding of the dependence of the various sectoral activities on biodiversity and what the mutual benefits of sound biodiversity management to each sector will be.

1.4.2. South African context

South Africa has an exceptional richness of biodiversity and has an astonishing variety of biomes within which high species diversity and endemism occur. Past economic pressure, particularly due to the expansion of agriculture (Downing 1978), accompanied by a lack the integration of biodiversity concerns into land use planning has, however, resulted in extensive fragmentation and transformation of our landscapes. This transformation has been accompanied by the loss of plant species, habitats and ecological processes. An evaluation of the biodiversity status of landscapes in KwaZulu-Natal indicates that 30% of the landscapes in this Province have been transformed by more than 40% (i.e. beyond the theoretical threshold for the significant disruption of ecological processes) (Goodman 2000a). In addition, 76% of these landscapes are under-protected and 9% are in critical need of conservation action.

Since 1994, the mainstreaming of biodiversity considerations in South Africa has occurred against the backdrop of dramatic social and political change. Enormous disparities of power and access to land and a skewed distribution of population and wealth have arisen due to the country's historic political situation. Social and economic redress has therefore been prioritized in provincial

development strategies such as the Provincial Growth and Development Strategy (PGDS) of KwaZulu-Natal (KZNPG 2004). This PGDS aims primarily to provide a framework to direct provincial socio-economic development and planning initiatives, to outline strategic interventions to achieve goals and targets and to set a common vision to co-ordinate activities within all levels of government and its partners.

Although the elements that are encompassed in environmental legislation to ensure the environmental rights of citizens (section 24 of the Constitution, Act 108 of 1996) have been broadened considerably since the publication of the Environment Conservation Act in 1989 (Act 73 of 1989), there has been a lack of legal guidance on the integration of environmental management considerations in political, social and economic policies at a broader, strategic level. It is therefore noteworthy that environmental management and the conservation of biodiversity have been adopted as a cross-cutting multi-sectorial strategy in the KwaZulu-Natal PGDS and that an attempt is being made to ensure that environmental considerations are integrated into the strategic provincial objectives regarding good governance and socio-economic development (KZNPG 2004).

The transformation status of landscapes in KwaZulu-Natal (Goodman 2000a; EKZNW 2005) indicates that an urgent strategy for the evaluation of existing land use impacts on biodiversity is required to inform future decisions regarding land use in order to ensure the management and conservation of biodiversity assets in the Province. The impacts of land use on biodiversity integrity and ecosystem services must be considered together with social and economic priorities to ensure that appropriate mitigation strategies are adopted which would facilitate environmentally sustainable development.

1.5. Evaluation of land use impacts

There is an increase in the recognition by society that biodiversity is associated with a large variety of values (such as its aesthetic, conservation, economic and educational values). While the management of biodiversity has traditionally focused on the conservation of habitats and species that are threatened or endangered, this approach has gradually shifted to one that is more holistic, multiple-scale, hierarchical and interdisciplinary (Noss 1983, 1990; White, Preston, Freemark and Kiester 1999; Poiani, Richter, Anderson and Richter 2000). Decision-making in natural resource management has become increasingly interdisciplinary and dependent on contributions from not only biology and ecology, but also other applied sciences such as agriculture, social and political sciences.

Although the trend to adopt a broader perspective in the management of biodiversity is increasing in South Africa, the assessment and management of the impacts of land use on biodiversity are still largely guided by the rather focused approach prescribed by the current environmental impact assessment (EIA) legislation. The EIA process as prescribed by the Environment Conservation Act (Act 73 of 1989) (ECA), in conjunction with the requirements of the National Environmental Management Act (Act 107 of 1998), essentially focuses on the assessment and management of environmental impacts of land use at a project and site specific level. There are currently no legal requirements and set procedures for a strategic environmental assessment (SEA) or for its contribution to the EIA process in South Africa and authorities seldom prescribe a SEA as a prerequisite for an EIA.

The current focused approach to the evaluation of land use impacts therefore largely relies on environmental information collected at a site specific level and little, if any, guidance from information regarding the biodiversity status at the

landscape level is provided. It is information regarding the status of biodiversity at the landscape level that can guide decisions regarding the desirability of individual land uses and assist with the promotion of those land uses that would facilitate the conservation of biodiversity. Special attention can also be given to the mitigation of land uses that are associated with significant impacts on biodiversity. Environmental information at a landscape level will also provide an indication if individual land uses will contribute to any existing impacts in a cumulative manner.

Within the broad, multi-sector framework suggested by integrated environmental management (DEAT 2004a) there is also a need for the evaluation of impacts of land use on the biodiversity at the landscape level so that guidance can be provided to strategic planning decisions that facilitate sustainable development.

1.6. Objectives of this study

The continued transformation of natural landscapes due to economic pressures and the limited opportunity to increase protected areas where production and development needs must be met, present a challenge to biodiversity conservation. This study is accordingly motivated by the need for a strategic focus in the evaluation of the impacts of land use on the integrity of landscape biodiversity, in order to facilitate integrated environmental management and land use decisions that promote the conservation of biodiversity and sustainable development. The following broad objectives are set for this study:

- a) The development of a methodology for an assessment of the impacts of land use on the integrity of landscape biodiversity. With respect to different levels of investigation and specific study areas the following are essential:

- (i) The identification of land uses or enterprises that have the most impact and pose the greatest threats for biodiversity integrity.
 - (ii) An assessment of the land uses or enterprises which offer the best potential for intervention to facilitate the maintenance of biodiversity integrity and the making of suggestions in this regard.
- b) The proposal of a model for the evaluation of land use impacts on biodiversity in accordance with the methodology developed.
 - c) An examination of how the proposed model could be used as a tool to facilitate integrated environmental management.

CHAPTER 2

LAND USE IMPACTS ON LANDSCAPE BIODIVERSITY

2.1. Defining and characterizing biodiversity

2.1.1. Changing perceptions of biodiversity

Changing perceptions regarding biodiversity are the result of a shift in the approach of ecologists and land managers who have traditionally largely ignored interactions among the different elements in a landscape or ecosystem and focused only on the diversity of species and their endangered status (Forman 1981; Noss 1983, 1990). More recently, biodiversity is being viewed from a broader, hierarchical perspective and the need to conserve dynamic, multi-scale ecological processes that sustain the entire spectrum of biological components and their supporting natural systems is considered to be essential (Noss 1990; Angermeier and Karr 1994; Poiani *et al.* 2000). The entire spectrum of ecological processes such as decomposition, nitrogen cycle, pollination, seed dispersal, energy capture, herbivory and predation must therefore be considered responsible for the maintenance of natural systems.

2.1.2. Defining biodiversity

The following are definitions that reflect perceptions of biodiversity:

- *The variety of life in all its forms, levels and combinations. ... (It includes ecosystem diversity, species diversity and genetic diversity (IUCN 1991).*
- *The variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the*

ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems (Article 2, Convention of Biological Diversity, UNEP 2005).

- *The aggregate of species assemblages (communities), individual species, and genetic variation within species and the processes by which these components interact within and among themselves (United States Bureau of Land Management in Cooperrider 1991).*

2.1.3. Hierarchical characterization of biodiversity

Hierarchical theory is concerned with the organizational complexity within systems. Organized systems can accordingly be divided into discrete functional components that operate at different spatial or temporal scales. In landscape ecology, the hierarchical paradigm provides the framework for the definition of functional components, the scales at which they operate and their relationships with each other (Urban, O’Niell and Shugart 1987).

Within the context of hierarchy theory as a framework for ecosystem analysis, the concept of an ecosystem as dual organization was introduced by O’Neill, De Angelis, Waide and Allen (1986). This approach describes an ecosystem as being the product of structural constraints that operate on organisms and of functional constraints that operate on processes and the approach recognizes that ecosystem instability will result when constraints are broken down. While levels of complexity as related to functions and processes within communities or ecosystems are examined in the dual organization approach, this excludes a description of the spatial and temporal arrangement of ecosystems.

(a) *The primary attributes of biodiversity*

The hierarchical approach to ecosystem analysis has been expanded to describe the organization of biodiversity. Composition, structure and function are recognized as the three primary attributes of biodiversity (Franklin 1988). These attributes determine the biodiversity of an area and are considered to be interdependent. Attributes encompass multiple levels of organization and are described as follows:

(i) *Composition*

“Composition” refers to the identity and variety of elements in a collection and includes the relative abundance of habitats or species and measures of their diversity, richness and distribution (Noss 1990).

(ii) *Structure*

“Structure” is the physical organization or pattern of an ecosystem, from habitat complexity and population structure as measured within communities to the pattern of patches, porosity, connectivity and other elements at the landscape level (Noss 1990). Structure in the context of landscape, therefore refers to the spatial relationships among distinctive elements such as ecosystems, and specifically to the distribution of energy, materials and species in relation to sizes, shapes or configurations of the ecosystems (Forman and Godron 1986; Turner and Gardner 1992).

(iii) *Function*

The interactions among the spatial elements of a landscape, including flows of energy, materials and species among component ecosystems, are attributes of function. This includes ecological and

evolutionary processes such as gene flow disturbances and nutrient cycling (Turner and Gardner 1992; Noss 1990). An understanding of the reciprocal relationship between spatial pattern and ecological flows is considered to be a primary goal of landscape ecology (Wu and Hobbs 2002).

In the context of a landscape, function depends on the characteristics of its networks and matrix and the conductivity that exists within it (Forman and Godron 1986). Networks are composed of corridors and nodes. Corridors are the conduits and filters for movement of plants, animals, material and water across the landscape, while nodes are the intersections of corridors and sources or sinks of flowing objects. Movement through the matrix of a landscape depends on connectivity and the boundaries crossed between the landscape elements. The network and matrix characteristics of a landscape therefore affect movement across it. This movement depends on whether objects use corridors as conduits or cross barriers or use breaks in the landscape.

(b) Organizational levels for assessing terrestrial biodiversity

The hierarchical approach to the characterization of biodiversity and the identification of its major components at several levels of organization is considered to be useful in that it provides a conceptual framework for identifying specific, measurable indicators to monitor the status of biodiversity (Urban *et al.* 1987; Noss 1990). Four levels of organization for biodiversity are proposed by Noss (1990):

- Landscape (regional landscape);
- Community - ecosystem;
- Population - species; and

➤ Genetic.

The landscape (or regional landscape) level constitutes the highest and the genetic the lowest level of organization. Monitoring of higher order constraints can be provided by indicators at lower levels or vice versa. For example, details on the identity and abundance of species or populations of species can provide information on the status of ecosystem communities or landscape composition. The hierarchy concept therefore suggests that biodiversity can be monitored at multiple levels of organization and at multiple spatial and temporal scales. No single layer of organization (e.g. genetic, population, community) is considered to be fundamental because the different layers are inter-dependent and will provide different answers regarding the biodiversity integrity of a given area.

2.2. Landscapes and their transformation

2.2.1. Defining a landscape

A landscape is defined as a heterogeneous land area with a distinctive combination of interacting elements that are repeated in similar form throughout it (Forman and Godron 1986; Turner 1989). These elements include climate, landform, geology, soils and vegetation. Three major elements of landscapes are recognized. The first is physical structure as dictated by topographic features; the second is surface texture as described by soil and vegetation and the third is atmospheric influences as determined by climate (Fairbanks and Benn 2000).

Landscape ecology therefore emphasizes relatively large areas, the properties of component ecosystems and their interaction. Landscapes vary in size from a few hectares to millions of hectares. Accordingly, a small patch of forest

surrounded by grassland or an entire vegetation biome may constitute a landscape.

2.2.2. Transformation of natural landscapes

The origin and development of landscapes is influenced by a combination of natural processes and human influences. The impacts on landscapes by humans and their role in landscape development can be traced for thousands of years. The exponential growth of the human population is the factor that has contributed most to the extent of human influence on ecosystems and natural processes in landscapes. Human settlements have drastically changed patterns and processes in landscapes and the attributes of current disturbance regimes differ considerably from those of historical times.

The primary human influence on landscapes is to rescale patterns and processes in space and time. Changes in patch dynamics and bounded regions, the introduction of novel patches and dynamics and the homogenization of patterns, have been recognized as being the consequences of anthropogenic influences that result in the rescaling of patterns and processes in natural landscapes (Urban *et al.* 1987). While the alteration of the natural fire regime due to human activities may rescale landscape patterns and processes in time and space, the establishment of roads and linear structures may establish new boundaries and increase landscape fragmentation. The spatial scale and dynamics of human land use may introduce novel patterns that disrupt natural landscape processes and result in the homogenization of patterns and a reduction in habitat and species diversity in a landscape.

To describe the combined effects of all human influences on a landscape, a landscape modification gradient comprising five primary landscape types has been described by Forman and Godron (1986). A gradient of human impact that

extends from a natural landscape without significant human impact to an urban landscape which has been extensively transformed is recognized. Intermediate landscapes are associated with an increase in human impact and are described as “managed”, “cultivated” and “suburban” landscapes.

Numerous examples of the impacts of land use and the transformation of natural landscapes have been recorded. In South Africa, widespread transformation of landscapes due to the influences of human settlements has been linked primarily to the expansion of agriculture (Downing 1978). Plant species composition has been dramatically altered especially in semi-arid grassland areas, primarily due to changes in the historical grazing regime as a result of the increases in the number of domestic livestock. Extensive transformation is due to cultivation and afforestation, and dramatic changes in vegetation composition of untransformed grazed land have been recorded in a number of grasslands in KwaZulu-Natal (O’Connor, Morris and Marriott 2003).

In the forests of inland northwest United States, human settlements have dramatically altered spatial patterns of forest, tree species composition, terrestrial habitat linkages and fire, and other disturbance processes (Reynolds and Hessburg 2005). Studies on the rural areas of the Hiroshima Prefecture in western Japan have indicated that the heterogeneity of the landscape is maintained through a balance between agricultural use and natural disturbances (Kamada and Nakagoshi 1996). Although both natural and anthropogenic factors contribute to landscape heterogeneity and the maintenance of landscape structure, anthropogenic disturbances may change as socio-economic environments change. Changes in land use due to changes in social activities will influence landscape structure and the relative importance of natural disturbance processes. It is the relationship between land use and natural disturbance that varies from one landscape to another and makes each unique.

2.3. Evaluation and conservation of landscape biodiversity

2.3.1. Biodiversity integrity of landscapes

The measurement of biodiversity can take place at multiple levels of organization and at increasing spatial and temporal scales from the genetic, species, population, community and ecosystem, to the landscape and biome level (Noss 1990, 1996). As the biodiversity priorities of each organizational level should take into account the properties of its subsets, the implications of these levels are important in the assessment and management of biodiversity.

Within the hierarchical concept of biodiversity, an understanding of its integrity at the landscape level is considered useful because sub-areas (or components) within the landscape can then be targeted for specific conservation actions (White *et al.* 1999). There is an increasing trend to make recommendations regarding biodiversity conservation that facilitate the conservation of multi-scale ecological patterns and processes that sustain a full complement of biota and their supporting systems (Angermeier and Karr 1994; Turner, Gardener and O’Niell 1995). The conservation of biodiversity at multiple levels of biological organization requires the definition of the scale of an investigation for a given site and the identification and protection of focal ecosystems (or key functional areas) and their components, as well as the processes required to support and sustain these ecosystems (Poiani *et al.* 2000). The outcome of biodiversity assessment at the landscape level can therefore inform policy decisions over a relatively large area and guide management decisions in specific communities or ecosystems within the landscape.

(a) Indicators of biodiversity integrity for landscapes

(i) Selection of biodiversity indicators

The following are proposed as important criteria for indicators of biodiversity integrity (Noss 1990):

- An indicator must be easy to describe;
- An indicator must be sufficiently sensitive over a range of stress to provide warning of a change;
- These changes must be easy to quantify; and
- The indicator must be distributed over the geographic area examined.

As the chances are remote that a single indicator would possess all the desired properties, a set of complementary indicators is preferred.

In the selection of indicators for evaluating biodiversity, Noss (1990) explains that the following prescriptions are important:

- The reason for the exercise must be examined;
- Indicators selected must be relevant to questions regarding management or policy that must be answered;
- Indicators for a particular level of organization can be selected from levels at, above or below it. For example, population indicators may be selected from the ecosystem, or landscape or species level; and
- Indicators must be chosen so as to be specific to the ecosystems that are being evaluated.

(ii) Examples of biodiversity indicators

In accordance with the hierarchical approach to the characterization of biodiversity (Noss 1990), the following elements are examples of indicator variables for inventorying, monitoring and assessing the compositional, structural and functional components of terrestrial biodiversity at the landscape level:

➤ Landscape composition

Examples of indicator variables for landscape composition include the identity, distribution, richness and proportions of habitat types and the collective patterns of species distributions (Noss 1990).

➤ Landscape structure

Heterogeneity; connectivity; spatial linkage; patchiness; porosity; fragmentation and pattern of distribution of habitat layer are examples of indicator variables for landscape structure (Forman and Godron 1986; Noss 1990).

➤ Landscape function

Indicator variables for landscape function include disturbance processes such as the extent, frequency and seasonality of fire and grazing; nutrient cycling rates; energy flow rates; rates of erosion and geomorphic and hydrologic processes (Forman and Godron 1986; Noss 1990; Fairbanks and Benn 2000).

(iii) Monitoring of biodiversity indicators

Landscape structure can be monitored through the use of aerial photography and satellite imagery and the use of data obtained with geographic information systems (Forman and Godron 1986). The monitoring of indicators of landscape composition requires more intensive ground-truthing than the inventorying of

criteria for landscape structure, because species or habitat types may have to be identified (Noss 1990). Landscape function can be monitored through the evaluation of disturbance and recovery processes and the rates of biogeochemical or hydrologic processes.

2.3.2. Conservation of landscapes

Of fundamental importance in the conservation of biodiversity is the adoption of a holistic approach that focuses on the management of whole landscapes and includes areas that are protected and those that are transformed. In systematic conservation planning, a strategy for the management of whole landscapes is considered to be essential for the realization of conservation goals (Margules and Pressey 2000). These goals must acknowledge the biodiversity impacts of particular land uses in the context of the whole landscape. Management actions or interventions must address individual activities that occur in the landscape. The manner in which human activities influence ecological processes as applicable at the landscape level has become an important field of study because socio-economic processes at this level are considered to be the primary motivation for land use decisions and changes in land use (Wu and Hobbs 2002). The critical challenge in this regard is that land use planning needs to adopt an approach that considers the status of landscape biodiversity and that successfully integrates human needs and processes into biodiversity management.

Systematic conservation planning as proposed by Margules and Pressey (2000) assigns various tasks to do and decisions to make in stages. These stages are:

- the compilation of biodiversity data on the region that is to be managed;
- identification of conservation goals for the region;
- a review of existing conservation areas;

- selection of additional conservation areas;
- implementation of conservation actions; and
- the maintenance of the required values for conservation areas.

This process is not unidirectional and feedback may result in the changing of decisions made at any step and consequently a repeat in the process may be made.

Bearing in mind that representivity and persistence of biodiversity are considered to be the overall goals for systematic conservation planning, the first two stages (i.e. the compilation of data on the biodiversity status and identification of conservation goals for a planning region) may be considered to be the most critical in the exercise. An evaluation of the status of rare or threatened species and the biodiversity status of a planning region (or landscape) will be reflective of its transformation status and provide an indication of its conservation value. The conservation value of planning regions will in turn provide quantitative information on their biodiversity status to assist in the determination of targets and priorities with respect to the conservation of species or vegetation or other key elements. Accordingly, conservation targets will inform the need for additional conservation areas and the nature of conservation actions or management that will be required to ensure adequate representivity of biodiversity elements and their persistence in a planning region.

2.4. Land use and integrated environmental management

2.4.1. The concept of integrated environmental management

Integrated environmental management (IEM) essentially prescribes the need for a holistic approach to environmental management and provides the basic

principles, including environmental assessment and management tools that are aimed at promoting sustainable development. Accordingly, IEM emphasizes the need to integrate social, economic and biophysical elements of the environment in decision-making regarding the use of any environmental resources (DEAT 2004a).

(a) Defining integrated environmental management

IEM is broadly defined by the Department of Environmental Affairs and Tourism (DEAT 2004a) as follows:

IEM provides a holistic framework that can be embraced by all sectors of society for the assessment and management of environmental impacts and aspects associated with an activity for each stage of the activity life cycle, taking into consideration a broad definition of environment and the overall aim of promoting sustainable development.

With regard to the definition of IEM, the following is important:

- The holistic framework provided by IEM is in accordance with the broad definition of an “environment”. Accordingly, the environment consists of biophysical, social and economic components, as well as the interconnections between these;
- An “activity” refers to any policy, plan, programme or project that is either being planned or implemented; and
- “IEM” covers the entire life cycle of the activity and may include a decommissioning or post-decommission phase or for as long as environmental impacts associated with the activity remain significant.
- A potential hierarchical relation exists between various IEM tools. Various components of IEM, from strategic to site specific levels of investigation can therefore be employed to inform different

development phases of a project development cycle. For example, IEM tools such as strategic environmental assessments, environmental impact assessments and environmental management plans may be used to inform decision-making regarding project plans and programmes, project design and project implementation and monitoring.

2.4.2. South African law

(a) The Constitution of the Republic of South Africa

The Bill of Rights in Chapter 2 of the Constitution of the Republic of South Africa Act 108 of 1996 enshrines the rights of all people in the country and affirms the democratic values of human dignity, equality and freedom. The principal environmental right provided for in the Bill of Rights in the Constitution is contained in section 24 under the heading “Environment”. This states the following:

Everyone has the right to: (a) an environment that is not harmful to their health and well-being; (b) to have the environment protected for the benefit of present and future generations through reasonable legislative and other measures that (i) prevent pollution and ecological degradation; (ii) promote conservation; and (iii) secure ecologically sustainable development and the use of natural resources while promoting justifiable economic and social development.

(b) Environment Conservation Act and the environmental impact assessments process

The first significant step towards a consideration of environmental issues in decisions regarding land use in South Africa came in 1997 when regulations were promulgated in terms of section 21(1) of the Environment Conservation Act 73 of 1989 (ECA) (refer to Government Notice No. R. 1182 dated 05 September 1997). These regulations provide a list of activities that may have a detrimental effect on the environment and for which authorization is required in terms of sections 22(1) of the Act. Environmental impact assessment (EIA) regulations have been provided in terms of sections 26 and 28 of the ECA (refer to Government Notice No. R. 1183 dated 05 September 1997). These regulations apply to the EIA application procedure for authorizations of site specific activities as identified under section 21 of the ECA.

The EIA process in terms of the ECA essentially consists of a scoping phase that may be extended to include a full environmental impact assessment (DEAT 1998b). The scoping report produced during the scoping phase provides a description of the project, environmental issues and alternatives identified and public participation. A record of decision may be issued after the consideration of the scoping report by the relevant authority (provincial or national authority). If the information on alternatives and details regarding the significance of environmental issues in the scoping report is insufficient for the relevant authority to make a decision on the application, it must be supplemented by an environmental impact report (EIR) and a full EIA will be required. The extent and significance of environmental impacts and proposed mitigation for these impacts must be included in the EIR together with further details of the public participation process. Authorizations in records of decision are issued in terms of the requirements of section 22 of the ECA and may include conditions that relate to

the management and mitigation of environmental impacts as identified during the EIA process.

EIAs as required in terms of the ECA are for the commencement of new or upgraded projects on a specific site. Mitigation usually proposed is therefore for site specific rather than the cumulated impacts (at the landscape level) of the proposed activity. There is currently no legal requirement for the undertaking of a strategic environmental assessment (SEA) as part of any EIA for any listed activity.

(c) The National Environmental Management Act and environmentally sustainable development

The importance of sustainable development as the guiding principle for environmental management was first incorporated in South African legislation in section 2 of the ECA. This section has subsequently been repealed and the definition for sustainable development is now captured in section 2(3) of the National Environmental Management Act (Act 107 of 1998) (NEMA) where it is stated that: *development must be socially, environmentally and economically sustainable.*

NEMA is currently the principal act that guides environmental management in South Africa. While the preamble to this Act emphasizes co-operative governance (in accordance with section 41 of the Constitution), the promotion of institutions in this regard and the co-ordination of environmental functions by organs of state, the national environmental management principles in section 2 provide an important foundation for all decisions regarding land use.

(d) Amendments to the National Environmental Management Act

Sections 24, 43, 47 and 50 of the NEMA have recently been amended by the National Environmental Management Amendment Act 56 of 2002 (NEMA Amendment Act 56 of 2002) and the National Environmental Management Amendment Act 8 of 2004 (NEMA Amendment Act 8 of 2004) to provide for environmental authorizations. EIA regulations published in terms of these amendments will replace those under the ECA and provide for a more extensive list of activities (including threshold values for activities) that may have a detrimental effect on the environment. Activities that are expected to have a significant impact on the environment will be clearly distinguished. The EIA process will accordingly be extended to provide for a more prescriptive process for the authorization of activities that are expected to have a significant impact on the environment.

(e) Environmental management frameworks

The NEMA Amendment Act 8 of 2004 provides for geographical areas based on environmental attributes in which specified activities may not commence without authorization and geographical areas in which specified activities may be excluded from authorization. Section 2 of this Act amends section 24(3) of the principal Act (NEMA) to provide for the compilation of additional information or maps that specify the attributes of the environment, in particular geographic areas and can be used for environmental management frameworks. It is also proposed that any person or organ of state can initiate such a framework and that the contents of these frameworks must be taken into account in decisions regarding environmental management.

The NEMA Amendment Act 8 of 2004 therefore provides a legal mechanism for the establishment of environmental management frameworks that contain information to assist the management of impacts which land use proposals might have on biodiversity at the landscape level.

(f) The National Environmental Management: Biodiversity Act

The National Environmental Management: Biodiversity Act 10 of 2004 (NEMA Biodiversity Act) has the fundamental objective of providing for the management and conservation of biological diversity within South Africa in accordance with the framework of NEMA. Chapter 2 of the NEMA Biodiversity Act allows for the establishment of the South African National Biodiversity Institute (SANBI). Major functions of SANBI include the collection, processing and dissemination of information about biodiversity and the sustainable use of indigenous biological resources, the undertaking of research in this regard and the co-ordination of the rehabilitation of ecosystems. This includes an assessment of the impacts of land use on biodiversity and the determination and implementation of appropriate rehabilitation measures.

Chapter 3 of the NEMA Biodiversity Act provides for integrated and co-ordinated biodiversity planning, the monitoring of the conservation status of the various components of South Africa's biodiversity and the promotion of biodiversity research. Provision is made for a national biodiversity framework to integrate and co-ordinate biodiversity management by organs of state in all spheres of government, non-government organizations, the private sector, local communities and the public. The national biodiversity framework may determine norms and standards for provincial and municipal environmental conservation plans. These conservation plans must relate to the land use management frameworks of municipalities.

Chapter 3 also provides for bioregions, bioregional plans and biodiversity management plans. Bioregions are geographic areas which contain elements of biological and cultural historical value, while bioregional plans contain measures for the effective management of biodiversity and the components of biodiversity within the bioregions. Biodiversity management plans aim to conserve specific species or ecosystems. It is clear that land use development proposals and integrated development plans of municipalities must be consistent with any bioregional and biodiversity plans that may be applicable.

2.4.3. Strategic environmental assessment

Within the concept of IEM, SEA is widely used as a tool that focuses at a strategic level on the environmental implications of decisions made at a policy, plan or programme level (DEAT 2004a). By focusing at the strategic level, a SEA can complement and provide a framework for project level, site specific environmental assessments.

(a) Definitions of a strategic environmental assessment

There is currently no single internationally accepted definition of what constitutes a SEA (DEAT 2000) and the following illustrate the variety of interpretations of a SEA:

- *SEA is a systematic process for evaluating the environmental consequences of a proposed policy, plan or programme initiatives in order to ensure that they are fully included and appropriately addressed at the earliest appropriate stage of decision-making on par with economic and social considerations (Sadler and Verheem 1996);*

- *SEA is a process to assess the environmental implications of a proposed strategic decision, policy, plan, programme, piece of legislation or major plan (DEAT 1999); and*
- *SEA is an instrument that must be adapted to existing decision-making processes. It is more political than technical, and is related to concepts rather than to activities with geographic and technological specifications (Partidario 2000).*

The aim of a SEA is essentially to provide decision makers and other affected stakeholders with information on the potential environmental impacts of policies, plans or programmes to enable the implementation of appropriate mitigation measures in a proactive manner (CSIR 2003). The SEA must integrate social, biophysical and economic aspects of the environment to proactively inform plans and programmes in a manner that promotes sustainable development (DEAT 2000).

The principles for SEA in South Africa as proposed by DEAT (2000, 2004b) attempt to be consistent with those underpinning the concept of integrated environmental management and are set within the prescripts of NEMA. The SEA is based on the concept that development must be socially, environmentally and economically sustainable and that environmental quality must be considered throughout the life cycle of policies, programmes and projects (CSIR 2003). Within the concept of sustainability, the SEA must therefore identify environmental opportunities and the constraints and set criteria for levels of environmental quality to guide development plans or programmes.

Because EIAs are generally associated with the evaluation of site specific environmental impacts of projects, they seldom allow for sufficient opportunity to consider issues such as long-term trends, macro- or landscape-scale impacts, cumulative impacts and the status of biodiversity resources and strategic processes. Through the identification of threats and opportunities for biodiversity

at the landscape level at an early stage in the decision-making process and prior to the initiation of development projects, a SEA may overcome the limitations of an EIA. The further incorporation of relevant biodiversity strategies and action plans, details on the requirements of protected areas and the conservation of species, ecosystems and habitats in a SEA, allow it to facilitate EIA decisions that promote environmentally sustainable development.

The following are suggested as being essential elements for the stages of the SEA process (DEAT 2000):

- Identification of broad plan and programme alternatives;
- Screening;
- Scoping;
- Situation assessment;
- Formulation of sustainability parameters for the development of the plan or programme;
- Development and assessment of the alternative plans and programmes;
- Decision-making;
- Development of a plan for implementation, monitoring and auditing; and
- Implementation.

Although a SEA is essentially proposed as a stand-alone process, it is considered to be flexible enough to be incorporated into other planning processes such as the integrated development plan (IDP) process of municipalities (DEAT 2000). A SEA is seen as adding value to, or complementing the IDP process and is a means of integrating the concept of sustainability into planning. Environmental constraints identified in the SEA process which indicate the limits of acceptable change may be used to guide planning and ensure that development is sustainable. In addition, environmental opportunities as identified in the SEA process may also be enhanced through appropriate planning. DEAT (2000) therefore suggests that, through the identification and alignment of appropriate elements of the SEA with that of a

specific planning process (such as the IDP process), the SEA can be effectively integrated into such a planning process to ensure that environmental considerations are incorporated in it.

2.4.4. Integrated environmental management in KwaZulu-Natal

(a) A framework for biodiversity conservation and land use decisions in KwaZulu-Natal

Taking the prescripts of a systematic approach to conservation planning as proposed by Margules and Pressey (2000) into account, Ezemvelo KwaZulu-Natal Wildlife (EKZNW) (originally the KwaZulu-Natal Nature Conservation Service) has produced a report on the conservation value of land in KwaZulu-Natal (Goodman 2000a, 2000b). This report is the outcome of a programme that includes the development of a GIS database to evaluate the conservation value of land based on its biodiversity attributes. The analysis was conducted across the biodiversity hierarchy (excluding the genetic level) and included terrestrial landscapes, wetland, grassland and forest ecosystems, vegetation communities and species from eight broad taxonomic groups.

The EKZNW Report identifies priority landscapes through the use of the concepts of conservation status and vulnerability (Benn 2000; Goodman 2000a). Conservation status is determined by landscape rarity, degree of transformation and its protection status. Rarity of a landscape is a measure of the aerial percentage of the landscape in KwaZulu-Natal, while the extent of transformation and protection status is calculated from land-cover information. Vulnerability of a landscape is an indication of the potential threat of future land use changes as measured by the diversity of land uses in a landscape. It is assumed that exposure of a landscape to a wide range of land uses is an indication that it is vulnerable to future change.

By overlaying maps of the conservation status as defined by rarity, degree of transformation and protection status, and vulnerability (to land use change), priority landscapes in terms of conservation action are identified in the EKZNW Report. Results indicate that 76% of landscapes in KwaZulu-Natal are under-protected, 30% have been transformed by more than 40% and 9% are critically important for conservation action. A weighted combination of the endemic protection and fragmentation status was used to determine the importance of vegetation communities. Results also indicate that all endemic plant communities are under-protected, that the protection status of most is less than 3% and that 45% of 85 threatened plant species are not found in a protected area.

Although the EKZNW study concludes that the compilations of available information have identified many gaps, it is stressed that the database is valuable for planning purposes and needs to be maintained and improved in a strategic manner. The study also indicates that research priorities for the future include the need to identify the means of optimizing the protection status of biodiversity in KwaZulu-Natal to ensure that the 10% conservation goal recommended by the International Union for the Conservation of Nature (IUCN) is achieved.

(b) The KwaZulu-Natal Provincial Environmental Implementation Plan

In accordance with the requirements of section 41 of the Constitution of South Africa (Act 108 of 1996), NEMA was promulgated to give effect to co-operative environmental governance. The procedures to facilitate environmental governance are specified in Chapter 3 of NEMA and provide the framework for the KwaZulu-Natal Provincial Environmental Implementation Plan (KZN EIP) (DAEA 2002). In accordance with the requirements of NEMA the KZN EIP must

contain a description of provincial policies, plans and programmes that may affect the environment significantly. The manner in which policies, plans and programmes comply with the requirements of NEMA as well as the national norms and standards stipulated by the Constitution, must also be described.

The KZN EIP is therefore targeted at all provincial and local government departments within KwaZulu-Natal and aims to integrate decision-making and facilitate the achievement of responsible environmental management and sustainable development within the Province. This includes decisions regarding the management of biodiversity and land use.

(c) Integrated development plans for municipalities in KwaZulu-Natal

In terms of the requirements of the Municipal Systems Act (Act 32 of 2000) and the KwaZulu-Natal Planning and Development Act (Act 5 of 1998), each municipality is required to prepare an IDP for the whole municipality. An IDP is defined as being a *strategic planning instrument which guides and informs all planning, budgeting, management and decision making in a municipality* (DAEA 2003).

The terms of reference for environmental considerations within an IDP are provided by Chapter 3 of NEMA. According to section 16(4) of NEMA each provincial government must ensure that:

- *the relevant provincial environmental implementation plan is complied with by each municipality within its province, and*
- *municipalities adhere to the relevant environmental implementation and management plans, and the principles contained in section 2 of NEMA in the preparation of any policy, programme or plan,*

including the establishment of integrated development plans and land development objectives.

The principles for sustainable environmental development and the integration of biophysical, social and economic considerations as described in Chapter 1 of NEMA must be included in the development of an IDP. The incorporation of the following are therefore considered to be important in an IDP (DAEA 2003):

- identifying environmental degradation and environmental risks;
- involving competent stakeholders in charge of environmental concerns;
- making sure that environmental opportunities, problems and threats are reflected;
- assessing alternative strategies by considering environmental impacts;
- considering environmental aspects when designing projects; and
- ensuring compliance with environmental policies and legislation.

The KwaZulu-Natal Department of Agriculture and Environmental Affairs has proposed the following five phases for the development of an IDP (DAEA 2003):

(i) Phase 1: Analysis

This phase sets the terms of reference for the IDP and aims to ensure that priorities regarding community needs are identified and knowledge of available and accessible resources and the dynamics that influence municipal development are considered. Environmental issues are identified in this phase and the environmental assets and conservation required within the municipality are examined. Key stakeholders are identified and alternative projects are analysed within workshops. State of environment reports and strategic environment assessments are considered useful sources of environmental information to facilitate this phase.

(ii) Phase 2: Strategies

This phase addresses the need for an inter-sectoral approach, ensures that existing policy and guidelines are considered and that innovative and cost effective solutions are found to the various development options. Key participants from relevant local, provincial, national authorities and corporate service providers are identified and inter-sectoral workshops are held to facilitate alignment of projects. Alternative projects are analysed and the most desirable options selected. The environmental sustainability of projects is important and appropriate indicators must be identified to guide environmental performance and inform environmental management plans. Projects must be guided by the requirements of national and provincial environmental legislation and relevant provincial conservation strategies.

(iii) Phase 3: Projects

This phase establishes the role of the project task team in the project planning process. Project proposals are formalized and their potential contribution to sustainable development is examined. The identification of environmental issues also takes place in this phase and the use of indicators and mitigation and monitoring requirements are also evaluated.

(iv) Phase 4: Integration

This phase is to ensure that IDP projects are evaluated for alignment with strategic guidelines and objectives of the municipality and that these projects are integrated into existing municipal programmes. It is also essential that the projects are integrated with any existing sector programmes and that projects are aligned with the requirements of the municipality's integrated environmental programme. During this phase environmental management plans will be examined and project proposals will be presented to the IDP Representative Forum for consideration.

(v) *Phase 5: Approval*

The purpose of this phase is to ensure that, prior to adoption of the draft plans by the Municipal Council, relevant stakeholders and interested parties are provided with an opportunity to comment on these draft plans. District level alignment and legal compliance must be evaluated and any further amendments completed, prior to final adoption by the council.

A key component of an IDP is the requirement to prepare a Spatial Development Framework (SDF) together with a Land Use Management System (LUMS) which can apply to the whole municipality (Kahn, von Riesen and Jewell 2001). In accordance with the new LUMS for KwaZulu-Natal, a system of “wall-to-wall” Planning Schemes is proposed as the basis for the single LUMS required for a municipality. The new LUMS has been designed to provide a single system that can be applied to all areas within a municipality, whilst making provision for differentiation between the areas to allow for different local planning, development and conservation needs. Included in the LUMS are mechanisms to revise existing Planning Schemes so that they can provide for integrated land use and environmental management mechanisms in IDPs.

All municipalities are required to prepare IDPs that include SDFs. The purpose of an SDF is to provide strategic direction to municipal decisions that relate to the use, development and planning of land at a broad scale (DAEA 2003). SDFs must include information on the conservation of both the built and natural environments, as well as areas in which particular land uses should be encouraged or not and details on the intensity of land development. Strategic environmental assessments are a key component of a SDF.

Planning Schemes are intended to form the basis of a municipality’s LUMS and must contain the following details (Kahn *et al.* 2001):

- A policy statement regarding the proposed future development of the area;

- A description of the area to be affected by the scheme;
- Districts, or land use areas and key land uses such as agriculture, settlement, and land reserved for civic and social purposes;
- The location of key roads;
- The location of environmentally sensitive areas;
- The location of utilities and services; and
- The location of community land uses.

An elementary Planning Scheme will contain details of various planning scheme districts (such as low density residential and core mixed-use), as well as information on various land use zones. These land use zones may include environmental management, residential, general mixed, civic and social and agricultural zones. More comprehensive Planning Schemes apply to the larger and more complex urban and metropolitan areas and will contain a greater number of districts. These districts are based on the need for a finer differentiation of land use and land use intensity for larger towns and cities. The rural component of Planning Schemes are primarily to manage land that is outside urban areas and these schemes have as key functions the promotion of sustainable land use, the protection of prime agricultural land and the protection of areas of environmental and biodiversity significance.

2.5. Multi-criteria analysis

2.5.1. Introduction

Multi-criteria analysis (MCA) deals essentially with complex decisions that involve a large amount of information, a number of alternative outcomes and criteria to assess these outcomes. MCA techniques can be used to identify a single

preferred option, to rank options, to short-list a number of options for further investigation, or simply to distinguish acceptable from unacceptable alternatives.

The following are considered to be key features of MCA (DTLR 2002):

- MCA establishes preferences between options (alternatives) by reference to an explicit objective or set of objectives for which measurable criteria have been established to assess the extent to which the objective (or goal) has been achieved; and
- MCA emphasizes the judgement of a team. This may be in relation to the objective or objectives, the estimation of the relative weights for performance criteria and the contribution of each option to achieving the objective.

MCA has important advantages over informal judgement that is unsupported by analysis. These advantages include the following (DTLR 2002):

- MCA is an open, transparent and explicit process;
- The choice of objective or objectives and criteria used by the decision-making group are open to examination;
- Scores and weights are explicit and used according to established techniques; and
- Scores and weights can be cross-referenced to other sources of information on relative values and can provide an audit trail.

A performance matrix or consequence table is considered to be a standard feature of MCA (DTLR 2002). Each row describes an option and each column the performance of the options against each criterion. Criteria are established with respect to objectives or the overall objective of the exercise. Individual performance assessments may be expressed as numerical or “bullet point” scores or colour coding may be used. The performance matrix may constitute the final product of an analysis, or a further assessment of the extent to which objectives are met by the matrix entries may be required.

In the application of numerical analysis to a performance matrix, MCA techniques commonly apply scoring and weighting in two stages (DTLR 2002):

- *Scoring*: In this stage the expected consequences of each ranking are assigned a numerical score on the strength of a preference scale for each option for each criterion. The more preferred option scores higher on the scale and the less preferred lower. The most preferred option is associated with the highest value on the scale and the least preferred with the lowest. Intermediate values represent a constant linear expression.
- *Weighting*: The assignment of numerical weights to define the relative scores for each criterion with respect to the objectives or overall objective of the exercise occurs during weighting. Relative scores will then be adjusted on the preference scale.

2.5.2. Approaches to multi-criteria analysis

In the choice of a MCA technique, the number of alternatives or options to be appraised is an important consideration (DTLR 2002). Although some problems involve outcomes which are infinitely variable, most policy decisions are about choices between discrete options. With a finite number of options, an assessment of the performance of each option against the criteria for its evaluation is important. Exercises with a large set of criteria will require more data and resources than those with fewer, and is an important factor when deciding to implement a simpler or more detailed MCA technique. How MCA techniques process the basic information in the performance matrix is the primary manner in which they are distinguished from each other.

The following are well-known approaches to MCA (DTLR 2002) to use:

- Direct analysis of the performance matrix;
- Multi-attribute utility theory;

- Linear additive models;
- Outranking methods; and
- Analytic Hierarchy Process.

(a) Direct analysis of the performance matrix

This procedure involves a direct inspection of the performance matrix and although it yields a limited amount of information about the relative merits of various options, it indicates if certain options dominate others.

(b) Multi-attribute utility theory

An example of this theory is the three stage procedure as applied by Keeney and Raiffa (1976). In this procedure, the establishment of a performance matrix is the first stage, while the second is a determination of the inter-dependence of criteria. The third stage consists of a mathematical estimation of the decision regarding the performance of an option on each of the separate criteria. Although the procedure is effective, it is considered to be relatively complex and more appropriate for implementation in major projects where time and expertise are available.

(c) Linear additive models

These are simple models in which it is assumed that criteria are preferentially interdependent of each other. This model expresses the combination of an option's values on many criteria as an overall value. The value score on each criterion is multiplied by a weight of that criterion and weights are then added to provide the overall value. This arithmetic is however only appropriate if criteria

are mutually preference independent (i.e. preferences associated with the consequences of options are independent of each other from one criterion to the next). Linear additive models are widely applied in MCA approaches.

(d) Outranking methods

These methods evaluate alternatives and use outranking to eliminate those that are dominant. All options are assessed in terms of the extent to which they exhibit sufficient outranking with respect to the full set of options being considered as measured against a pair of threshold parameters. Concerns about the outranking approach are that it is dependent on arbitrary definitions of what outranking constitutes and that threshold parameters are set and later manipulated by the decision-maker.

(e) Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) also develops a linear additive model and in its standard format, employs procedures for deriving weights from scores obtained by pair-wise comparisons between criteria and options. Users generally find the pair-wise comparison method of data input straightforward and convenient.

(i) Hierarchy of decisions

According to Schmoldt, Kangas and Mendosa (2001a), the AHP has three important components. These are (1) the structuring of a problem into a hierarchy which consists of a goal and subordinate features (referred to as decomposition), (2) pair-wise comparisons between elements at each level

(evaluation), and (3) the development of level specific priorities from the local to global (synthesis).

Subordinate levels of a hierarchy may include objectives, scenarios, events, actions, outcomes or alternatives as they relate to the overall goal or objective of the exercise. Alternative courses of action are compared at the lowest level of the hierarchy and pair-wise comparisons are made between all elements at a particular level with respect to the level above it. Comparisons are concerned with the relative preference or importance of two criteria with respect to the determination of the overall stated objective.

As pair-wise comparisons are made between criteria at each level of the hierarchy and between decision alternatives at the lowest level, the AHP therefore uses a hierarchy to organise decision-making (Schmoldt, Mendosa and Kangas 2001b; ISNAR 2003). The ranking or weighting of each criterion with respect to the overall objective is recorded. Criteria may be broken down into sub-criteria which constitute different levels of the hierarchy and the pair-wise comparisons are repeated for each level of the hierarchy.

(ii) Criticism of the Analytic Hierarchy Process

One of the major criticisms of the AHP is the problem of rank reversal (DTLR 2002). This involves the possibility that the addition of another option to a list of options can influence the ranking of two unrelated options and therefore requires the careful examination of options that are chosen for an evaluation.

2.5.3. The Analytic Hierarchy Process in natural resource management

Since the adoption of Agenda 21 (UN 1999) there has been an increasing awareness that an integrated approach to environmental management is essential. Accordingly, the management of biodiversity has become increasingly complex due to a multiplicity of management objectives that must be considered to address legislative requirements and public interest. Within this context the application of multi-criteria analysis for decision support in natural resource management has become popular (Chuntharpursat 2000; Schmoldt and Peterson 2000; Schmoldt *et al.* 2001a; Eastman 2003).

Use of independent expert opinions in decision-making regarding the management of natural resources has become increasingly important, and their input together with that from other stakeholders is considered to be essential to ensure objectivity and integrity. The AHP (Saaty 1980) is a multi-criteria tool for making decisions. This tool is considered to be relevant to nearly any ecosystem management application that requires the evaluation of multiple opinions and where multiple participants or complex decision-making processes are involved (Schmoldt and Peterson 1997, 2000, 2001; Schmoldt *et al.* 2001b; Schmoldt, Peterson and Smith 2001c; Reynolds and Hessburg 2005). The ease of application of the AHP has increased its popularity and it has been used to facilitate decisions regarding the siting of artificial water points in the Mkuzi Game Reserve in KwaZulu-Natal, forest planning in Australia (Proctor 1999) and the resolution of land use conflict in a fragile ecosystem of the Baringo district in Kenya (Mwasi 2001).

(a) Group decision-making

Application of group decision-making has become increasingly important in natural resource management because a range of resource specialists and stakeholders can be included in one integrated process that allows multiple attributes of a problem to be investigated (Peterson and Schmoltdt 1999; Proctor 1999; Schmoltdt and Peterson 2000, 2001). Workshops are considered to be important settings for group decision-making as dialogue among participants, group deliberations, individual interactions and collective decisions are considered to be important and useful to obtain information about group preferences (Schmoltdt and Peterson 2000, 2001).

The following procedure includes group decision-making and the AHP and has been proposed for the evaluation of alternatives in natural resource management (Schmoltdt and Peterson 2001):

- use of a “strawman” document that acts as a discussion framework and template to initiate and pattern group discussion;
- brainstorming to facilitate decision-making; and
- participation in the AHP as the decision structuring and analysis component to produce judgements.

Resulting numerical judgements of alternative priorities generated through applying the AHP can be analysed statistically to indicate where group members agree and where priority values are significantly different. Schmoltdt and Peterson (2001) explain that group decision-making adds the following benefits to an evaluation exercise:

- the added knowledge that each person brings to the decision-making process;
- the interaction between participants that allows for the examination of multiple approaches to a problem; and

- the increase in acceptance of decisions due to the participation of stakeholders and experts.

Although it is often assumed that decisions by groups are superior to those of individuals, groups are in reality only seen to perform better than their average individual member, but worse than their best individual (Rogelberg, Barnes-Farrell and Lowe 1992). Problems encountered in group decision-making include a lack of agreement within the group (consensus) and expectations of individuals to conform and reach consensus (Schmoldt and Peterson 2001; Schmoldt *et al.* 2001b). These problems can result in the failure of the group to adequately consider individual opinions and it may accept a middle-ground position that compromises a better alternative, or avoids a less desirable alternative for the sake of agreement. Interactive group decision-making that applies the AHP is considered to be efficient and cost-effective, as it elicits a large amount of expert knowledge in a short time (Schmoldt and Peterson 2001). Ideally, the deficiencies of group decision-making should therefore be avoided or at least managed while its inherent benefits are exploited.

CHAPTER 3

EVALUATION OF LAND USE IMPACTS ON LANDSCAPE BIODIVERSITY

3.1. General evaluation procedure

The general approach to an analysis of the impact of land use on the integrity of biodiversity at the landscape level for a specific study area, that incorporates decision-making by experts and the application of the Analytic Hierarchy Process (AHP) (Sections 2.5.2 and 2.5.3), requires the following:

- 1) The identification and description of:
 - (i) A set of land use categories; and
 - (ii) A set of indicators of biodiversity integrity.
- 2) The application of the AHP and decision-making by experts to evaluate the relative impacts of land use on biodiversity integrity.

3.2. Spatial scale of enquiry

As impacts on biodiversity integrity and intervention strategies are scale dependent, an explanation of scale is essential. For an evaluation of the impacts of land use on biodiversity integrity at the landscape level, land use categories are chosen as the level of enquiry. Land uses may be described in categories which include a number of primary land uses. For example, croplands as a land use category represent the cultivation of all the crops types as described for a particular landscape.

3.3. Expert opinion

A review of literature indicates that very little empirical information is available for the formal, quantitative evaluation of the differences amongst land uses or cover types in the vegetation types of KwaZulu-Natal in terms of impact on or compatibility with biodiversity conservation. A significant amount of information is, however, available from experts in biodiversity and natural resource management, who have confronted these issues. The essential question is what the relative benefits or detriments of one land use ranked against another are as far as impacts on biodiversity integrity are concerned. The approach to this assessment must therefore facilitate decision-making in the absence of sufficient quantitative information and this was essentially three-fold:

- a) Through the use of workshops and personal interviews, expert insight (verbal) was formalized into an explicit qualitative statement (numerical score) of the relative importance of alternatives regarding the issue investigated through the application of the AHP.
- b) In order to offset possible bias in expert opinion, any available empirical information was used to assess the validity of these opinions.
- c) Available empirical information was reviewed in order to identify important generalities.

3.4. The Analytic Hierarchy Process

3.4.1. Hierarchy of decisions

The AHP uses a hierarchy to organize decision-making criteria in which pair-wise comparisons are made between criteria at each level of the hierarchy and between decision alternatives (Schmoldt *et al.* 2001b; ISNAR 2003). In a simple hierarchy land use alternatives will, for example, constitute the lowest level in the

hierarchy and indicator criteria for scoring the alternatives with respect to the overall objective (maintenance of biodiversity integrity) will constitute the intermediate levels. Indicator criteria can be broken down into sub-criteria which constitute different levels of the hierarchy of decisions. Pair-wise comparisons are then made for indicator criteria or sub-criteria and priorities for land use alternatives at each level are obtained. Overall ranking of land uses is therefore dependent on decisions made concerning criteria at each level.

3.4.2. General application

The general application of the AHP is accordingly as follows:

- 1) Application of the AHP with decision-making by experts to undertake the comparative judgements of biodiversity indicator criteria and of land use alternatives in order to:
 - Firstly, undertake comparative judgements (pair-wise ranking) of criteria with respect to their importance as indicators of biodiversity integrity at various hierarchical levels (as applicable); and
 - Secondly, undertake comparative judgements (pair-wise ranking) of land uses with respect to each indicator at each level in the hierarchy.

- 2) Final ranking of land uses to determine the relative impact of each on biodiversity integrity:
 - Determination of relative weights for land use alternatives with respect to their impacts on biodiversity integrity for a specific organizational level in the hierarchy; and
 - Determination of the overall ranking of land uses with respect to their impacts on biodiversity integrity for the study area.

(a) Ranking of biodiversity indicators

The first step in the AHP is to undertake pair-wise comparisons of the relative importance of a set of criteria as indicators of biodiversity integrity. In the AHP the relative importance of two criteria (pair-wise comparisons) is rated on a nine-point continuous scale (Saaty 1977) (Table 3.1). Rating scores range from “extremely less important” or least preferred (1/9) to “extremely more important” or most preferred (9). An “equally important” or preferred comparison is rated at 1 and intermediate values are rated between 1 and 1/9 and 1 and 9.

Table 3.1: The continuous rating scale of the Analytic Hierarchy Process (Saaty 1977)

1/9	1/7	1/5	1/3	1	3	5	7	9
extremely	very strongly	strongly	moderately	equally	moderately	strongly	very strongly	extremely
less important					more important			

The rating of one criterion versus another with respect to the overall objective is recorded and reasons for decisions are noted. Pair-wise comparisons of criteria must be repeated as selected for each level in a hierarchy of decisions.

Table 3.2 provides an example of a pair-wise comparison of n biodiversity indicator criteria ($C_1... C_n$). Only values for the lower-half of the matrix are scored (in bold) as the upper-half of the matrix represents the reciprocal value.

In the AHP, priority weights for each criterion are derived by taking the principal eigenvector of a square reciprocal matrix of the pair-wise comparisons (Saaty 1980). This value is approximated by calculating the average weights for each column in a normalized matrix. All matrix calculations were done in Microsoft Excel.

Table 3.2: A $n \times n$ matrix (M) according to the Analytic Hierarchy Process with pair-wise ranking of criteria (C) as indicators of biodiversity integrity (M= $n \times n$ for C_n criteria)

	C_1	C_2	C_3	...	C_n
C_1	w_1/w_1	w_1/w_2	w_1/w_3	...	w_1/w_n
C_2	w_2/w_1	w_2/w_2	w_2/w_3	...	w_2/w_n
C_3	w_3/w_1	w_3/w_2	w_3/w_3	...	w_3/w_n
⋮	⋮	⋮	⋮	⋮	⋮
C_n	w_n/w_1	w_n/w_2	w_n/w_3	...	w_n/w_n

(b) Ranking of land use alternatives with respect to indicators

The next step is to rank land use alternatives with respect to each indicator criterion in a series of pair-wise comparisons. For n criteria and A land use alternatives, a pair-wise matrix comprising the ranking of all alternatives for a specific indicator criterion is given in Table 3.3. The continuous rating scale according to Saaty (1977) as depicted in Table 3.1 is again applied to rank A_n land use alternatives with respect to each biodiversity indicator criterion. Also, assuming the positive reciprocal properties are valid and that the matrix is cardinally consistent, the weightings for each land use alternative with respect to each of the criteria (a_1 to a_n) can be derived from the column entries of the normalized matrix (Table 3.3).

(c) Final ranking of land uses

Finally, the overall priority (OP_r) or the relative weightings of land uses with respect to their impacts on biodiversity integrity can be determined as described in Table 3.4. The overall priority (OP) for each land use is obtained from the sum of the product of each priority weight for the impacts of the land use on each indicator criterion (Table 3.3) and the relative weight for the specific indicator criterion (Table 3.2).

As many decision-making situations involve preferential selection among a finite set of alternatives, the AHP allows for the ranking and prioritization of alternatives on the basis of numerical scores. Accordingly, pair-wise comparisons are made among all land use alternatives (at a lower level) with respect to each indicator element in the level above. The final ranking of alternatives and a priority value for each is obtained at the lowest level in the hierarchy.

The AHP approach, therefore, explicitly recognizes and incorporates the knowledge and expertise of the participants in the priority setting process by using their subjective judgements and allows for the integration of objectively measured information, as it becomes available (e.g. quantitative values for criteria).

(d) Consistency of scores

The degree of consistency that has been applied in pair-wise comparisons that have been used to obtain the ratings in the AHP can be evaluated by calculating the consistency index (CI) (Saaty 1977; Eastman 2003). Judgement of consistency can be checked by calculating the consistency ratio (CR) of the CI.

Table 3.3: A $n \times n$ matrix (M) according to the Analytic Hierarchy Process with pairwise ranking of the impacts of land use alternatives (A) on a specific indicator of biodiversity integrity (M= $n \times n$ for A_n land uses)

	A_1	A_2	A_3	...	A_n
A_1	a_1/a_1	a_1/a_2	a_1/a_3	...	a_1/a_n
A_2	a_2/a_1	a_2/a_2	a_2/a_3	...	a_2/a_n
A_3	a_3/a_1	a_3/a_2	a_3/a_3	...	a_3/a_n
.
.
.
A_n	a_n/a_1	a_n/a_2	a_n/a_3	...	a_n/a_n

Table 3.4: Final ranking to determine overall priority weights (OP_r) for land use alternatives

$$\begin{aligned}
 OP_1 &= a_{11}(w_1) + a_{21}(w_2) + a_{31}(w_3) + \dots + a_{n1}(w_n) \\
 OP_2 &= a_{12}(w_1) + a_{22}(w_2) + a_{32}(w_3) + \dots + a_{n2}(w_n) \\
 OP_3 &= a_{13}(w_1) + a_{23}(w_2) + a_{33}(w_3) + \dots + a_{n3}(w_n) \\
 &\vdots \\
 &\vdots \\
 &\vdots \\
 OP_r &= a_{1r}(w_1) + a_{2r}(w_2) + a_{3r}(w_3) + \dots + a_{nr}(w_n)
 \end{aligned}$$

For a matrix ($A=n \times n$) the CI is determined by using the dominant eigenvalue follows:

$$CI = \frac{(\text{dominant eigenvalue}) - n}{n - 1}$$

If $CI = 0$ then A is consistent;

If $CI \neq 0$ then calculate CR;

$$CR = CI/RI_n;$$

If $CR = CI/RI_n \leq 0.10$ then A is consistent enough;

If $CR = CI/RI_n > 0.10$ then A is seriously inconsistent.

The random index RI_n is based on the size of a matrix and the average value of the CI for randomly chosen entries in A and is given by:

n	2	3	4	5	6	7	8	9	10
RI	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Dominant eigenvalues of matrices were calculated using Poptools for Microsoft Excel. Matrices in which the ratios applicable to pair-wise comparison scores given for the first column are applied to all remaining columns of the matrix will be inherently consistent ($CI = 0$).

An evaluation of the consistency of scoring was conducted for all matrices. Only consistent matrices were accepted. The sources of inconsistency in unacceptable matrices were examined and participants were requested to re-evaluate their scores, if required.

CHAPTER 4

IMPACT OF LAND USE ON BIODIVERSITY OF THE MISTBELT GRASSLAND

4.1. Introduction

4.1.1. Selection of the study area

The selection of the Mistbelt Grassland of KwaZulu-Natal as a study area for the evaluation of the impacts of land use on biodiversity integrity, in accordance with the objectives given in Section 1.3, is motivated primarily by the extent of the transformation and the conservation status of this vegetation type.

(a) Extent of transformation

The Mistbelt Grassland is recognized as being one of the most highly transformed vegetation types in KwaZulu-Natal. A comparison of the status of land use on eleven sites in this vegetation type that were all grassland in the 1940s with that in the 1980s, indicated that 82% had been converted to timber plantations, while 9% were cultivated and only 9% remained untransformed (O'Connor *et al.* 2003). Subsequent land-cover information indicates that the transformation status of the Mistbelt Grassland has increased from 56.0% in 1995 to 62.7% in 2000 and that the area that is considered degraded (but not transformed) also increased from 3.6% to 5.9% during this period (EKZNW 2005) (refer to Table 4.1). The 2000 land-cover information indicates that the Mistbelt Grassland is the sixth most transformed vegetation type in KwaZulu-Natal and that its contribution to transformed land in the Province was 16.8%, the largest for all vegetation types.

(b) Conservation status

Land-cover information indicates that although the target for conservation of the Mistbelt Grassland is 23.0%, only 0.62% or 3685.2ha was formally protected in KwaZulu-Natal in 2000 (EKZNW 2005) (refer to Table 4.1). Due to the transformation status and lack of formal protection, the Mistbelt Grassland has accordingly been rated as a priority for urgent conservation attention (Goodman 2000a).

Table 4.1: Transformation and conservation status of the Mistbelt Grassland (Midlands Mistbelt Grassland) in KwaZulu-Natal according to 2000 land-cover information (EKZNW 2005)

STATUS IN 2000	AREA (ha)	PERCENTAGE
Protected (formally)	3685.2	0.623 (target = 23%)
Degraded	34793.9	5.878
Transformed	370966.0	62.670
TOTAL	591931.0	100.000

4.1.2. Description of study area

(a) Location and climate

The Mistbelt Grassland in KwaZulu-Natal occurs along the escarpment from Ixopo in the south to Greytown in the north (Figure 4.1). For the purposes of this study the location of this vegetation type will be as described for the Moist Midlands Mistbelt by Camp (1997). Altitude ranges from 900m to 1400m and the topography is described as being generally hilly. The soils of the Mistbelt Grassland are characterized by yellow or red apedal subsoils with topsoils high in

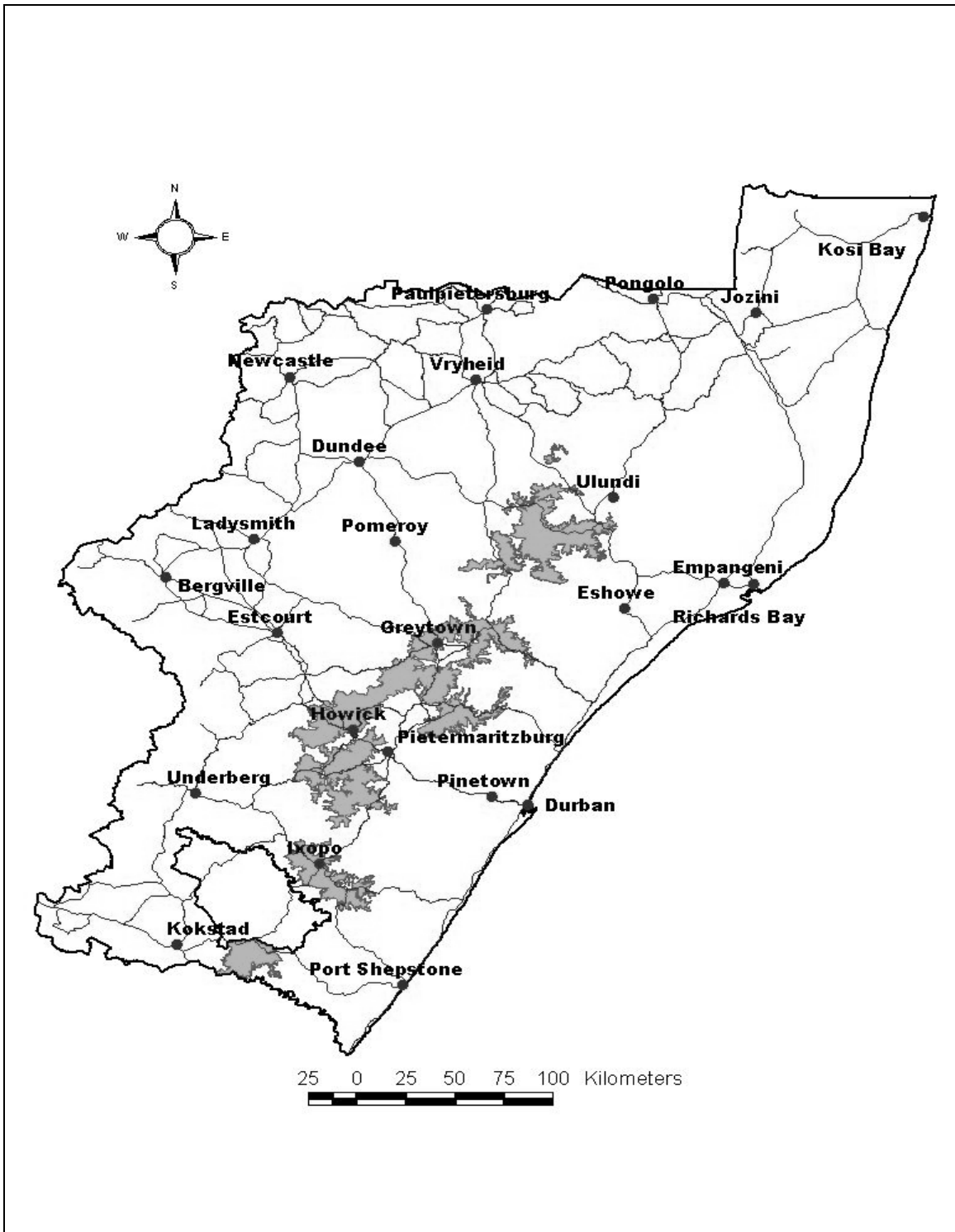


Figure 4.1: Map of the Mistbelt Grassland of KwaZulu-Natal (Camp 1997).

organic matter and free-draining (Low and Rebelo 1996). These soils are described as dystrophic due to the high rainfall.

The climate of the Mistbelt Grassland is temperate but humid and temperatures vary between -2°C and 38°C with a mean annual temperature of 17°C (Camp 1997). The annual rainfall ranges from 800 mm to 1280 mm, mist from moist easterly winds is common during the summer, droughts are uncommon and usually of short duration, hail occurs occasionally and frost varies from light to severe. As warm north-westerly (“berg”) winds during spring and early summer may be followed by sudden cold temperatures or cold fronts, weather conditions are considered to be unpredictable.

(b) Vegetation

The Mistbelt Grassland has been described as the Natal Mistbelt Ngongoni Veld (Veld Type 45) by Acocks (1975) and the Short Mistbelt Grassland of the Grassland Biome (Vegetation Type 47) by Low and Rebelo (1996).

According to Camp (1997) few relic areas of the former *Themeda triandra* grassland vegetation remain in the Mistbelt Grassland. Together with the dominant *Themeda triandra*, this grassland is today dominated by species such as *Tristachya leucothrix*, *Trachypogon spicatus*, *Eragrostis capensis*, *Eragrostis racemosa* and *Monocymbium ceresiiforme*.

Poor management practices, including excessive burning, particularly during the season of active grass growth and continuous selective overgrazing, have largely destroyed the palatable grasses and resulted in grassland of low pastoral value (Camp 1997). Hardy pioneer grasses such as *Aristida junciformis*, *Eragrostis plana*, *Sporobolus africanus* and *Hyparrhenia hirta* have replaced the palatable grasses.

Mixed *Podocarpus* forests are a feature of the Mistbelt Grassland (Camp 1997). These forests occur mainly on the cooler, south-facing aspects of the escarpment which are moist and protected from frost and fire. Camp (1997) explains that a feature of these forests is that there are abrupt margins where fire has destroyed the ecotone, or that the forest margin may consist of rank grasses, shrubs and young trees.

4.2. Evaluation

4.2.1. General approach

The general approach to the evaluation of impacts of land use on the biodiversity integrity of the Mistbelt Grassland is described in Section 3.1.

4.2.2. Workshops

For this evaluation, a group of biodiversity experts (Appendix A1) participated in a series of workshops at which the Analytic Hierarchy Process (AHP) was applied (Appendix B). Participants selected for workshops are all recognised experts who have experience in the evaluation and management of land use impacts on biodiversity. The AHP was explained in detail at each workshop and a simple example of its application was discussed. Where workshop time was limited, further interviews were held with participants to complete the scoring. For each pair-wise comparison, as much emphasis was placed on the reasons for decisions as the decisions themselves and the rationale for each score was noted.

(a) Pilot workshops

A series of three pilot workshops were held and their objectives were as follows (Appendix B1):

- To establish a workshop procedure for the evaluation of impacts of land use on landscape biodiversity in the Mistbelt Grassland; and
- To undertake a preliminary evaluation of the impacts of land use on landscape composition, function and structure using a group decision-making exercise that employs the AHP.

(b) Formal workshop

The procedure established at the pilot workshops was applied to a formal workshop (Appendix B2). At this workshop, impacts of land use on all three components of landscape biodiversity were examined. A detailed workshop information document was prepared to provide the necessary background information on the study. This document provided an introduction to the relevant theory, the evaluation procedure employed at the pilot workshops and the results obtained.

Due to time constraints at the formal workshop, only indicators for biodiversity integrity (for landscape composition, structure and function) were ranked during the proceedings. Personal interviews were conducted with participants after the workshop to conclude the ranking of land uses with respect to each indicator.

4.2.3. Land uses selected

The following land use categories were selected for the Mistbelt Grassland:

- Livestock ranching;
- Conservation;
- Timber plantations;
- Croplands;
- Rural settlements; and
- Urban settlements.

(i) Livestock ranching

For the purposes of this evaluation, “livestock ranching” refers to the farming of domestic livestock on uncultivated indigenous vegetation and cultivated pastures. Land used for private conservancies, private game farms and rural settlements in tribal areas were included in this category. Livestock ranching therefore includes extensive farms that are under private tenure and used for the production of meat and other animal products. Farming of domestic stock is based mainly on indigenous grassland so that it may be supplemented by winter feed derived from planted dryland pastures of species such as *Eragrostis curvula*, *Digitaria eriantha* and *Chloris virgata*.

(ii) Conservation

“Conservation” refers to areas that are formally conserved, national, provincial, and municipal reserves whose declared function is biodiversity conservation or similar. Private nature reserves are excluded from this category because their objectives in terms of biodiversity management are usually driven by economic

demands and accordingly differ from formally conserved areas. Lakes and other bodies of water administered by the Department of Water Affairs and Forestry were included in this category.

Conservation areas offer a benchmark for the measurement of impacts on biodiversity and it is assumed that they are well managed. These areas are, however, generally not pristine and most areas were previously livestock ranches and the infrastructure of dams and roads are usually maintained.

As formal conservation constitutes less than 1% of the area of the Mistbelt Grassland (EKZNW 2005), it was considered to be insignificant as a land use category at the formal workshop and was excluded from the evaluation.

(iii) Timber plantations

“Timber plantations” refers to the cultivation of alien timber varieties in plantations for the purposes of commercial afforestation. *Pinus* spp., *Eucalyptus* spp. and *Acacia* spp. (wattle) are common varieties. Empirical studies indicate that commercial afforestation has a major impact on the biodiversity of many areas in South Africa (Pott 1997). In KwaZulu-Natal, approximately 7% of the land area or 20% of the total transformed area is under plantations (Armstrong *et al.* 1998). Almost all of the timber estates were established on former livestock ranches, from which they have inherited some of their infrastructure such as dams. The extent to which grassland has been transformed to timber, depends on the limitations due to the presence of wetlands, riparian or rocky areas and steep slopes.

(iv) Croplands

“Croplands” refer to cultivated agricultural land planted with dryland and irrigated crops (summer and winter varieties) such as maize and wheat and sugar cane for commercial production purposes. Areas planted in the Mistbelt Grassland with sugar cane are extensive and they comprise approximately 8% of the land-cover (DAEA 2001).

Although the Mistbelt Grassland has a high rainfall, irrigation of crops is common during drier months and fertilizers, pesticides and herbicides are frequently applied. The rates of fertilization will depend on the crop type, whether it is irrigated or not, and the soil type. Herbicides are routinely used for the control of broadleaved weeds, while pesticides are commonly used in crops like potatoes.

The limits to cultivation vary to some extent and depend on the crop type. Most annual crops have similar constraints in terms of slope and soil depth, but sugar cane is planted on steeper slopes because it is a perennial crop. Wetlands should be exempt from cropping, but in reality many croplands have, in accordance with historical agricultural policies, been extended into wetlands, which have been drained as required. Most dryland crops, especially maize, will have stover of high nutritional value that is available for livestock in winter.

Irrigated areas are usually cultivated throughout the year and generally raise two crops per annum. Irrigated crops are therefore more intensively managed in terms of fertilizers, herbicides and insecticides and provide a higher yield per hectare than dryland crops.

(v) Rural settlements

“Rural” or “communal” settlements were included in livestock ranching for the pilot workshops, but treated as a separate category for the formal workshop. This category typically consists of areas of human settlement, croplands and extensive rangelands, as well as infrastructure to support the communities. A common settlement pattern is a core housing area with near urban densities and a decreasing density of households towards the periphery. There are often extensive pathways as a result of the movement of people and domestic animals between houses and kraals and adjoining settlements. Although communal rangelands tend to support a greater richness of stock than commercial enterprises, stocking rates are usually much higher and formal management systems, such as rotational grazing systems, are absent.

(vi) Urban settlements

“Urban settlements” refer to formal and less formal residential areas, as well as commercial and industrial land uses. Settlements in the urban and peri-urban fringe are included and rural settlements in tribal areas are excluded.

All urban settlements can be characterized by some degree of industrial activity, a centralized business and retail district, formal residential areas, in most cases poorly serviced informal residential areas and supporting infrastructure (transport, services). In addition there is a peri-urban fringe that consists mainly of smallholdings or cottage or less formal industries.

4.2.4. Land uses omitted

Land use categories were selected so that they account for the greatest proportion of land cover area of the Mistbelt Grassland (DAEA 2001). Land uses related to infrastructure such as roads, railways, powerlines and communications networks in rural areas were excluded from the evaluation.

4.2.5. Biodiversity indicators selected

In a hierarchical approach, Noss (1990) recognizes composition, function and structure as the three primary attributes or components for the regional landscape, community-ecosystem, population-species and genetic organizational levels of biodiversity. Indicator variables for assessing the impacts of land uses at the regional landscape level were identified for each component of biodiversity. The indicators used at workshops are summarized in Table 4.2.

Although indicators of the integrity of landscape biodiversity were chosen so as to minimize potential confounding, especially among the three components (composition, function and structure), it is realized that the components of biodiversity are related and that confounding will never be completely eliminated. It is also noted that indicators of biodiversity integrity at one organizational level may provide an indication of the integrity of another level or levels. For example, an indicator such as the status of a particular species (population-species level) may provide an indication of biodiversity integrity at the community-ecosystem and regional landscape levels.

Table 4.2: List of indicators selected for assessing the impact of land use on biodiversity integrity of the Mistbelt Grassland (Appendix B)

LANDSCAPE COMONENT	INDICATORS SELECTED AT WORKSHOPS	
	Pilot workshops	Formal workshop
Composition	<ol style="list-style-type: none"> 1. Forest integrity 2. Grassland integrity 3. Wetland integrity 4. Riparian integrity 5. Integrity of indigenous fauna 	<ol style="list-style-type: none"> 1. Forest integrity 2. Grassland integrity 3. Wetland integrity 4. Riparian integrity 5. Integrity of indigenous fauna
Function	<ol style="list-style-type: none"> 1. Natural disturbance processes 2. Geomorphic processes 3. Nutrient cycling 4. Hydrological processes 5. Reproductive processes 	<ol style="list-style-type: none"> 1. Natural disturbance processes 2. Geomorphic processes 3. Nutrient leakage 4. Hydrological processes 5. Extinction rate
Structure	<ol style="list-style-type: none"> 1. Grassland transformation 2. Grassland fragmentation 3. Grassland physiognomy 	<ol style="list-style-type: none"> 1. Grassland transformation 2. Grassland fragmentation 3. Grassland physiognomy 4. Loss of heterogeneity

(a) Landscape composition

“Landscape composition” refers primarily to the natural asset in terms of habitats and species and their characteristics as related to types, distribution and richness or endemism are important (Noss 1990).

The following indicators for the integrity of landscape composition were selected at workshops (Table 4.2):

- Forest integrity;
- Grassland integrity;
- Wetland integrity;
- Riparian integrity; and
- Integrity of indigenous fauna.

(i) Forest integrity

Forests are a very important component of the Mistbelt Grassland and occur mainly on the south-facing aspects of hills and mountains where there is more moisture and protection from fire. While the contribution of forests to the conservation of water resources is recognized, they have been heavily exploited in the past and species such as *Podocarpus* spp. have been extensively used for building and furniture material. Camp (1997) explains that the main threat to forests exists from extensions to timber plantations.

(ii) Grassland integrity

Grassland is the main vegetation component of the Mistbelt Grassland and has been extensively transformed (EKZNW 2005; Goodman 2000a, 2003; O'Connor *et al.* 2003). Loss of the arable component of grassland has primarily been due to cultivation (crops including sugar cane) and afforestation (timber plantations). Remaining grasslands are commonly used for grazing, but have been severely affected by impacts of indiscriminate burning and overgrazing due to poor management practices (Camp 1997). These practices have destroyed many palatable grass species and resulted in grassland of largely low pastoral value.

(iii) Wetland integrity

Due to the high rainfall, wetlands are common in the Mistbelt Grassland. "Wetlands" are defined as areas with a high water table, hygrophilous plants, impeded drainage, anaerobic conditions for at least part of the year and soils shaped by water based processes. Important hydrological functions, such as

water storage, flood attenuation, water quality enhancement and groundwater recharge (Cowan 1996; Goodman 2000a) are performed by wetlands. The maintenance of wetland integrity is therefore important for the conservation of water resources.

(iv) *Riparian integrity*

In this evaluation, wetlands have been scored separately from non-wetland riparian areas. Riparian habitat is characterized by regular flooding, but with well drained soils and can be recognized by the plant communities present that directly express the soil water conditions and soil depth, with a distinct loss of grassland species. Legislative controls regarding impacts on riparian and wetland areas by the timber industry and the fact that these areas are now excluded from planting has been considered in this study.

Streams and rivers are common throughout the Mistbelt Grassland and are considered to be an important source of water, especially for the lower lying and drier areas to the east of the escarpment (Camp 1997).

(v) *Indigenous fauna*

The status of indigenous fauna as related to the integrity and maintenance of the total species complement was considered to be a priority and the essence of this indicator. An increase in the relative abundance of one or more species at the expense of the representation of another species due to the impact of land use is interpreted as being a compromise to biodiversity integrity.

The Mistbelt Grassland is a prime habitat for a number of Red Data species. These include mammals such as Dobson's rough-haired golden mole and birds such as the blue swallow, wattled crane and blue crane (Goodman 2000a).

(b) Landscape function

The functioning of a landscape is primarily related to the movement of energy, water, minerals and nutrients and species and assemblages of species across the various combinations of its structural features. Processes that are common to both natural and transformed landscapes, (e.g. hydrological functioning) and processes that depend on the nature of transformation, (such as fire and grazing regimes) are described under ecosystem functioning (Noss 1990).

The following indicators for the integrity of landscape function were selected at workshops (Table 4.2):

- Natural disturbance processes;
- Geomorphic processes;
- Nutrient cycling;
- Hydrological processes;
- Reproductive processes; and
- Extinction rate.

(i) Natural disturbance processes

For the purposes of this study "natural disturbance processes" relate to the fire and grazing regimes. Fire is considered to be the single most important ecological factor that determines the presence and extent of the grassland biome in South Africa (O'Connor and Bredenkamp 1997). Although the biota of the biome are well adapted to repeated fires, community organization and ecosystem

functioning are markedly influenced by a variation in the fire regime (Mentis and Tainton 1984). Changes to the natural fire regime, due to the livestock grazing practices and cropping, have resulted in the transformation of grasslands such as the Mistbelt Grassland. The result has been a mosaic of grassland patches and other covers, the size and configuration of which is expected to further influence the natural fire regime.

Grazing by large mammalian herbivores is considered to be a key process in the maintenance of grasslands of South Africa (Downing 1978). Indigenous mammalian herbivores have been replaced by domestic livestock, usually at higher stocking densities and with entirely different grazing preferences and regimes, resulting in the degradation of vegetation. Livestock have, however, maintained grazing as an essential ecological process.

(ii) *Geomorphic processes*

Soil erosion and sedimentation are geomorphic processes considered in this assessment. Although soil erosion and sedimentation are natural processes in a landscape and heavily dependent on climate, they can be influenced considerably by land use. Disturbance processes associated with land use frequently result in accelerated rates of soil erosion and deposition (Forman and Godron 1986). Accelerated soil erosion and donga formation is frequent in high rainfall areas such as the Mistbelt Grassland, where poor management of topsoil has occurred.

(iii) *Nutrient leakage*

Many production systems in ecosystems are directly or indirectly influenced by the amount of flow of nutrients and the manner in which the natural nutrient cycle

occurs. Nutrient leakage may occur due to increased runoff, soil erosion, fertilization, industrial pollution, animal waste product flows and ineffective sanitation. Phosphorus is lost mainly through the loss of soil. Nutrient leakage or the loss of nutrients is globally recognized as being one of the most serious threats to the maintenance of ecosystem functioning and biodiversity (Dalton and Brand-Hardy 2003).

The nutrient status of the soils of the Mistbelt Grassland are considered to be inherently very low as they are highly leached (Camp 1997). Accordingly, disturbance processes due to land use that has a negative impact on water quality may contribute to further imbalances in the nutrient status of soils.

(iv) Hydrological processes

Important hydrological processes considered in this study were the status of surface and groundwater and their importance in the maintenance of biodiversity integrity. Hydrological functioning is characterized by the quantity, quality and seasonality of water flowing through a system per annum and relates to that expected under pristine conditions. The expected nutrient status of an aquatic system is a reflection of the regional geology and climate; water from pristine catchments in moist environments such as the Mistbelt Grassland is expected to be clear and nutrient poor. Biota of this system is therefore adapted to dystrophic conditions.

The perturbation of water quality or quantity or the seasonality of flow can have an impact on the biodiversity integrity of a landscape. Both increases and decreases in water flow can have a negative impact on aquatic systems and changes to the seasonality of flow can change concentrations of nutrients or pollutants in a system.

Although hydrological function is related to annual rainfall and its dilution effect, land use alternatives can influence water quality and quantity. For example, the abstraction of water for irrigation or the addition of agricultural chemicals can influence water quality and quantity in the hydrological cycle. Increases in water flow will also result from land uses associated with an increase in hardened surfaces. Increased runoff and less soil storage will also have a negative impact on the biodiversity status of a landscape.

(v) *Reproductive processes*

Pollination and seed dispersal are considered to be important reproductive processes and impacts of land use on them were considered in this evaluation. The persistence of biodiversity integrity is dependent on the maintenance of appropriate processes of pollination and seed dispersal to ensure the continued status of keystone species. Land use practices that disrupt essential genetic flows within a landscape due to spatial changes and a loss of connectivity, reduce the competitive edge of these species and will therefore have a negative impact on biodiversity.

(vi) *Extinction rate (local extinction)*

At the formal workshop it was decided to replace “reproductive processes” as an indicator of the integrity of landscape function with “rate of extinction”. As the Mistbelt Grassland is under severe threat due to transformation, the rate of extinction was considered a more appropriate indicator of landscape function.

The dynamic balance between extinction and recolonization on the one hand and the rate of extinction or recolonization on the other is recognized as an important indicator of the health of ecosystem functioning (Noss 1990). The understanding

of ecosystem responses to the loss of plant species is considered to be essential for the optimal management of grasslands (Schlapfer, Pfisterer and Schmid 2005). The loss of species and the reduction of species diversity have been linked to negative influences on ecosystem processes such as primary production and nutrient cycling.

Biodiversity integrity is therefore compromised by land use impacts that result in a loss of species diversity and the flow of key species from a landscape due to disturbance or transformation.

(c) Landscape structure

“Landscape structure” is described by the extent, nature and arrangement of the transformed natural asset and is considered to be of fundamental importance in the persistence of biodiversity. “Landscape structure” emphasizes spatial relationships among the distinct elements of its ecosystems and describes the distribution of energy, materials, species and populations in relation to numbers, kinds, sizes, shapes and configurations of these (Noss 1990).

Landscape structure and its relationship to biodiversity has been well documented in literature. Patch size and shape, corridors and connectivity, heterogeneity and perimeter to area ratio are recognized as being important structural features of landscapes that control the composition and abundance of species (Forman and Godron 1986; Noss 1990).

The following indicators for the integrity of landscape structure were selected at workshops (Table 4.2):

- Grassland transformation;
- Grassland fragmentation;
- Grassland physiognomy; and

- Grassland heterogeneity.

(i) Grassland transformation

In this study, “grassland transformation” relates to the extent of transformation of the natural asset in the landscape. Typically, changes in species, their numbers and distribution patterns within ecosystems due to the impacts of land use have been recorded.

Transformation of the Mistbelt Grassland due to poor management of agricultural practices has been extensive. Camp (1997) explains that excessive burning followed by heavy overgrazing has, for example resulted in the large scale replacement of the historically dominant *Themeda triandra* grassland with less palatable hardy pioneer species such as *Aristida junciformis* (Ngongoni grass) , *Eragrostis plana*, *Sporobolus africanus* and *Hyparrhenia hirta*.

The loss of the natural grassland asset of the Mistbelt Grassland due to land use has been dramatic and Goodman (2000a) indicates that over 70% of the natural vegetation has been transformed. Transformation has been to mainly timber (39% of land cover), croplands (11% of land cover) and sugar cane (8% of land cover) (DAEA 2001).

(ii) Grassland fragmentation

For this study, “fragmentation” has been assessed in terms of the configuration of the natural asset of the landscape that remains after transformation. Fragmentation is described in terms of the size and configuration of patches and corridors in a landscape matrix (Forman and Godron 1986). Connectivity is

described by the extent of physical connection and porosity of the potential flow within the patches or corridors.

The generally hilly, rolling topography of the Mistbelt Grassland has resulted in grassland communities that are naturally more fragmented and have lower connectivity than the open grasslands of, for example, the central Free State. The extensive transformation of vegetation due to land use practices such as timber, crop and sugar cane production in the Mistbelt Grassland has dramatically increased natural fragmentation. Accordingly, connectivity and porosity in this vegetation type have been further reduced and the integrity of biodiversity compromised.

(iii) *Grassland physiognomy*

“Grassland physiognomy” refers to the spatial and seasonal variation in height, density and cover of grassland in the landscape. Natural grassland is characterized by seasonal changes in its physiognomic characteristics due to natural disturbance processes such as the fire and grazing regimes. The assessment of physiognomy relied mainly on the extent of the permanent change in the vertical dimension, rather than seasonal and cover changes in the grassland.

(iv) *Grassland heterogeneity*

Grassland heterogeneity was included at the formal workshop (Table 4.2) as an indicator of the integrity of landscape structure in the Mistbelt Grassland. “Heterogeneity” of a landscape refers to the amount of contrast in the spatial arrangement and distribution of elements such as species, populations, patches, corridors, matrix and energy. With moderate disturbance, heterogeneity

increases and the flows of energy and biomass across boundaries separating the patches, corridors and the matrix of a landscape increase (Forman and Godron 1986). Although moderate disturbances may establish more patches and corridors in a landscape, increasingly severe disturbance will result in the loss of the naturally occurring contrast in the spatial arrangement of the elements of a pristine landscape, the loss of structural heterogeneity and the loss of integrity of biodiversity. It is this loss of naturally occurring spatial heterogeneity that is associated with the transformation of landscapes and is therefore proposed as a measure of the loss of biodiversity integrity.

Landscape heterogeneity strongly influences processes or organisms that depend on multiple patches and the interaction among these patches as for example, controlled by the flow of water, air or disturbance (Chapin *et al.* 1998). The maintenance of landscape heterogeneity is considered to be essential for the provision of habitat that ensures a continued species richness. It has been demonstrated that the simplification of habitat diversity has an adverse affect on reptile diversity and that the maintenance of habitat heterogeneity may maintain high reptile diversity by providing a large number of different niches (Fischer, Lindenmayer and Cowling 2004).

Changes in butterfly assemblages have been associated with changes in vegetation structure following selective logging which resulted in a decrease in habitat heterogeneity and a change in shade and open gaps in tropical forests (Hamer *et al.* 2003). The maintenance of habitat heterogeneity through retention of undisturbed areas of vegetation within production areas is considered to be the key to ensuring the conservation of biodiversity.

4.2.6. The Analytic Hierarchy Process

The general approach for application of the AHP as described in Section 3.4 is used in an evaluation of the impacts of land use on the biodiversity integrity of the Mistbelt Grassland.

(a) Ranking of indicators

The relative importance of individual indicators of the integrity of the compositional, functional and structural components of biodiversity for the Mistbelt Grassland was examined in this exercise (Section 4.2.5; Table 4.2). Indicators were described in detail to workshop participants and any points of uncertainty were clarified. Elements or processes were rated in pair-wise comparisons, the basic question being what the relative importance of one element or process was with respect to another as an indicator of biodiversity integrity for the Mistbelt Grassland. Scoring was according to the continuous rating scale of the AHP.

Individual scores of participants were examined and extreme scores debated. Geometric means of the participants' scores were taken as the workshop score. Relative weights for indicators of the compositional, functional and structural components of biodiversity were then calculated from the row sums of the normalized matrix.

(b) Ranking of land uses with respect to indicators

The next step was to rank land uses with respect to impacts on each indicator of biodiversity integrity for the Mistbelt Grassland. Land uses selected for the workshops are described in Section 4.2.3.

In this exercise, pair-wise comparisons were made of the relative impact of two land uses with respect to a specific indicator of the integrity of the compositional or structural or functional components of biodiversity. Individual scores of participants were recorded and extreme values were debated. The geometric mean of participants' scores for each comparison was recorded as the workshop score and used to produce a normalized matrix for the calculation of the relative weights for land uses with respect to impacts on each indicator.

(c) Consistency of scores

The degree of consistency of scoring for all pair-wise comparisons was calculated in accordance with the method described in Section 3.4.2. Only matrices that were consistent were accepted (i.e. for a matrix $A = nxn$; if $CR = CI/RI_n \leq 0.10$). Scores for inconsistent matrices were examined by participants and amended as required.

(d) Final ranking of land uses

The final step in the AHP was to calculate overall relative weights for the land uses with respect to their impact on biodiversity integrity (objective for the exercise). Overall weights for land use categories with respect to impacts on the integrity of biodiversity composition, function and structure were calculated from

the weights for land use impacts on each indicator and the weights were calculated for each indicator (Section 3.4.2).

Ranking of the compositional, functional and structural components then provided an overall indication of the relative impact of land use on landscape biodiversity.

4.3. Results

4.3.1. Pilot workshops

Table 4.3: Weights for indicators of the integrity of landscape composition, structure and function for the Mistbelt Grassland (pilot workshops) (Appendix B1)

COMPONENT	INDICATOR	Level 1	Level 2
Composition		0.111	
	Forest integrity		0.116
	Grassland integrity		0.347
	Wetland integrity		0.231
	Riparian integrity		0.204
	Faunal integrity		0.103
Function		0.333	
	Disturbance processes		0.190
	Geomorphic processes		0.069
	Nutrient leakage		0.380
	Hydrological processes		0.265
	Reproductive processes		0.095
Structure		0.556	
	Transformation		0.600
	Fragmentation		0.200
	Physiognomy		0.200

Table 4.4: Weights for the impact of land use on the indicators of landscape composition, function and structure for the Mistbelt Grassland (pilot workshops) (Appendix B1)

COMPONENT	INDICATOR	LAND USE				
		Livestock	Conservation	Timber	Crops	Urban
Biodiversity integrity		0.061	0.031	0.275	0.192	0.441
Landscape composition		0.052	0.030	0.318	0.193	0.408
	Forest integrity	0.052	0.029	0.267	0.161	0.491
	Grassland integrity	0.049	0.029	0.383	0.231	0.307
	Wetland integrity	0.053	0.030	0.271	0.152	0.494
	Riparian integrity	0.052	0.030	0.285	0.203	0.430
	Faunal integrity	0.057	0.032	0.324	0.175	0.412
Landscape function		0.070	0.031	0.285	0.195	0.419
	Disturbance processes	0.055	0.029	0.219	0.267	0.432
	Geomorphic processes	0.115	0.038	0.086	0.288	0.473
	Nutrient leakage	0.079	0.031	0.320	0.150	0.421
	Hydrological processes	0.057	0.030	0.331	0.184	0.398
	Reproductive processes	0.069	0.029	0.298	0.198	0.406
Landscape structure		0.057	0.032	0.261	0.190	0.460
	Transformation	0.059	0.032	0.281	0.177	0.451
	Fragmentation	0.055	0.033	0.235	0.235	0.442
	Physiognomy	0.053	0.031	0.228	0.181	0.507

Table 4.5: Weights for the impact of land use on the overall biodiversity integrity for the Mistbelt Grassland (pilot workshops) (Appendix B1)

	COMPONENT:	Composition	Function	Structure	
	WEIGHT:	0.111	0.333	0.556	WEIGHT
LAND USE:	Livestock	0.052	0.070	0.057	0.061
	Conservation	0.030	0.031	0.032	0.031
	Timber	0.318	0.285	0.261	0.275
	Crops	0.193	0.195	0.190	0.192
	Urban	0.408	0.419	0.460	0.441

4.3.2. Formal workshop

Table 4.6: Weights for indicators of the integrity of landscape composition, structure and function for the Mistbelt Grassland (formal workshop) (Appendix B2)

COMPONENT	INDICATOR	Level 1	Level 2
Composition		0.111	
	Forest integrity		0.118
	Grassland integrity		0.558
	Wetland integrity		0.246
	Riparian integrity		0.040
	Faunal integrity		0.039
Function		0.333	
	Disturbance processes		0.271
	Geomorphic processes		0.061
	Nutrient leakage		0.267
	Hydrological processes		0.269
	Extinction rate		0.131
Structure		0.556	
	Transformation		0.355
	Fragmentation		0.260
	Physiognomy		0.165
	Heterogeneity		0.219

Table 4.7: Weights for the impact of land use on the indicators of landscape composition, function and structure for the Mistbelt Grassland (formal workshop) (Appendix B2)

COMPONENT	INDICATOR	LAND USE					
		Livestock	Timber	Crops	Pasture	Rural	Urban
Biodiversity integrity		0.032	0.232	0.189	0.129	0.106	0.313
Landscape composition		0.033	0.183	0.167	0.087	0.131	0.399
	Forest integrity	0.052	0.191	0.073	0.056	0.285	0.342
	Grassland integrity	0.025	0.198	0.197	0.085	0.073	0.422
	Wetland integrity	0.038	0.147	0.155	0.110	0.178	0.372
	Riparian integrity	0.051	0.134	0.127	0.082	0.152	0.454
	Faunal integrity	0.032	0.211	0.147	0.070	0.183	0.357
Landscape function		0.037	0.235	0.178	0.101	0.112	0.337
	Disturbance processes	0.035	0.256	0.169	0.103	0.076	0.360
	Geomorphic processes	0.059	0.175	0.203	0.086	0.197	0.280
	Nutrient leakage	0.036	0.204	0.227	0.110	0.098	0.327
	Hydrologic processes	0.033	0.262	0.139	0.089	0.145	0.331
	Extinction rate	0.039	0.231	0.165	0.113	0.107	0.345
Landscape structure		0.029	0.240	0.199	0.153	0.097	0.281
	Transformation	0.028	0.232	0.219	0.150	0.106	0.264
	Fragmentation	0.028	0.224	0.183	0.164	0.091	0.310
	Physiognomy	0.031	0.292	0.199	0.107	0.109	0.263
	Heterogeneity	0.030	0.232	0.186	0.181	0.082	0.289

Table 4.8: Weights for the impact of land use on the overall biodiversity integrity for the Mistbelt Grassland (formal workshop) (Appendix B2)

	COMPONENT:	Composition	Function	Structure	
	WEIGHT:	0.111	0.333	0.556	WEIGHT
LAND USE:	Livestock	0.033	0.037	0.029	0.032
	Timber	0.183	0.235	0.240	0.232
	Crops	0.167	0.178	0.199	0.189
	Pasture	0.087	0.101	0.153	0.129
	Rural	0.131	0.112	0.097	0.106
	Urban	0.399	0.337	0.281	0.313

4.4. Discussion

This discussion includes comments made by workshop participants during the evaluation process (Section 4.2; Appendix A1).

4.4.1. Relations among indicators

The three components of biodiversity, namely landscape composition, structure and function were ranked in terms of their relative importance to overall biodiversity integrity at the landscape level. Results indicate that landscape structure is of primary importance (Table 4.3; Table 4.6). Concerning transforming landscapes, the dynamics of transformation describe the manner in which transformation will continue. It is the structural component of the landscape that will determine the long-term viability of the remaining natural asset and the manner in which functional and compositional elements and processes will continue effectively. Persistence of original biota will depend on

the ability of ecosystem functions to continue in the transformed landscape and therefore ecosystem functioning is rated higher than landscape composition.

(a) Landscape structure

The relative contribution of transformation, fragmentation and physiognomy to landscape structure is determined by conditional relations (Table 4.3; Table 4.6). The relative weights recorded at both the pilot and formal workshops indicate that transformation is more important as an indicator of biodiversity integrity than fragmentation or physiognomy. This is to be expected, as changes to fragmentation and physiognomy will not occur without transformation. “Fragmentation” refers to the quantity of natural asset that remains after transformation. At the formal workshop, heterogeneity was ranked higher than physiognomy but lower than fragmentation. Therefore, changes in heterogeneity in a landscape are considered less to be important than its transformation or fragmentation.

(b) Landscape function

The results from both the pilot workshops and formal workshop indicate that natural disturbance processes (such as fire and grazing), nutrient cycling and hydrological processes dominate landscape functioning (Table 4.3; Table 4.6). Although results from the pilot workshop ranked hydrological function slightly more important than natural disturbance processes, at the formal workshop it was considered equally important to disturbance processes and nutrient cycling. Geomorphic and reproductive processes, together with extinction rates were ranked lowest.

The results indicate that nutrient leakage, impacts on the nutrient status of the Mistbelt Grassland and the maintenance of hydrological processes are considered to be critical for biodiversity integrity. Nutrient imbalances (loading or loss) are commonly associated with a number of land use activities and have the potential to disrupt ecosystem functioning in natural communities. Although the impacts of point sources such as feedlots were not considered for the Mistbelt Grassland, activities such as cropping (e.g. sugar cane) and the grazing of livestock on pastures are common and contribute to nutrient loading and imbalances in the soil nutrient status. The disruption of the nutrient cycle in timber production commonly occurs due to the negative impact that this land use has on the hydrological status of soil. A reduction in groundwater will disrupt nutrient availability and have an impact on ecosystem functioning in over-utilized catchments.

At the formal workshop, hydrological functioning was considered to be equally important as disturbance processes and as nutrient leakage. The contribution of hydrological functioning to the maintenance of biodiversity in the Mistbelt Grassland as a high rainfall grassland, was considered to be critical. The status of wetlands and riparian areas is influenced by the hydrological status of their soil and the surrounding land use. Water quality is influenced by a reduction in quantity and changes to the seasonality of flow and increased eutrophication may influence aquatic biota. Land uses such as timber production and the growing of sugar cane limit surface runoff and use large quantities of groundwater, therefore having a negative impact on catchments along the escarpment of the Mistbelt Grassland. These catchments are the source of numerous east-flowing rivers.

Natural disturbance processes are also considered to be important indicators of the integrity of ecosystem function (Table 4.3; Table 4.6). Fire and grazing are natural disturbance processes that are considered to be essential for the maintenance of grasslands. In the Mistbelt Grassland, the natural incidence of

fire due to lightning and other causes has been severely restricted by transformation of grassland and uncontrolled, indiscriminate and un-seasonal burning is common.

As geomorphic processes are essentially long-term processes, they were scored as being the least important and were considered at the pilot workshop to be only marginally more important than reproductive processes. Impacts on nutrient cycling and hydrological processes can give a more direct indication of the integrity of ecosystem functioning than geomorphic processes can, and may have to be qualified in terms of impacts on nutrient status or water retention by soil.

At workshops, extinction rates and impacts on reproductive processes were considered to be the least important. Limited empirical information is available on extinction or recolonization rates, and these measures are associated with processes occurring over extended periods of time and are difficult to quantify. Although the persistence of biodiversity integrity is dependent on reproductive processes and these should therefore be considered, they are more difficult to quantify than the other indicators for ecosystem functioning.

(c) Landscape composition

The priority habitat as an indicator of biodiversity integrity for the Mistbelt Grassland is that of the grassland component (Table 4.3; Table 4.6). This is due to the extent of grassland within this vegetation type and its species richness. The integrity of wetlands was considered to be the second most important indicator, while the status of forest, riparian areas and indigenous fauna were not considered to be as important in terms of their biodiversity asset, as grasslands were.

Wetlands, forest and riparian areas cover a considerably smaller area than grasslands and although the integrity of riparian areas and wetlands are important for hydrological functioning, these areas were perceived as being considerably less important for the maintenance of overall composition integrity than grasslands were.

The status of indigenous fauna was also considered to be less important than that of the habitat components. The biodiversity integrity of habitats are more readily measurable and are of prime importance for the maintenance of the status of faunal species. Due to the extensive transformation of the Mistbelt Grassland, limited numbers of important indicator species such as the oribi, blue swallow and others remain. Specialized habitat requirements and the inability to adapt to transformed landscapes exclude the use of these species as important indicators of the integrity of biodiversity composition.

4.4.2. Impact of land uses on biodiversity

(a) Ranking of land uses

The relative impact of land use on landscape structure (Figure 4.2; Figure 4.3; Table 4.4; Table 4.7), landscape functioning (Figure 4.4; Figure 4.5; Table 4.4; Table 4.7) and landscape composition (Figure 4.6; Figure 4.7; Table 4.4; Table 4.7) is relatively consistent and provides an overall statement of the extent of impact on biodiversity integrity for the Mistbelt Grassland as summarized in Figure 4.8 and Figure 4.9.

The profile for impacts of land uses on the integrity of the structural, functional and compositional components of landscape biodiversity was consistent with respect to conservation, livestock ranching, croplands, timber plantations and urban development (Figure 4.2; Figure 4.3; Figure 4.4; Figure 4.5; Figure 4.6;

Figure 4.7). Conservation was associated with the lowest impact and livestock ranching, croplands, timber plantations and urban developments with a progressive increase in impacts on biodiversity integrity. The trends for cultivation of pastures and rural developments indicated that rural developments are associated with a greater impact on landscape composition and function, but a lower impact on landscape structure than pastures are.

Although an increase in impacts on all indicators of the integrity of landscape structure, function and composition occurred from conservation to livestock ranching, croplands, timber plantations and urban developments, trends are not easily discernable.

(b) Profile of individual land uses

Land uses selected ranged from and represented activities associated with relatively untransformed natural assets, such as conserved areas, to completely transformed areas such as those associated with urban development.

(i) Urban development

Urban development was ranked as having a very high (extremely negative) impact on biodiversity integrity in all evaluations for all three landscape components (Table 4.5; Table 4.8; Figure 4.8; Figure 4.9). This land use is associated with a near complete transformation with only fragments of the natural landscape asset remaining. Landscape functioning is also severely affected and natural disturbance processes such as fire and grazing regimes, while geomorphic processes, nutrient leakage and hydrological processes are completely disrupted. Urban developments are also associated with extreme

loss of compositional elements and impacts on all habitats were rated as being very high (Table 4.4; Table 4.7).

(ii) *Timber plantations*

The impact of timber plantations on the overall biodiversity integrity of the Mistbelt Grassland was rated second highest and was surpassed only by the impact of urban development (Figure 4.8; Figure 4.9). Timber plantations are associated with extreme transformation, fragmentation and physiognomic change of the natural asset of the landscape (Armstrong *et al.* 1998). Major disruptions of natural disturbance processes such as fire and grazing occur as these are completely excluded. Rankings for landscape function indicate that hydrologic processes, such as surface and groundwater status and the nutrient status of soils, are also severely affected.

(iii) *Croplands*

Relative impact of crops on landscape biodiversity integrity was ranked lower than timber but higher than pastures or rural developments or livestock ranching (Figure 4.8; Figure 4.9). Croplands are, as timber is, associated with transformation and fragmentation of structural elements in the landscape. Natural disturbance processes such as fire and grazing regimes are totally disrupted by croplands and the impact of this land use on nutrient leakage was rated at the formal workshop as being very high.

Impacts of croplands on grassland habitat were ranked highest, while the impact on forest was rated low (Table 4.4; Table 4.7). The grassland component is the largest habitat in the Mistbelt Grassland and generally has topography and soils

that are well suited for cultivation. Forest is the smallest component, largely inaccessible and seldom transformed to croplands.

(iv) Pasture

The relative impact of cultivated pasture on biodiversity integrity was evaluated only at the formal workshop (Figure 4.9). While the overall impact of pasture was ranked lower than croplands, it was scored higher than rural developments or livestock ranching. Impacts on heterogeneity and fragmentation as structural components of the landscape and wetland habitat were rated high for pasture (Table 4.7).

(v) Rural developments

Rural developments were rated higher than livestock ranching, but lower than cultivated pasture (Figure 4.9). Impacts on forest habitat and geomorphic and hydrologic processes as indicators of landscape functioning were rated high for rural developments (Table 4.7). These impacts are related to the nature of agricultural activities, such as grazing and croplands, and the unregulated use of water resources associated with these settlements.

(vi) Livestock ranching

With the exception of formal conservation, grazing by domestic livestock (commercial enterprise) was rated as having the lowest overall impact on landscape biodiversity integrity in the Mistbelt Grassland (Figure 4.8; Figure 4.9). The most significant impact associated with livestock ranching is that on

geomorphic processes and includes accelerated soil erosion, trampling and pathway formation (Table 4.4; Table 4.7).

(vii) Conservation

Formal conservation, as expected, was rated as having the lowest impact on biodiversity integrity in the Mistbelt Grassland and relative weights for landscape structure, function and composition were all very low (Table 4.4; Figure 4.8).

4.4.3. Recommendations for land uses

(a) Formal conservation

Formal conservation of the Mistbelt Grassland is obviously the most beneficial land use and essential for the maintenance of biodiversity integrity. With only 0.623 % of the Mistbelt Grassland currently protected and a target of 23 % for formal protection (EKZNW 2005), there is a critical need for the establishment of additional conservation areas. A protected area network that includes all habitat types (grassland, forest, wetlands and riparian areas) will be essential to ensure the conservation of all biodiversity components.

(b) Livestock ranching

Livestock ranching is a land use that can facilitate the maintenance of grassland biodiversity integrity in the Mistbelt Grassland. The effectiveness of this will be determined by correct management, the type of livestock and the grazing regime applied. Intervention strategies include combining domestic stock with different

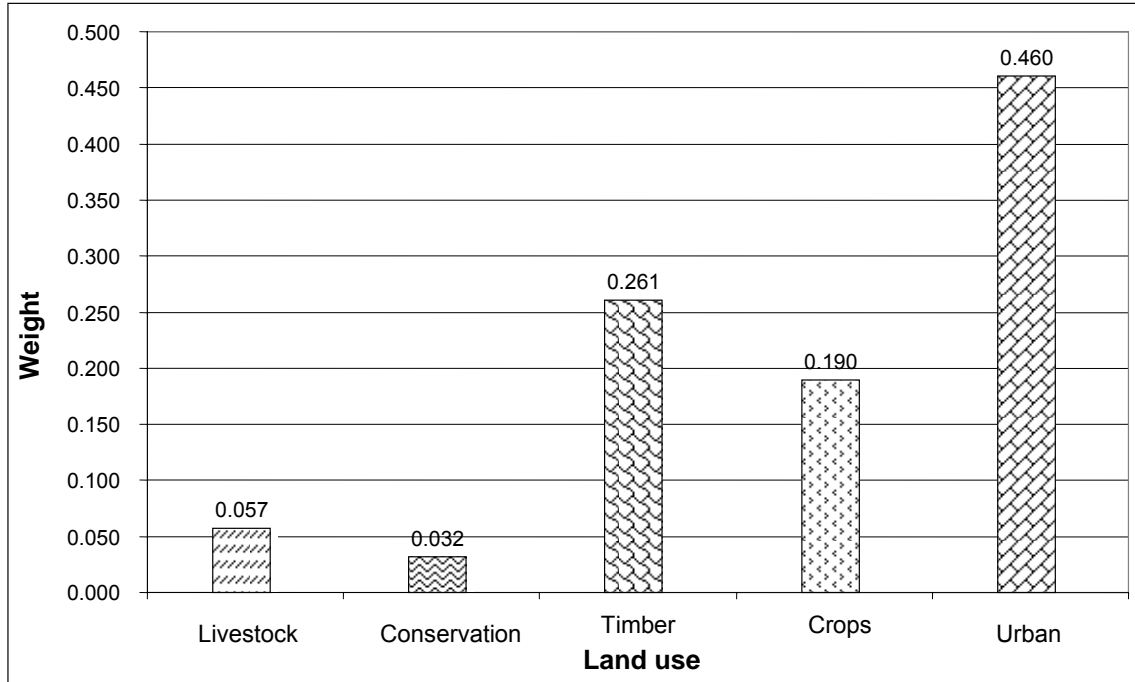


Figure 4.2: Relative impact of land use on landscape structure in the Mistbelt Grassland (pilot workshop).

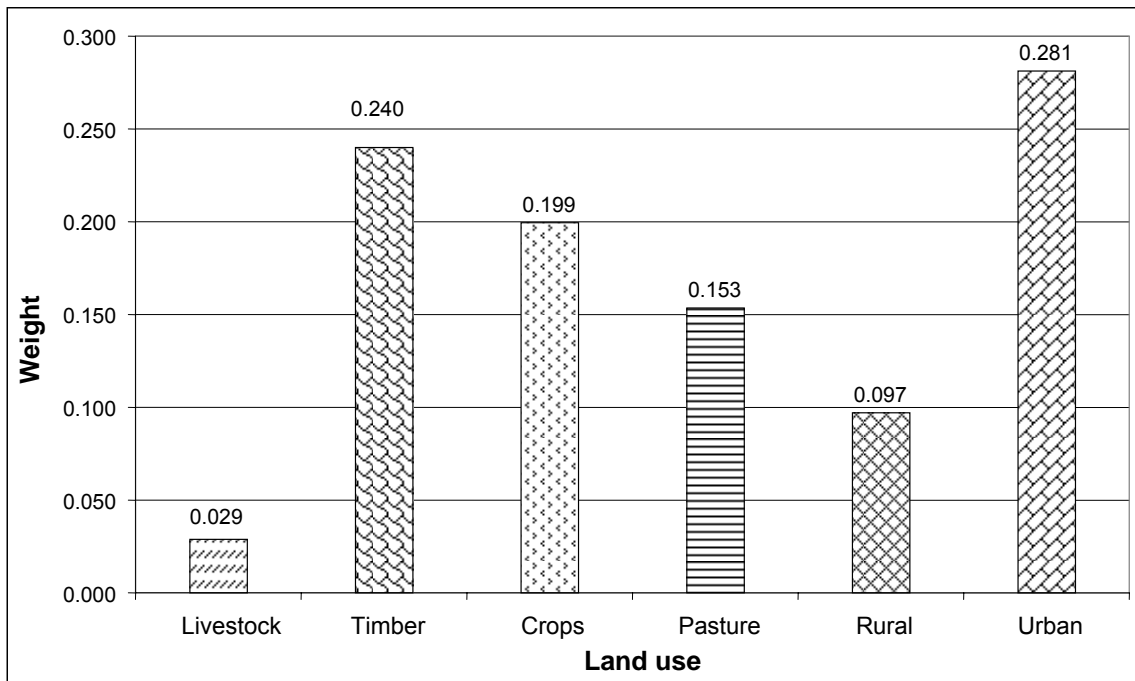


Figure 4.3: Relative impact of land use on landscape structure in the Mistbelt Grassland (formal workshop).

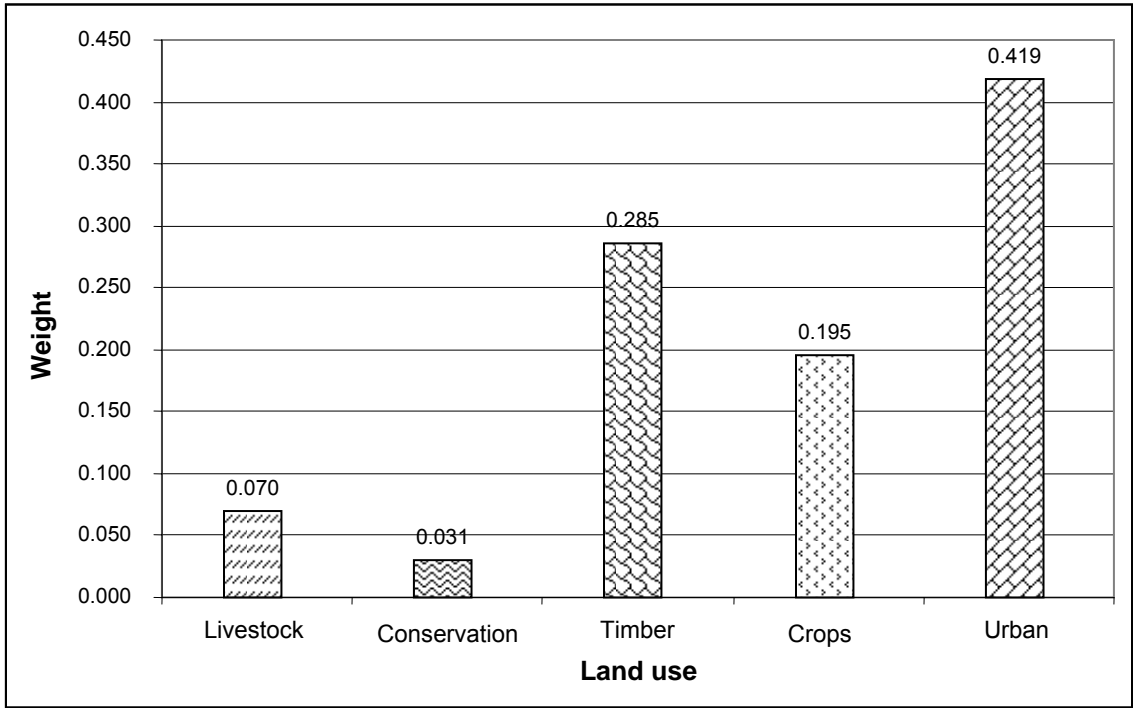


Figure 4.4: Relative impact of land use on landscape function in the Mistbelt Grassland (pilot workshop).

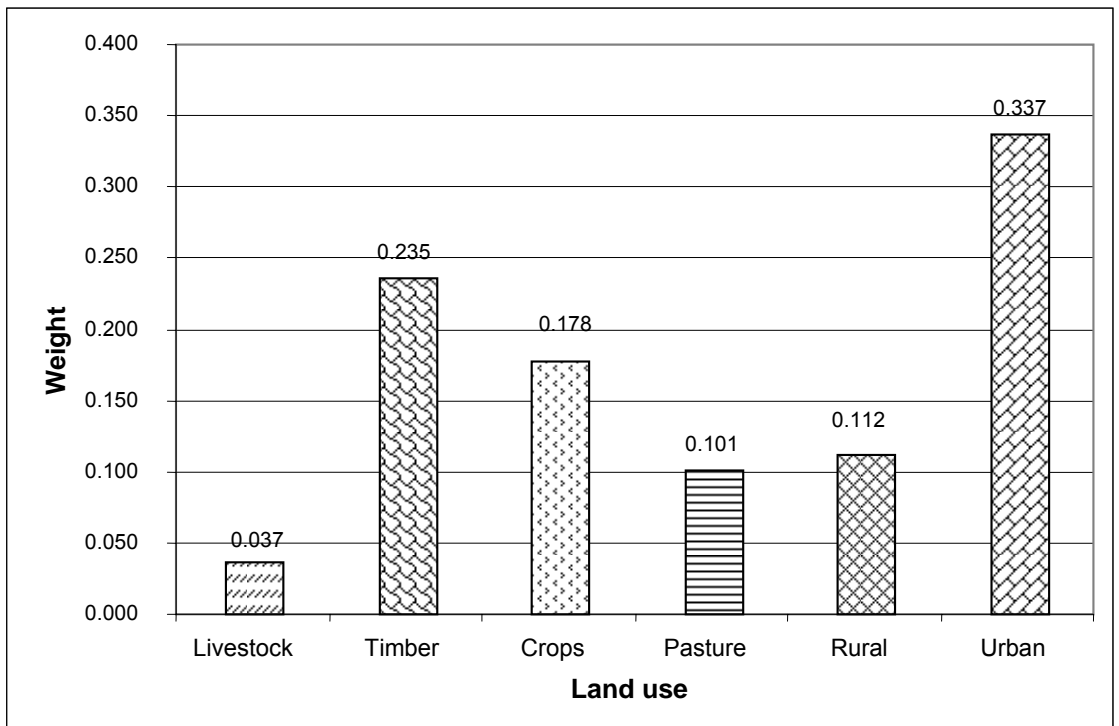


Figure 4.5: Relative impact of land use on landscape function in the Mistbelt Grassland (formal workshop).

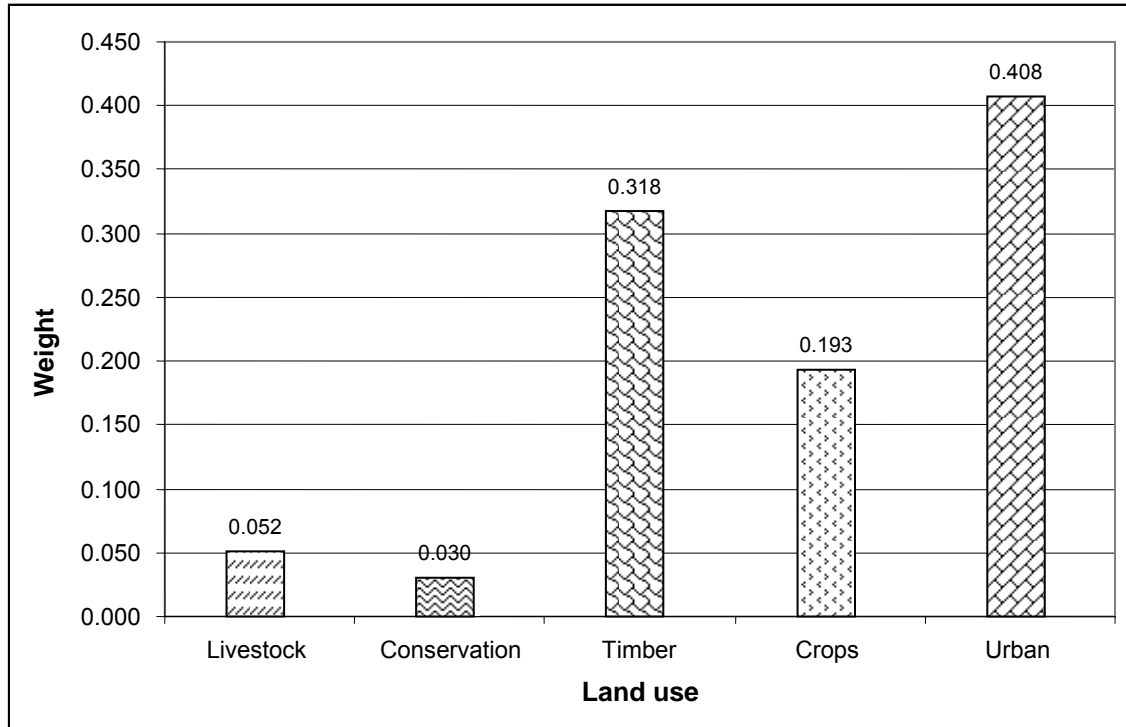


Figure 4.6: Relative impact of land use on landscape composition in the Mistbelt Grassland (pilot workshop).

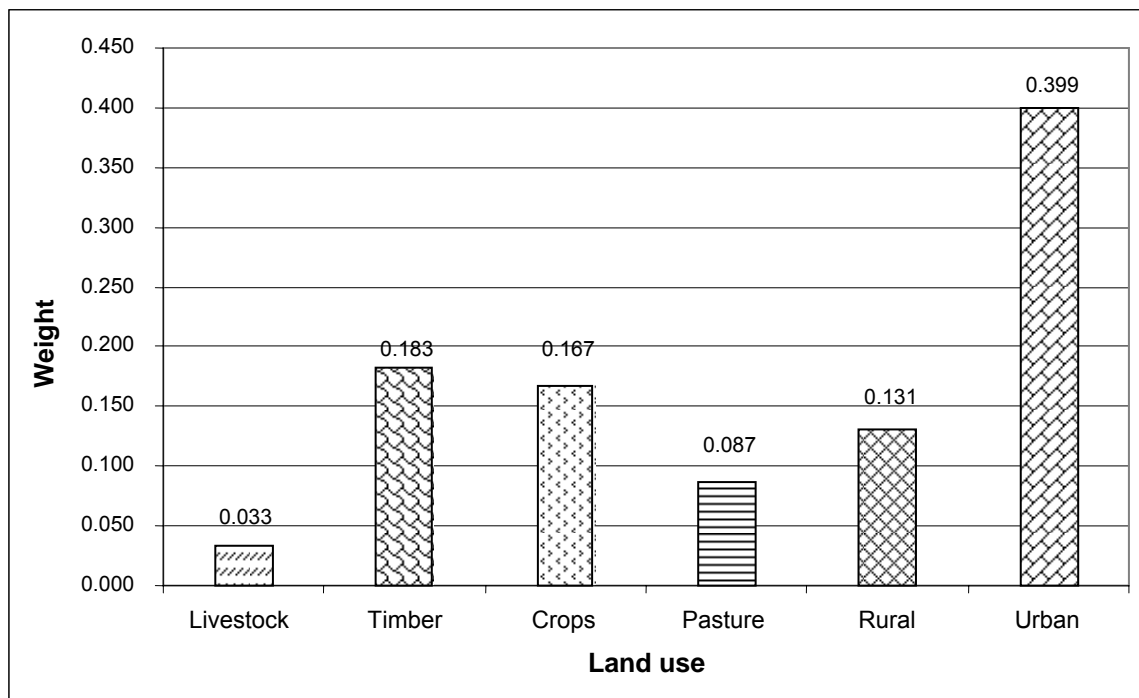


Figure 4.7: Relative impact of land use on landscape composition in the Mistbelt Grassland (formal workshop).

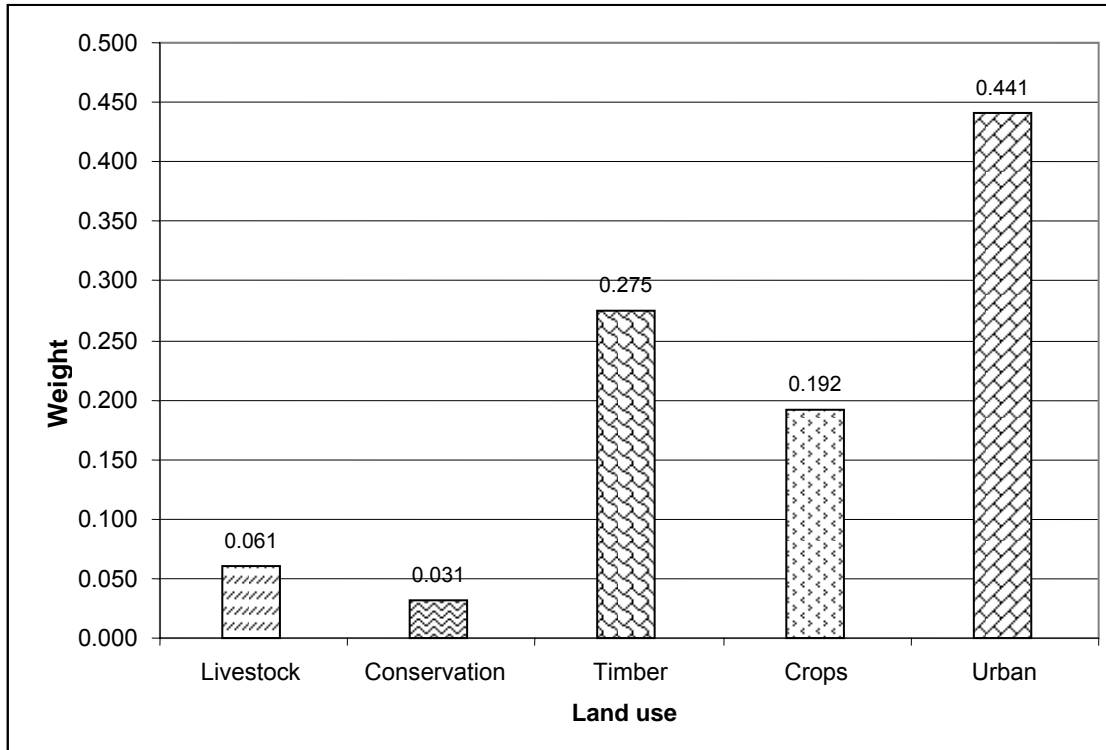


Figure 4.8: Relative impact of land use on overall biodiversity integrity of the Mistbelt Grassland (pilot workshops).

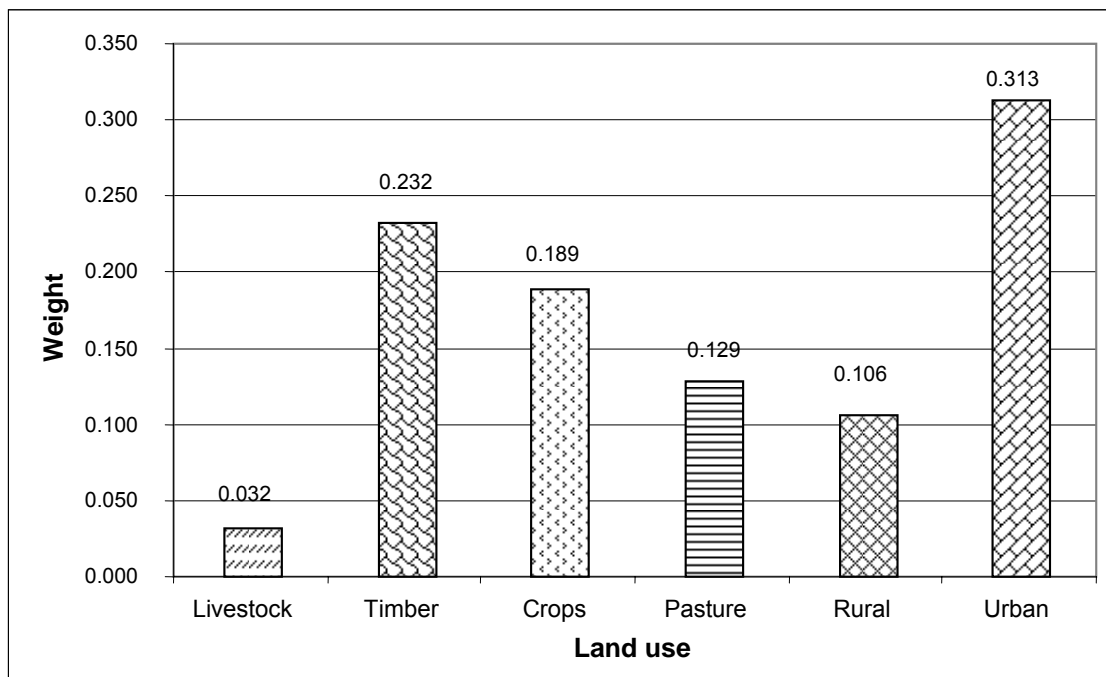


Figure 4.9: Relative impact of land use on overall biodiversity integrity of the Mistbelt Grassland (formal workshop).

grazing or browsing preferences, integrating domestic stock with game ranching and a grazing regime that has the minimum impact on ecosystem function (especially the reproductive processes of plants).

(c) Rural settlements

This land use, as it occurs in the Mistbelt Grassland, contributes very little to the maintenance of biodiversity and many practices associated with it need to change. Key interventions may include the regulation of the harvesting of medicinal plants, hunting by humans and pets, cropping, impacts of livestock (specifically related to stocking densities) and adequate soil conservation measures.

(d) Cultivated pastures

Although pastures present a limited opportunity for intervention and improvement of biodiversity integrity, the frequency of cultivation and the species sown in the pastures are important. Interventions may include the establishment of long-lived pastures or the sowing of species such as *Eragrostis* to encourage colonization by other indigenous grasses and greater species richness in pastures (O'Connor 2005).

(e) Croplands

Loss of grassland to croplands in the Mistbelt Grassland has been extensive and interventions are essential to facilitate the maintenance of biodiversity. Although the transformation of virgin ground to crops is important to ensure adequate food production and the type of crop planted is largely determined by factors driven by

the market, the spatial orientation of croplands to ensure adequate essential linkages and corridors is critical for the maintenance of the landscape's structural integrity. Methods to limit fragmentation are essential where transformation results in the establishment of a monoculture. Although key issues about cropping are whether it is irrigated or not, and whether dryland crops are associated with less intensive cultivation and a reduced impact on biodiversity, nevertheless it may be argued that irrigated crops have a greater yield per hectare and will result in less transformation of natural vegetation per ton of harvest.

(f) Timber plantations

Timber production is associated with extensive transformation and fragmentation of the landscape, severe impacts on ecosystem functioning (specifically nutrient leakage and hydrological functioning) and habitat loss. Potential for the mitigation of impacts associated with timber production is, however, limited and should be directed at the maintenance of biodiversity integrity in the macro-landscape. The impacts of timber plantations must be minimized through the limitation of access infrastructure by planting only on areas that can be properly accessed, limitation of impacts during felling, control of soil erosion, control of alien herbaceous and woody plants after felling and finally, the prevention of the burning of slash.

In the macro-landscape context, plantations should be established so that adequate undisturbed areas are allowed between plantations and corridors are provided for ecological linkages. To limit soil erosion, planting should be restricted in areas that are steep and topographically problematic. Marginal rainfall areas should also be avoided to prevent impacts on the hydrological status of catchments. Environmental impact assessments for the establishment

of new timber plantations must accordingly consider impacts on the biodiversity integrity of the greater landscape.

(g) Urban developments

Virtually a complete loss of biodiversity integrity of the landscape is associated with urban developments and there are limited opportunities for intervention. The most critical factor with urban developments is, as with croplands and timber plantations, the arrangement of the “footprint”. Expansion should be limited to areas that are the least important to biodiversity integrity and it is essential that there is maintenance of corridors of undisturbed areas to ensure adequate ecological linkages in the macro-landscape. Rather than encouraging low density development, the trend should be for regulations that ensure an increase in density and more open space systems that would allow for natural asset linkages of adequate proportions to reduce the barriers formed by urban environments.

Appropriate vehicles to address the maintenance of biodiversity in urban areas are provided through the environmental management plans in the Land Use Management Framework that must inform the Integrated Development Plans of municipalities (Kahn *et al.* 2001).

CHAPTER 5

IMPACT OF LAND USE ON BIODIVERSITY OF THE MOIST SUB-BIOME OF THE GRASSLAND BIOME

5.1. Introduction

5.1.1. Selection of the study area

The selection of the Grassland Biome as a study area is motivated by the need to examine the application of the methodology employed for the evaluation of land use impacts on biodiversity integrity at the vegetation-type level in the Mistbelt Grassland (Chapter 4), to a broader biome level.

Grasslands are used for a multitude of purposes, some of which contribute to the erosion of biodiversity integrity more than others. Although many negative impacts of land uses are well known, little information on their relative impact or benefit for conservation of biodiversity is available. This evaluation was restricted to the moist sub-biome of the Grassland Biome because many biodiversity experts on this component were available to participate in it. This study contributed towards an analysis of the impact of land uses on biodiversity integrity in the Grassland Biome that was undertaken for the National Grasslands Initiative of the South African National Biodiversity Institute (O'Connor and Kuyler 2005).

(a) Conservation status of grasslands

Despite the fact that the Grassland Biome contains a very high level of biodiversity and a number of unique biodiversity features, only approximately 2%

of the biome has been formally protected (DACEL 2003). A number of smaller endemic antelope, nearly half of the endemic mammal species and third of the South African butterfly species that are threatened with extinction (half of which are endemic) occur in the Grassland Biome (DACEL 2003). In addition, this biome contains 10 of the 14 globally threatened bird species found in South Africa (Lombard 1995).

The Grassland Biome is one of the most threatened biomes in Southern Africa (Scholes and Biggs 2005) and almost 60% is irreversibly transformed (DACEL 2003). Transformation of the natural vegetation of the biome is mainly due to agricultural activities and timber production. It is estimated that approximately 23% of the Grassland Biome is currently under cultivation, with virtually the entire remaining area being used as rangeland for domestic livestock (Fairbanks *et al.* 2000). Although grasslands provide essential ecosystem services necessary for economic development, the Grassland Biome also supports a large human population and resource demands have serious environmental implications that threaten its biodiversity integrity (DACEL 2003).

5.1.2. Description of the study area

(a) Location and vegetation

An overview of the location and characteristics of the Grassland Biome and its component vegetation types is presented by Low and Rebelo (1996). The Grassland Biome occurs mainly on the high central plateau of South Africa, and the inland areas of KwaZulu-Natal and the Eastern Cape. The topography is generally flat and rolling, but includes the escarpment. Altitude varies from near sea level to approximately 2 850 m.

Grasslands in this biome are dominated by a single layer of grasses and their cover is dependent on rainfall and grazing. Frost, fire and grazing are responsible for the maintenance of the dominance of grass and prevention of the establishment of trees (DACEL 2003). Trees, may, however dominate in localized areas that are protected from frost and fire.

Two categories of grasses, namely sweet and sour grasses occur in the Grassland Biome. Sweet grasses have a low fibre content, are palatable and nutritious during the winter. Sour grasses occur in areas with higher rainfall (above 625 mm), on more acidic soils and are less palatable than sweet grasses.

(b) Sub-biomes

The Grassland Biome is the most important area in which crops are grown in South Africa and other important agricultural activities include forestry, dairy production, grazing by livestock and game and urbanization (DACEL 2003). The biome varies considerably across its breath in terms of patterns of land use and supported diversity, and is therefore divided into the following three sub-biomes on the basis of climatic potential for land use (Low and Rebelo 1996):

- (a) A *moist sub-biome* receiving 900 mm or more rainfall per annum in which both afforestation and cropping are possible (along the eastern escarpment from Mpumalanga through to the Eastern Cape and the midlands of KwaZulu-Natal).
- (b) A *mesic sub-biome* receiving between approximately 650 and 900 mm of rainfall per annum, in which cropping but not commercial afforestation is feasible. The main part of the highveld, from Pretoria south to Winburg and from Bethlehem and Harrismith west to Lichtenburg, forms this sub-biome.

- (c) *A relatively semi-arid sub-biome* receiving less than about 650 mm rainfall per annum on average, situated mainly in the southern and western Free State.

5.2. Evaluation

5.2.1. General approach

The general approach to the evaluation of land use impacts on the biodiversity integrity of the moist sub-biome of the Grassland Biome is as described in Section 3.1 and as applied for the Mistbelt Grassland study (Section 4.2).

5.2.2. Interviews

Due to time constraints and the limited availability of biodiversity experts to attend a formal workshop at short notice, personal interviews with participants were conducted for this study. A total of 43 experts were consulted (Appendix A 2). Participants selected for interviews are all recognised experts on the indicators or categories of indicators used in the evaluation and have practical experience in the management of land use impacts on biodiversity.

5.2.3. Land uses selected

Land uses selected for the Mistbelt Grassland (Section 4.2.3) were expanded and more categories added for Grassland Biome evaluation. Categories were selected so that they included dominant ones and those that might offer some

benefit to biodiversity conservation. The following land use categories were selected for the moist sub-biome of the Grassland Biome:

- Conservation estate;
- Recreation;
- Rural settlement;
- Commercial ranching;
- Dairy;
- Dryland cropping;
- Irrigated cropping;
- Game Farming;
- Plantation forestry; and
- Urban and peri-urban settlement.

(a) Conservation estate

“Conservation estate”, as described for the Mistbelt Grassland study (Section 4.2.3), refers to areas that are national, provincial, and municipal reserves whose declared function is biodiversity conservation or similar. Formal conservation areas within the Grassland Biome occupy a very small percentage of its surface area, especially if the uKhahlamba Drakensberg National Park is excluded. Private nature reserves would be part of this set provided their objective is similar. Conservation areas offer a benchmark for most indicators of biodiversity and it is assumed that they are well managed.

Conservation areas are not pristine. Almost all such areas in the grassland biome were previously livestock ranches and the infrastructure of dams and the like are usually maintained. Stocking rates are usually benign by comparison with livestock ranches and game farms, although selective grazers (e.g. black wildebeest, blesbok) exercise area-selective grazing. The main transformation that takes place is related to the provision of accommodation for visitors.

(b) Livestock ranching

“Livestock ranching” refers to extensive farms under private tenure, used for producing meat and other animal products for commercial markets as described for the Mistbelt Grassland study (Section 4.2.3). Farming with domestic stock is based mainly on indigenous grassland supplemented by winter feed. Some operations grow crops for silage. Livestock ranching can vary in accordance with the animal types farmed, which in almost all cases are cattle or sheep or a combination thereof.

The impact of livestock ranching is dependent on the nature of its management. Although livestock producers may invest considerable effort in rotational grazing systems, management of the stocking rate usually has an overriding effect on vegetation change (O'Reagain and Turner 1992) and rest afforded during flowering seasons is very important. Fire management, especially in relation to grazing is considered to be critical.

(c) Game farming

Game farming has shown a consistent increase as a commercial farming activity across the Grassland Biome over the past two decades, although it is better developed in semi-arid grasslands than in the moist sub-biome. It has been developed mainly on previous livestock ranches and game farms support comparable infrastructure, although most internal fences are removed. Game farming differs from conservation property in that it is a production activity, with concomitantly higher stocking rates and it supports a profile of herbivores or wildlife that is selected according to economic demands.

Although game farming is usually based on herbivores indigenous to South Africa, many of the farms carry wildlife species that would not have historically occurred in the area. For example, most game farms in the moist areas of KwaZulu-Natal stock large herds of blesbok and zebra. The grazing impact of selective grazers such as blesbok and wildbeest can be severe (Scotcher 1982).

Although based on indigenous grassland, most game farms in moist sub-biome will maintain planted pastures for winter feed owing to the poor nutritional quality of grassland during this period. As with livestock ranching, variation in management can have a conspicuous effect. Because of the area-selective grazing habits of wildlife and the lack of internal fences, management of fire is more critical on game farms than on livestock ranches.

(d) Tourism and recreation

The provision of tourist and recreational facilities is a growing industry within the sub-biome and it occurs in many different forms:

- Trout farms for recreational angling are especially important in the southern Dakensberg and the KwaZulu-Natal midlands. This land use usually results in increased damming of rivers;
- Water bodies of almost any size invariably attract a host of recreational activities, centred on fishing and boating;
- “Eco-estates” and “golfing estates” are increasing in their applications for permission to be established. These involve the construction of housing units allied with maintaining a proportion of the property as a farming area or a natural undeveloped area;
- Rural “getaways” have grown in numbers over the past decade, in which either land-owners forsake production activities and erect accommodation for casual visitors, or urbanites purchase their own “get-away” in a rural

- area. These properties are usually only a few hectares in size and have become common in the KwaZulu-Natal midlands;
- Recreational enjoyment of the natural asset (e.g. hiking trails) is common in areas adjacent to the formally protected areas such as the uKhahlamba Drakensberg National Park;
 - Use of the area for four-by-four trails and by quad-bikes or similar is a growing activity; and
 - The proliferation in rural areas of small-scale manufacturing or production activities (e.g. home furniture factories) that utilize only a portion of the property for this purpose. The Midlands Meander of KwaZulu-Natal is a prime example.

A characteristic of most tourist and recreational developments is the construction of infrastructure such as roads and electricity lines and levels of disturbance in this regard will invariably increase with time. The majority of properties on which such activities are conducted have previously been used for agricultural production in some form. Although the inherited natural asset is not necessarily always transformed, it is not necessarily used well.

(e) Rural settlement

Rural or “communal” areas, as for the Mistbelt Grassland study (Section 4.2.3) typically contain areas of settlement, croplands, and extensive rangelands, as well as infrastructure for transportation, services and the movement of pedestrians and domestic animals. The relative proportion of these components can, however, vary widely across the sub-biome. Cropping occurs in areas around settlements and where soils are suitable. Although maize is the most important crop, vegetable gardens and certain cash crops are not uncommon. Amounts of fertilizer application are far less than for commercial croplands and the use of pesticides is not common.

Communal rangelands tend to support a greater richness of stock types than their commercial counterparts and cattle, sheep, boer goats, angora goats, horses and donkeys may be present. In addition, other animals such as pigs and chickens are generally free-ranging and make use of croplands and rangeland. Stocking rates are about threefold higher than rates on comparable commercial farms (Tapson 1993) and rotational systems are absent.

(f) Dairy farming

In the Grassland Biome, dairy farming is an intensive agricultural activity which is based on summer and winter pastures, crops and indigenous grassland. Summer pastures are commonly kikuyu (*Pennisetum clandestinum*), which is grazed in situ, and hay crops (e.g. *Eragrostis curvula*, *Chloris virgata* or *Digitaria erantha*) which are harvested about three times during the growing period. Winter pastures are irrigated and are most commonly annual ryegrass (*Lolium multiflorum*) or perennial ryegrass (*Lolium perenne*). Maize is commonly grown to provide silage.

Dairy farms have more infrastructure than livestock ranches and the natural asset maintained on them is generally land that cannot be cultivated because it is too rocky or steep or wet.

(g) Dryland cropping

Although wheat and maize are the most characteristic dryland crops cultivated in the moist sub-biome of the Grassland Biome, sugar cane is common on the eastern fringe in wet and in relatively warm parts. The growing season for dryland crops depends on rainfall patterns and generally increases in relation to

the east-west gradient of decreasing annual rainfall across the sub-biome. Rates of fertilizer application depend on the soil and crop type and the rainfall regime. Herbicides are routinely used for the control of broadleaved weeds, while pesticides may be used for certain circumstances.

As with dairy farming, the remaining natural asset is land that usually cannot be cultivated. The limits to cultivation vary to some extent and depend on the crop type. Constraints for annual crops in terms of slope and soil depth are generally similar and perennials such as sugar cane are planted on steeper slopes. Although the cultivation of crops in wetlands should be restricted, they were drained as required in terms of previous agricultural policies. Most dryland crops, especially maize, will have stover of high nutritional value available for livestock in winter. Livestock ranching is therefore an expected component of dryland cropping.

(h) Irrigated cropping

The following are some key distinctions between dryland and irrigated cropping:

- A greater number of crops generally are raised by irrigated cropping than dryland cropping and may include intensive vegetable production;
- Irrigated areas are used year round and generally two crops are harvested per annum,
- Irrigated crops are more intensively managed than dryland crops in terms of fertilizers, herbicides and insecticides;
- Irrigated crops can obviously only be grown where water is available;
- Irrigated crops are generally sown at higher densities than dryland crops;
- Arable land that cannot be accessed by irrigation equipment will usually be used for dryland cropping;
- Rocky or steep areas and wetlands usually ensure that some natural asset remains on farms where irrigated cropping is practised; and

- Owing to the lack of crop stover during winter, livestock are not as commonly associated with irrigated cropping as with dryland cropping.

(i) Timber plantations

Timber plantations in the moist sub-biome of the Grassland Biome are, as described for the Mistbelt Grassland study (Section 4.3.2), comprised of alien *Pinus*, *Eucalyptus* and *Acacia* species that have been planted on grassland. The timber industry has emerged during the past three or more decades as a major industry. Almost all of the timber estates were established on former livestock ranches, from which they have inherited infrastructure such as roads and dams. The extent to which topographic and edaphic limits to planting restricts the area of grassland transformed to timber obviously depends on the conditions of the property and the presence of wetlands and steep or rocky areas.

(j) Urban settlement

“Urban settlement” is defined as an urban core surrounded by a peri-urban fringe. Urban settlements can range in size from villages (e.g. Himeville) to small towns (e.g. Bergville) to large towns (e.g. Ladysmith) to cities. All of these can be characterized by some degree of industrial activity, a centralized business and retail district and formal residential areas. In most cases, poorly serviced informal residential areas and supporting infrastructure (transport, services) are present. In addition, there is a peri-urban fringe that usually consists of mainly smallholdings and cottage industries.

The remaining natural asset of urban settlement is usually restricted to habitats that cannot be transformed such as wetlands, rivers and part of their riparian fringe and extremely rugged hills.

5.2.4. Land uses omitted

Some land uses with well recognized impacts on the environment have been excluded because they affect only a small surface area. Examples include very intensive production activities (e.g. feedlots, chicken farms and pulp mills) and mining. These activities are best assessed on a case-by-case basis.

5.2.5. Biodiversity indicators selected

Indicators of biodiversity integrity were selected as for the Mistbelt Grassland study (Section 4.2.5), in accordance with the hierarchical approach advocated by Noss (1990) (refer also to the general approach to the methodology in Section 3.1).

Indicators selected for the integrity of biodiversity composition, structure and functioning for the moist sub-biome of the Grassland Biome at the various levels of enquiry in the Analytic Hierarchy Process (AHP) are indicated in Table 5.1 and Table 5.2. The integrity of landscape composition, structure and functioning reflects the primary level of enquiry. This list is considered to be sufficient for profiling the relative impacts of land uses. The choice of indicators for composition, structure and functioning as reflected in Table 5.1 and Table 5.2 was made so as to limit potential confounding. Minimal confounding between landscape composition and landscape structure is expected, because the first relates to natural asset and the second to transformed habitat. There is, however, some confounding between landscape composition and landscape functioning because untransformed habitats and transformed systems will both influence ecosystem functioning.

(a) Landscape composition

“Landscape composition” is described by natural asset in terms of (i) habitats and (ii) supported species, and (iii) the threat posed to these by alien plants.

(i) Habitats

For this study, six broad habitat types have been defined (Table 5.1). Together, these habitat types account for almost the total surface area of the sub-biome, and are considered to be adequate for assessing the impact of land use on the natural asset. These habitat types are the following:

- Grassland;
- Rocky grassland;
- Forest;
- Wetlands;
- Aquatic habitats; and
- Riparian habitats.

The habitat types are described as follows (refer also to the description provided for grassland, forest, wetlands and riparian habitats in Section 4.2.5 of the Mistbelt Grassland study):

➤ **Grassland**

Grassland is the main habitat that is subject to transformation within the sub-biome. Although all arable activities require grassland, not all grassland is, however, arable. Grassland includes both deep soils suitable for agriculture and shallow, non-rocky soils that cannot be ploughed.

➤ ***Rocky grassland***

This habitat is one in which boulders or rocks cover a significant proportion of the ground and in which hilly areas would commonly occur. The extreme example of cliffs or boulder fields was ignored for this evaluation. Rocky grassland areas cannot be ploughed.

➤ ***Forest***

This habitat consists of natural forest and is restricted to the moist sub-biome of the Grassland Biome. Although forest patches are associated mainly with steep south- and east-facing slopes, they occasionally develop on north-facing locations where sufficient water is available.

➤ ***Wetlands***

Wetlands have a high water table, hygrophilous plants, impeded drainage, anaerobic conditions for at least part of the year and soils shaped by water-based processes. Wetlands differ in their vulnerability to perturbation of their hydrological regime in relation to mean annual rainfall. Wetlands in the wetter areas of the sub-biome derive a far greater proportion of their water budget from rainfall than those of the more arid regions, which rely mainly upon fluvial processes. The proportion of landscape covered by wetlands decreases from east to west in direct relation to the decrease in mean annual rainfall.

➤ ***Riparian habitats***

A comprehensive description of a riparian zone should consider the spatial extent of the geomorphological processes shaping that zone. Although much of the riparian zone in the moist sub-biome constitutes wetlands, riparian zones and wetlands have, in this exercise, as for the Mistbelt Grassland study (Section 4.2.5), been scored separately. Riparian habitat is characterized as being regularly flooded but well drained and is recognized by those plant communities that directly express the soil depth and soil water conditions required for this form of hygrophilous vegetation. Riparian areas usually contain scrubs, some woody vegetation and an abundance of soft forbs. Depending on valley topography, the riparian zone can extend quite a distance from the river.

For both wetland and riparian vegetation, cognisance has been taken of legislative controls concerning impacts on these habitats.

➤ ***Aquatic habitats***

Aquatic environments are directly dependent on hydrological functioning so that redundancy between these two indicators can be expected. Water quality is critical for aquatic biota. Water quality is impaired by increased turbidity resulting from sediment inputs and from eutrophication. Riparian habitat and wetlands function as filtration agents of water inputs and as containing mechanisms for sediment inputs. Sedimentation of stream beds is the primary cause of habitat loss for aquatic insects.

Table 5.1: List of indicators selected for assessing the impact of land use on the integrity of landscape composition in the moist sub-biome of the Grassland Biome. The columns of indicators reflect their hierarchical ordering for assessment using the Analytic Hierarchy Process

Level 1	Level 2	Level 3	Level 4	
Landscape Composition	Habitat	Grassland		
		Rocky grassland		
		Wetland		
		Riparian		
		Forest		
		Aquatic		
		Species	Insects	
				Termites
				Dung beetles
	Mammals			Shrews
				Moles
				Mole-rats
				Small rodents
				Hares
				Mongoose
				Small antelope
				Aardvark
				Jackal, caracal
			Birds	
				Korhaans, bustards
				Migrant kestrels
				Martins, swallows
		Owls		
	Cranes			
	Game birds			
Alien plants	Herbaceous aliens			
	Woody aliens			

Table 5.2: List of indicators selected for assessing the impact of land use on the integrity of landscape structure and function in the moist sub-biome of the Grassland Biome. The columns of indicators reflect their hierarchical ordering for assessment using the Analytic Hierarchy Process

Level 1	Level 2	Level 3	Level 4	
Landscape structure	Transformation: extent			
	Cover diversity			
	Fragmentation	Extent		
		Connectivity		
		Porosity		
		Geometry		
Physiognomy				
Landscape function	Hydrological functioning	Water quantity		
		Water quality		
		Flow seasonality		
	Soil erosion			
	Biogeochemical processes	Primary productivity		
		Carbon storage		
		Nutrient leakage		
	Fire	Extent		
		Frequency		
		Intensity		
		Season		
	Grazing	Extent		
		Frequency		
		Intensity		
		Season		
	Biotic processes	Harvestable goods	Medicinal plants	
			Building materials	
			Craftwork materials	

(ii) Species

Three classes of animals were chosen for assessing the impact of land uses on species: insects, birds and mammals (Table 5.1). Selection was based on available knowledge and their perceived value as indicators.

In assessing biodiversity integrity relating to species, the maintenance of the species complement was a priority. An increase in the abundance of one or more species at the expense of the representation of another species is considered to compromise biodiversity integrity.

➤ Insects

Terrestrial invertebrates as indicators of ecological change associated with land use disturbances have been widely recognized (Rosenberg Danks and Lehmkuhl 1986; Andersen, Hoffmann, Muller and Griffiths 2002). The three insect groups chosen for assessment were termites, ants and dung beetles. Individual insect species may have a close association with a specific habitat but the three insect groups chosen are commonly encountered across a range of habitats. Ants were chosen because of their high species and trophic diversity, and termites and dung beetles because of their importance for ecosystem functioning in terms of nutrient recycling and as soil engineers.

➤ ***Birds and mammals***

Seven groups of birds and nine groups of mammals were chosen for an assessment of the impact of land use on landscape composition (Table 5.1). Each group within the category of either birds or mammals should have a representative species at any point in the biome and should be relatively homogeneous in terms of body size, social structure and trophic ecology by comparison with the other groups (Hockey, Dean and Ryan 2005). Only true grassland-dependent species have been included because the exercise is concerned with biodiversity integrity specifically of the grassland biome.

(iii) Alien plants

The threat of alien plants to biodiversity has been included in the evaluation of the integrity of landscape composition because they can reduce or eliminate either species or habitat (Table 5.1). These threats are conditional on the presence of biodiversity. The threat of alien plants posed by a land use relates to both its promotion of well established alien plants and the likelihood that the land use may introduce new species.

New seed sources of aliens can be introduced in a variety of ways. The most common source of new alien species is through gardening introductions and indigenous species planted well out of their range. Although a considerable number of woody alien invasives occur in the moist sub-biome, American Bramble (*Rubus cuneifolius*), Bugweed (*Solanum mauritianum*), Black Wattle (*Acacia mearnsii*), Silver Wattle (*Acacia dealbata*), and Mauritius Thorn (*Caesalpinia decapetala*) are common (Bromilow 1995).

In an assessment of the impacts of alien invasive plants, the following points need to be considered:

- Land use overall probably has little effect on aliens;
- Alien herbaceous species are generally more dependent on moisture than are woody species;
- The majority of new alien invasive woody species are members of the *Rosaceae*; and
- Roads and associated disturbances, rather than land uses, are probably the most important avenues of ingress for aliens.

Management practices may promote the establishment of aliens in the following ways:

- Animal movement is a potent source of dispersal;
- Selective grazing can create suitable conditions for establishment and growth;
- The fire regime, especially frequency and intensity of fire, is critical for woody aliens; and
- Areas of soil disturbance are foci for the establishment of woody alien plants.

(b) *Landscape structure*

“Landscape structure” is described by the extent, nature and arrangement of the untransformed natural asset (Forman and Godron 1986), which constitutes the primary template for persistence of biodiversity. For this study, landscape structure in the moist sub-biome of the Grassland Biome has been assessed in terms of the following four variables (Table 5.2):

- Extent of transformation;
- Fragmentation, including extent of fragmentation, porosity, connectivity, and geometry of the remaining asset;

- Diversity of ground covers resulting from the transformation process; and
- Physiognomy.

The indicator variables for landscape structure are described as follows (also refer to the description for the extent of transformation, fragmentation and physiognomy given in the Mistbelt Grassland study, Section 4.2.5):

(i) *Extent of transformation*

Grassland transformation refers to the extent of transformation of the natural grassland asset in the landscape. Typically, changes in species, their numbers and distribution patterns within ecosystems due to the impacts of land use have been recorded. Transformation of the moist sub-biome of the Grassland Biome has been primarily associated with an increase in agricultural activities and timber production (DACEL 2003).

(ii) *Fragmentation*

Fragmentation has been assessed in terms of the configuration of the natural asset remaining after transformation and includes the number and size of fragments (extent of fragmentation), connectivity, geometry (perimeter to area ratio) and porosity (Forman and Godron 1986). These four are not independent. Connectivity and geometry are partly dependent on the extent of fragmentation. Connectivity has been defined as the extent of physical connection of the remaining asset, whereas for porosity the influence is recognized of management or other practices (e.g. compatible land uses) on the potential flow of organisms.

Through the addition of roadless areas to patches of protected areas to form larger patches, an increase in landscape connectivity across the northern

Rockies has been demonstrated (Crist, Wilmer and Aplet 2005). Larger patches of protected areas will conserve more species that are sensitive to human activity and ensure more intact ecosystem processes (Turner, Romme, Gardner, O'Neill and Kratz. 1993).

(iii) Cover diversity

The impact of increasing cover diversity is considered to be a negative one during the initial period of transformation because each new cover type possibly introduces new pressures or threats to maintaining biodiversity integrity. Possible threats include alien plants, poisons and facilitation of the ingress of pests, pathogens or predators. As transformation proceeds and landscapes become increasingly fragmented, a diversity of cover types may broaden opportunities for biota to persist in remnant scraps of natural asset. For example, some biota may be able to use maize for movement among fragments or pastures for some feeding. Greater cover diversity was, however, considered overall to be a negative factor for biodiversity.

(iv) Physiognomy

Landscape physiognomy refers to spatial and seasonal variation in vertical height, density and cover. The characteristic of natural grassland is that it experiences seasonal changes in height through summer growth, winter (usually involving frost) dieback, attrition of phytomass by grazing mammals and by fire. Although fire can cause dramatic short-term changes in physiognomy, it has no long-term effect. Assessment of physiognomy relied mainly on the extent and permanence of change in the vertical dimension and less so on seasonality and vegetation cover.

(c) Landscape function

Landscape functioning involves the flow of energy, materials and species among component ecosystems (Forman and Godron 1986) and is characterized by processes common to both the natural and transformed components (e.g. biogeochemical processes, hydrological functioning), and by processes considered for the natural asset only but whose patterns depend on the nature of transformation (e.g. fire, grazing, biotic processes). Landscape functioning in the moist sub-biome of the Grassland Biome was evaluated in terms of the following (Table 5.2):

- Fire regime;
- Grazing regime;
- Biochemical processes;
- Hydrological functioning;
- Soil erosion; and
- Biotic processes.

The following description is provided for the indicators of landscape functioning:

(i) Fire regime

Fire is probably the single most important ecological factor determining the presence and extent of the Grassland Biome in South Africa (O'Connor and Bredenkamp 1997). The Biome's biota is well adapted to repeated fires, but community organization and ecosystem functioning are markedly influenced by variation in the fire regime (Mentis and Tainton 1984). Continuing transformation of the biome by a diversity of land uses has resulted in a mosaic of grassland patches and other covers. The size and configuration of remaining patches and nature of land use are expected to influence the fire regime. Land uses were

compared for whether the remaining natural assets differed from one another in terms of their fire regime, and were described by:

- total extent burnt each year;
- frequency of burning of a point location;
- average intensity of fires; and
- season of burning.

In an agricultural system with a fixed block-burning rotation over years, the total extent burnt each year is perfectly confounded with fire frequency. In systems with a variable approach to burning, such as some conservation properties (with point-source ignition) and communal rangelands (with multiple fire causation), different areas may be burnt at different frequencies even if the total extent of burning remains unchanged. The extent of burning may influence biodiversity integrity through spatially-related processes such as interactive effects with grazing.

Key influences on the fire regime of different land uses are the following:

- The fuel load which could accumulate;
- Security considerations for infrastructure (e.g. housing of tourism) or assets (e.g. timber plantations);
- Motivation for burning; and
- Choice by management of the season in which to burn and the time of day of the burn.

(ii) *Grazing regime*

Grazing is considered to be one of the key issues that influence the integrity of grasslands and is described as being the link between their maintenance, productivity, economic use and management for biodiversity (Watkins and Ormerod 2001). The abundance and impact of large herbivores would not have

been uniform across the biome but would have varied in relation to rainfall and soil characteristics (Bell 1982). High rainfall environments on leached soils in particular would historically have supported a low abundance of mammalian herbivores (Rowe-Rowe and Scotcher 1986). Indigenous mammalian herbivores have been replaced by livestock, but usually at a stocking rate far exceeding the former abundance of wildlife. This has resulted in the degradation of rangelands. Livestock have, nonetheless, ensured that grazing has been maintained as an essential ecological process.

This section of the study addresses the manner in which grazing functions as a natural ecological process on the remaining natural asset. Note that grazing of the transformed asset is ignored. Unlike fire, which is a discrete event, grazing affects an ecosystem through an uncountable number of small, but cumulative, impacts related both to the act of food ingestion and trampling that take place throughout the year. This pattern of use over the course of a year can be described by the same set of variables used for fire: extent; season; frequency; and intensity.

➤ ***Spatial extent of grazing***

The proportion of the property that is accessed on average per annum by grazing mammals is referred to as the “spatial extent” of grazing.

➤ ***Grazing season***

A season of grazing is the modal season in which grazing occurs. If grazing is concentrated into a single season of the year, then season may be important. Grazing during the early growing season is considered to have a far greater impact than grazing during the late growing season or dormant season.

➤ ***Frequency of grazing***

The frequency of grazing is considered to be the average number of times a tuft can be grazed in a year after having re-grown. If a tuft is re-grazed a number of times during a short period of stay during which regrowth would not have occurred then it can be considered as one grazing. If re-grazing of a tuft occurs after a ten-day period it constitutes a second grazing event as regrowth should have occurred.

➤ ***Intensity of grazing***

The intensity of grazing is defined as being the proportional removal of sward biomass over a year. Grazing intensity is directly dependent on stocking rate and animal type.

This assessment has addressed first-order effects and not any interactions or conditional relationships among grazing variables because the intention is to profile the relative impact of different land uses or management systems on biodiversity integrity. Grazing systems are not well investigated with respect to impacts on biodiversity, as research has focused on grass composition (O'Reagain and Turner 1992) which does not necessarily reflect plant diversity (Short, O'Connor and Hurt 2003).

(iii) Hydrological Functioning

(Refer in Section 4.2.5 to the description of hydrological functioning provided for the Mistbelt Grassland study).

Hydrological functioning is assessed according to its importance for maintaining biodiversity integrity and not for its role in delivery of water to humans. In pristine catchments relatively high summer rainfall yields result in high summer stream and river flows of water with low nutrient concentrations. This maintains base winter flows in larger streams and rivers.

➤ ***Water quantity, quality and seasonality of flow***

Hydrological functioning is characterized by the quantity of water flowing through the system per annum, the seasonality of that flow relative to pristine conditions, and water quality. Hydrological functioning varies in relation to mean annual rainfall in an obvious manner for water quantity, and for water quality from dilution effects. Expected nutrient status of an aquatic system would reflect regional geology and climate. Seasonality of flow relates to the quantity of flow during both the wet and dry seasons. Biota of aquatic and wetland systems are also adapted to inter-annual variation in flow, including floods and drought-flow conditions, and seasonality of flow (winter stress).

Perturbation of water quantity or quality or seasonality of flow could have an impact on the biodiversity integrity of these systems. Assessing these impacts is complicated by the conditional relationships among the three variables. For example, seasonality loses its significance under the extreme conditions of the river dying from pollution, conditions under which water quantity becomes important in order to flush the river. Seasonality of flow reflects annual variation in quality to some extent, because a reduction in base flow levels during winter will serve to concentrate nutrients and pollutants. This evaluation assumed average and not extreme conditions of a functioning river. Aquatic organisms are negatively affected by declines in water quality resulting from eutrophication or sedimentation. Soil erosion results in both. Both increases and decreases in water flow can have negative impacts on aquatic systems. Water quantity

flowing through a system can be reduced through impoundments, which increase evaporation loss, and through abstraction for irrigation or consumption.

This study has addressed hydrological functioning with respect to biodiversity integrity of aquatic and water-related systems (wetlands, riparian), but not water-based processes on dryland because these are dependent mainly on rainfall inputs which are assumed to be unaffected by land use.

(iv) Soil erosion

The physical process of soil erosion is well understood and the impact of land use on it can be predicted using empirical models (Wischmeier and Smith 1978). Key land use influences relate to the amount of exposed ground during rainfall (and wind) periods, the degree to which soil is loosened and the obstruction to overland water flow. Litter and established vegetation cover on the ground is critical for promoting infiltration rather than overland flow. The angle and length of the slope over which flow occurs, soil texture, nature of delivery of precipitation and mean annual rainfall are environmental variables, which have a strong influence on the loss of soil.

Most erosion resulting from livestock activities arises as a consequence of trampling and path formation rather than grazing (Roux 1980). Path formation and destabilization of slopes play a critical role. Sustained heavy grazing that creates extensive bare areas, especially around watering points, can be more important than paths but can be dealt with by responsible management.

(v) **Biogeochemical processes**

➤ **Primary productivity**

Primary productivity underpins trophic functioning. It is defined as being “the amount of vegetal dry matter produced per annum”. It should not be confused with the phytomass of standing vegetation because much of this can be carried over from previous years, the most obvious of which is the woody biomass of trees. Primary production of a land use was assessed as the sum of the main land covers of that land use. Primary production depends on the availability of water, nutrients and light. Any process (e.g. soil erosion) or management practice (e.g. irrigation, fertilization) influencing one or more of these availabilities should markedly affect primary production. Primary productivity of natural grassland is dependent on the accumulation of moribund material which reduces irradiance (Knapp, Briggs, Blair and Turner 1998). Moribund material accumulates most rapidly in moist grasslands. Fire is a key process for reducing moribund material and thereby maintaining productivity. Commonly used fire regimes are not considered to be injurious to productivity.

➤ **Nutrient leakage**

Many production activities have a direct or indirect impact upon the total amount and flow of nutrients. Nutrient leakage is recognized globally as being one of the most serious threats to maintaining sound ecosystem functioning and biodiversity (Dalton and Brand-Hardy 2003). Examples of the manner in which nutrient leakage occurs include fertilization losses, soil erosion, industrial emissions, flow of animal waste products and ineffective sanitation. The extent of loss per unit of soil depends on the amount of organic matter and can be substantial. Phosphorus is lost mostly through loss of soil material. In effect, all processes

influencing water quality would contribute to nutrient leakage. In addition, there may be gaseous losses but water-based processes are expected to be dominant. Gaseous release of nutrients may constitute a small proportion of the overall amount lost, but this fraction can make a significant contribution to greenhouse gases (e.g. atmospheric NO_x compounds from legume crops).

Water-based losses may occur through overland flow or through leaching. Leaching losses are related to rainfall regime and soil texture. They will be highest on coarse soils in a high rainfall regime, especially following a large rainfall event. A critical influence on overland flow or leaching is whether the nutrient is delivered from a point or a diffuse source. Point sources that produce a large amount of nutrients on an almost continuous basis can be particularly difficult to contain because few natural filtering mechanisms can process such a rate of flow.

The impact of nutrient leakage is most pronounced for dystrophic systems whose biota cannot persist in the face of competition from species adapted to high nutrient levels.

➤ ***Carbon Storage***

Grasslands are one of the most effective vegetation types for soil storage of carbon. Seastedt, Hayden, Owensby and Knapp (1998) developed a compelling hypothesis of the mechanism of this effect. While the storage of carbon is dependent upon repeated defoliation by fire (or possibly grazing), the efficiency of this storage in the soil increases with an increase in clay content and in mean annual rainfall and a decrease in mean annual temperature.

The main losses of carbon stores occur through soil disturbance, soil erosion and reduction of inputs. In agricultural systems, the frequency of soil disturbance by

tillage is the single most important influence. Carbon is easily lost through soil erosion because it is part of the light fraction and thus it is easily removed in water. Wetlands are more effective per unit area in storing carbon than any other vegetation formation. Drowning of wetlands under dams will ultimately release much of this stored carbon.

(vi) Biotic processes: Harvestable goods

A number of interactions among species or species-specific processes that ensure persistence of the components of a system in a particular state are included in the category of “biotic processes”. Common processes would include pollination, dispersal, competition, predation, mutualism, symbiosis and parasitism. These processes cannot be meaningfully assessed on their own because of the vast number of species involved and because most are not researched. An output-based measure was therefore felt to be useful for indexing whether biotic processes were being maintained. If individual species or groups of species are vulnerable to population reduction or even extirpation, then inter-species effects should cascade through the system. An output of particular relevance to South African grasslands is the use of the natural resource base for meeting human needs in rural areas. The impact of land use on the continued availability of harvestable goods is therefore an indirect assessment of the well-being of biotic processes.

The three main renewable resources utilized by rural peoples are building materials, medicinal plants (and animals) and craft materials. It is important that people meet their daily needs in terms of energy supply and shelter. Construction materials include timber (met mainly by exotic species) and thatching grass (mainly *Hyparrhenia* species) and occasionally reeds (e.g. *Phragmites australis*). Exotic wattle species are the main source of wood for both fuel and timber and wattle is supplemented to a limited extent by gum, pine,

and indigenous species such as *Acacia karroo*. Maintaining personal health is a daily preoccupation, for which medicinal plants are extensively used. Most medicinal plants in the rural areas of South Africa are not harvested for local consumption but for retail to urban societies (Mander 1998).

Medicinal plants can occur in forest, grassland, wetland, riparian areas and rocky grassland. Over a 1000 species are used in KwaZulu-Natal alone (Hutchings 1996). Although the diversity and availability of medicinal plants, thatching grass and craftwork material is less in the semi-arid sub-biome, it does not detract from their importance. Medicinal plants, building materials and craftwork materials were assessed separately then combined into a single index based on their importance for rural peoples.

5.2.6. The Analytic Hierarchy Process

The general approach for application of the AHP as implemented for the Mistbelt Grassland study and described in Section 3.4, was applied in an evaluation of the impacts of land use on biodiversity integrity of the moist sub-biome of the Grassland Biome.

(a) Ranking of indicators

The relative importance of individual indicators of the integrity of the compositional, functional and structural components of biodiversity for the sub-biome was examined in this exercise. Elements that were identified as indicators of biodiversity integrity were rated in pair-wise comparisons and verbal judgements were scored according to the continuous rating scale of the AHP.

Indicators were described in detail to interviewees and any points of uncertainty were clarified. Pair-wise comparisons of indicators with respect to their importance were undertaken, scores were examined and extreme ones debated. Geometric means of the participants' scores were used to calculate relative weights for indicators of the compositional, functional and structural components of biodiversity.

(b) Ranking of land uses with respect to indicators

The next step was to rank land uses with respect to impacts on each indicator of biodiversity integrity for the sub-biome. Land use alternatives selected were discussed with interviewees and any points of uncertainty were clarified.

In this exercise, pair-wise comparisons were made of the relative impact of two land uses with respect to a specific indicator of the integrity of the compositional or structural or functional components of biodiversity. The scores of participants were recorded and extreme values were debated. The geometric mean of participants' scores for each comparison was recorded as the workshop score. Weights for each matrix for impacts of land use with respect to specific biodiversity indicators were calculated.

➤ *Consistency of scores*

The degree of consistency of scoring for all pair-wise comparisons was calculated in accordance with the method provided in Section 3.4.2. Only matrices that were consistent were accepted.

(c) Final ranking of land uses

As for the Mistbelt Grassland study (Section 4.2.6), the final step in the AHP is to calculate overall relative weights for the land uses with respect to the objective at a specific level in the decision hierarchy (Section 3.4.2; Table 5.1; Table 5.2). Accordingly, relative weights for the impacts of land use for each level of the hierarchy (indicator categories) and overall weights with respect to impacts on the integrity of biodiversity composition, function and structure were calculated.

The ranking of the compositional, functional and structural components then provided an overall indication of the relative impact of land use categories on landscape biodiversity.

5.3. Results

Table 5.3: Weights of indicators for landscape composition in the moist sub-biome of the Grassland Biome (Appendix C 1.1)

Component	Indicator	Level 1	Level 2	Level 3	Level 4
Landscape composition		0.111			
	Habitat		0.643		
	Grassland			0.443	
	Rocky Grassland			0.163	
	Wetland			0.186	
	Riparian			0.071	
	Aquatic			0.056	
	Forest			0.081	
	Species			0.286	
	Insects			0.111	
	Ants				0.583
	Termites				0.333
	Dung beetles				0.083
	Birds			0.333	
	Larks, pipits, longclaws				0.035
	Bustards, korhaans				0.225
	Swallows, martins				0.049
	Owls				0.104
	Migrant kestrels				0.173
	Cranes				0.259
	Game birds				0.155
	Mammals			0.556	
	Shrews				0.037
	Moles				0.052
	Mole-rats				0.063
	Small rodents				0.082
	Mongoose				0.110
	Hares				0.110
	Small antelope				0.216
	Aardvark				0.163
	Jackal, caracal				0.168
	Alien plants			0.071	
Herbaceous			0.167		
Woody			0.833		

Table 5.4: Weights of indicators for landscape structure and function in the moist sub-biome of the Grassland Biome (Appendix C 1.1)

Landscape component	Indicator	Level 1	Level 2	Level 3
Landscape structure		0.556		
	Transformation		0.564	
	Fragmentation		0.230	
	extent			0.560
	porosity			0.229
	connectivity			0.099
	geometry			0.112
	Cover diversity		0.103	
Physiognomy		0.103		
Landscape function		0.333		
	Fire regime		0.298	
	frequency			0.313
	season			0.500
	intensity			0.125
	extent			0.063
	Grazing regime		0.128	
	frequency			0.238
	season			0.381
	intensity			0.286
	extent			0.095
	Soil erosion		0.191	
	Biogeochemical processes		0.213	
	Primary productivity			0.380
	Nutrient leakage			0.310
	Carbon storage			0.310
	Hydrological functioning		0.043	
	water quality			0.564
	water quantity			0.144
	seasonality of flow			0.292
	Harvestable goods (biotic processes)		0.128	
	medicinal plants			0.455
building materials			0.455	
craftwork materials			0.091	

Table 5.5: Weights for the impact of land use on indicators of landscape composition for the moist sub-biome of the Grassland Biome (Appendix C)

COMPONENT / INDICATOR	LAND USE									
	Conser- vation	Livestock ranching	Tourism and recreation	Game farming	Rural settlement	Dairy farming	Dryland cropping	Irrigated cropping	Timber estate	Urban and Peri- urban
Biodiversity integrity	0.032	0.063	0.079	0.047	0.121	0.132	0.112	0.121	0.136	0.156
Landscape composition	0.024	0.053	0.059	0.039	0.146	0.112	0.107	0.116	0.151	0.192
Habitat	0.025	0.061	0.057	0.047	0.142	0.109	0.099	0.104	0.170	0.187
Grassland	0.021	0.055	0.053	0.049	0.123	0.113	0.117	0.118	0.173	0.178
Rocky Grassland	0.030	0.069	0.070	0.050	0.147	0.084	0.056	0.050	0.222	0.222
Wetland	0.028	0.061	0.049	0.045	0.147	0.126	0.101	0.118	0.143	0.183
Riparian	0.023	0.068	0.062	0.041	0.154	0.115	0.100	0.120	0.137	0.181
Aquatic	0.027	0.065	0.053	0.038	0.150	0.130	0.084	0.108	0.161	0.185
Forest	0.032	0.070	0.062	0.046	0.213	0.073	0.090	0.086	0.141	0.187
Species	0.024	0.049	0.060	0.037	0.153	0.115	0.107	0.117	0.144	0.194
Insects	0.023	0.040	0.062	0.023	0.054	0.161	0.138	0.177	0.175	0.147
Ants	0.020	0.060	0.070	0.030	0.080	0.140	0.160	0.160	0.160	0.120
Termites	0.029	0.010	0.043	0.010	0.010	0.203	0.087	0.203	0.203	0.203
Dung beetles	0.024	0.024	0.082	0.024	0.047	0.141	0.188	0.188	0.165	0.118

(contd. ...)

Table 5.5 (continued): Weights for the impact of land use on indicators of landscape composition for the moist sub-biome of the Grassland Biome (Appendix C)

COMPONENT / INDICATOR	LAND USE									
	Conser- vation	Livestock ranching	Tourism and recreation	Game farming	Rural settlement	Dairy farming	Dryland cropping	Irrigated cropping	Timber estate	Urban and Peri- urban
Birds	0.023	0.038	0.084	0.047	0.157	0.113	0.092	0.112	0.149	0.186
Larks, pipits, longclaws	0.034	0.020	0.118	0.015	0.083	0.110	0.072	0.093	0.238	0.215
Bustards, korhaans	0.020	0.048	0.088	0.072	0.148	0.108	0.072	0.108	0.158	0.177
Swallows, martins	0.028	0.040	0.069	0.049	0.110	0.113	0.147	0.147	0.168	0.127
Owls	0.021	0.050	0.087	0.041	0.170	0.113	0.103	0.113	0.117	0.185
Migrant kestrels	0.026	0.026	0.082	0.032	0.130	0.116	0.101	0.116	0.180	0.191
Cranes	0.023	0.033	0.090	0.033	0.184	0.114	0.080	0.098	0.137	0.209
Game birds	0.021	0.021	0.067	0.052	0.170	0.117	0.095	0.117	0.148	0.192
Mammals	0.025	0.057	0.046	0.034	0.170	0.106	0.110	0.110	0.110	0.209
Shrews	0.030	0.042	0.042	0.030	0.175	0.115	0.111	0.103	0.132	0.222
Moles	0.035	0.035	0.042	0.035	0.134	0.098	0.120	0.138	0.147	0.218
Mole-rats	0.031	0.044	0.038	0.031	0.140	0.109	0.109	0.126	0.172	0.199
Small rodents	0.020	0.035	0.029	0.020	0.173	0.133	0.137	0.106	0.162	0.184
Mongoose	0.032	0.056	0.046	0.032	0.172	0.089	0.089	0.113	0.113	0.258
Hares	0.030	0.051	0.042	0.030	0.176	0.073	0.073	0.084	0.176	0.267
Small antelope	0.021	0.063	0.063	0.026	0.168	0.097	0.104	0.110	0.158	0.190
Aardvark	0.020	0.035	0.029	0.020	0.173	0.133	0.137	0.106	0.162	0.184
Jackal, caracal	0.022	0.100	0.053	0.069	0.185	0.113	0.113	0.113	0.036	0.196
Alien plants	0.022	0.065	0.064	0.026	0.105	0.110	0.142	0.145	0.135	0.187
Herbaceous	0.028	0.076	0.073	0.051	0.109	0.138	0.122	0.140	0.082	0.182
Woody	0.021	0.063	0.063	0.021	0.104	0.104	0.146	0.146	0.146	0.188

Table 5.6: Weights for the impact of land use on indicators of landscape structure for the moist sub-biome of the Grassland Biome (Appendix C)

COMPONENT / INDICATOR	LAND USE									
	Conser- vation	Livestock ranching	Tourism and recreation	Game farming	Rural settlement	Dairy farming	Dryland cropping	Irrigated cropping	Timber estate	Urban and Peri- urban
Landscape structure	0.021	0.055	0.088	0.037	0.101	0.143	0.115	0.131	0.145	0.162
Transformation	0.020	0.059	0.083	0.034	0.098	0.143	0.116	0.132	0.147	0.167
Fragmentation	0.021	0.039	0.085	0.037	0.098	0.137	0.121	0.138	0.142	0.183
extent	0.020	0.039	0.088	0.034	0.096	0.147	0.118	0.138	0.142	0.177
porosity	0.023	0.039	0.073	0.039	0.039	0.107	0.125	0.143	0.139	0.199
connectivity	0.022	0.038	0.084	0.044	0.087	0.087	0.125	0.141	0.133	0.185
geometry	0.023	0.041	0.091	0.041	0.081	0.140	0.128	0.128	0.152	0.175
Cover diversity	0.026	0.079	0.110	0.053	0.129	0.197	0.091	0.118	0.105	0.092
Physiognomy	0.022	0.044	0.099	0.038	0.099	0.109	0.122	0.122	0.183	0.161

Table 5.7: Weights for the impact of land use on indicators of landscape function for the moist sub-biome of the Grassland Biome (Appendix C)

COMPONENT / INDICATOR	LAND USE									
	Conser- vation	Livestock ranching	Tourism and recreation	Game farming	Rural settle- ment	Dairy farming	Dryland cropping	Irrigated cropping	Timber estate	Urban and Peri- urban
Landscape function	0.054	0.080	0.070	0.066	0.146	0.119	0.109	0.106	0.115	0.134
Fire regime	0.073	0.067	0.075	0.075	0.185	0.081	0.068	0.069	0.144	0.163
frequency	0.061	0.081	0.053	0.067	0.203	0.113	0.061	0.067	0.178	0.117
season	0.075	0.059	0.066	0.078	0.216	0.059	0.071	0.071	0.117	0.187
intensity	0.119	0.076	0.149	0.085	0.070	0.072	0.075	0.067	0.136	0.152
extent	0.037	0.037	0.104	0.067	0.079	0.115	0.067	0.065	0.211	0.217
Grazing regime	0.056	0.102	0.046	0.096	0.158	0.201	0.140	0.077	0.072	0.052
frequency	0.039	0.136	0.019	0.136	0.234	0.175	0.117	0.078	0.058	0.007
season	0.069	0.069	0.069	0.069	0.069	0.276	0.138	0.069	0.069	0.103
intensity	0.039	0.117	0.020	0.098	0.234	0.156	0.176	0.078	0.078	0.004
extent	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100
Soil erosion	0.021	0.091	0.041	0.029	0.144	0.107	0.144	0.145	0.150	0.129
Biogeochemical processes	0.077	0.095	0.096	0.084	0.108	0.106	0.106	0.106	0.091	0.132
Primary productivity	0.105	0.105	0.110	0.105	0.110	0.086	0.091	0.077	0.100	0.110
Nutrient leakage	0.028	0.076	0.073	0.051	0.109	0.138	0.122	0.140	0.082	0.182
Carbon storage	0.090	0.102	0.101	0.090	0.105	0.101	0.106	0.106	0.090	0.108
Hydrological functioning	0.030	0.076	0.061	0.051	0.129	0.139	0.095	0.152	0.116	0.150
water quality	0.029	0.085	0.056	0.054	0.130	0.140	0.109	0.142	0.094	0.161
water quantity	0.031	0.057	0.064	0.042	0.124	0.140	0.088	0.168	0.158	0.130
seasonality of flow	0.033	0.068	0.070	0.049	0.131	0.138	0.071	0.162	0.140	0.138
Harvestable goods (biotic processes)	0.023	0.050	0.091	0.050	0.112	0.159	0.129	0.151	0.079	0.158
medicinal plants	0.017	0.086	0.069	0.086	0.138	0.121	0.103	0.121	0.103	0.155
building materials	0.028	0.009	0.112	0.009	0.084	0.196	0.154	0.182	0.056	0.168
craftwork materials	0.023	0.070	0.093	0.070	0.116	0.163	0.128	0.151	0.070	0.116

Table 5.8: Weights for the impact of land use on the overall biodiversity integrity for the moist sub-biome of the Grassland Biome (Appendix C 2)

		COMPONENT:	Composition	Function	Structure	
		WEIGHT	0.111	0.333	0.556	WEIGHT
LAND USE:	Conservation		0.024	0.054	0.021	0.032
	Livestock		0.053	0.080	0.055	0.063
	Tourism		0.059	0.070	0.088	0.079
	Game		0.039	0.066	0.037	0.047
	Rural		0.146	0.146	0.101	0.121
	Dairy		0.112	0.119	0.143	0.132
	Dryland crops		0.107	0.109	0.115	0.112
	Irrigated crops		0.116	0.106	0.131	0.121
	Timber		0.151	0.115	0.145	0.136
	Urban		0.192	0.134	0.162	0.156

5.4. Discussion

This discussion includes comments made by participants during interviews in the evaluation process (Section 5.2; Appendix A 2).

5.4.1. Relations among indicators

The indicators defining landscape composition, structure and function showed a clear rank in terms of their relative importance with regard to biodiversity integrity (Table 5.3 and Table 5.4). This result was the same as that obtained for the Mistbelt Grassland study (Section 4.6). Landscape structure was considered to be of primary importance and landscape function was ranked second. The continued functioning of key ecosystem processes will determine the viability of

the remaining natural asset in terms of populations and species composition. Properly functioning ecosystem processes should ensure that a greater proportion of the original biota can persist in a transformed landscape. This dependence of landscape composition on the integrity of the remaining natural asset is the reason for it being ranked secondarily in importance to landscape functioning.

(a) Landscape structure

The relative contribution of transformation, cover diversity, fragmentation and physiognomy makes to landscape structure in the Grassland Biome is determined by conditional relations (Table 5.4). Without transformation, fragmentation, cover diversity and physiognomy are not relevant. Fragmentation reflects how much natural asset remains after transformation, which is more important than either the cover diversity or physiognomy of a surrounding transformed landscape. In terms of maintaining biodiversity on remaining fragments, cover diversity was rated equally important to physiognomy. Low cover diversity is not necessarily good, as a monoculture of *Eragrostis* pasture is undoubtedly more appropriate for biodiversity than a monoculture of timber.

The fragmentation process is dominated by the contribution that the extent of fragmentation makes because the other indicators are not relevant unless fragmentation has occurred (Table 5.4). By consideration of management influences and compatible land covers, porosity was ranked as having a greater importance than connectivity. Connectivity emerged as being largely redundant and because of this, the geometry of fragments was ranked third.

(b) Landscape function

Landscape functioning is dominated by the role of fire (Table 5.4) and it was considered the most important ecological process for maintaining this biome across its breadth. Grazing would be a priority ecological process in systems with very low fire frequency, but this was not considered a norm. Although the importance of grazing might increase across the sub-biome (east to west) in relation to decreasing mean annual rainfall and hence might lessen the importance of fire, this has not been considered. The contribution of biogeochemical processes and soil erosion were not considered to be meaningfully different. Biotic processes such as competition, mutualism and predation are dependent on the abiotic environment (reflected by soil erosion and biogeochemical processes) as influenced by the secondary determinants of fire and grazing. Hydrological functioning made the least contribution of the six indicators because it is primarily important in water-dependent biota or habitats.

In terms of maintaining a fire regime that is beneficial for biodiversity, it was considered that the season of burning has a very strong influence, while the frequency of burning also has a strong influence. The intensity and extent of burning were ranked as having the weakest influence (Table 5.4). The influence of extent of burning could be moderate to strong if interactive effects with grazing were considered. In this assessment, the extreme condition of the complete exclusion of fire was discounted as unrealistic for the biome, although this is known to result in rapid transformation of grassland to scrubland and woodland (O'Connor and Bredenkamp 1997).

Grazing season was ranked as having the most impact of the grazing variables on biodiversity integrity, and extent of grazing the least (Table 5.4). Grazing season relates to the season in which grazing occurs and will influence the growth cycle of plants being grazed and thus their ability to compete with less

palatable varieties. Although this will largely be influenced by management, the intensity of grazing will also be important.

The contribution of soil erosion to biodiversity integrity (Table 5.4) is a consequence of the obvious fact that soil is the medium for plant growth and for soil processes including hydrological functioning and biogeochemical cycling. The importance of soil erosion is underscored, however, by its widespread occurrence, which is often severe in nature, across the biome and among land uses.

Biogeochemical processes were ranked as being marginally more important than soil erosion (Table 5.4). The ranking of the components of biochemical processes indicates that, while primary productivity is considered to be the key process, nutrient leakage and carbon storage rank equally important. Primary productivity underpins trophic relationships and ecosystem functioning and carbon storage is directly dependent on primary productivity. Nutrient leakage is an everyday facet of land use that has the potential to disrupt the organization of natural communities.

Notwithstanding the fact that there are conditional relations among variables of hydrological functioning, water quality was rated as being the most important for maintaining aquatic biodiversity and seasonality and quantity was rated the least important (Table 5.4). Quality is usually more important than quantity because a change in quality can disrupt biota rapidly, whereas a decrease in quantity is usually associated with a slower impact process. Water quantity will assume the greatest importance under extreme conditions, such as a river being transformed from perennial to seasonal, while water quality affects aquatic biota more by eutrophication than by sedimentation.

The relative importance of medicinal plants, building materials and craftwork materials as indicators for harvestable goods reflects their need, use and

availability (Table 5.4). Medicinal plants and building materials were ranked as being equally important and more important than harvestable goods.

(c) *Landscape composition*

(i) *Habitats*

The role of landscape composition is dominated by habitat as opposed to species (Table 5.3). Species, however, have little value without habitat. Very clear differences in the relative importance of the six habitats have been recorded (Table 5.3). Owing to its extent and species richness within the Grassland Biome, grassland was ranked as being the priority habitat for biodiversity integrity. Rocky grassland is perhaps as rich per unit area but covers less area. Wetland, riparian and aquatic habitats were not considered to be as important for the maintenance of biodiversity asset as grassland was and although they are important for hydrologic functioning, they each cover a relatively small area. Wetlands, riparian and aquatic habitats are of decreasing significance in regions of greater aridity. Forest in the moist sub-biome was considered to be of equivalent importance to riparian areas and of greater importance than aquatic habitats.

(ii) *Species*

Mammals were ranked as being moderately more important than birds and strongly more important than insects as indicators of biodiversity integrity (Table 5.3). The reason for this is the spatial scale over which mammals function and their greater restriction than birds to an area.

Ants were considered to be the most important group for reflecting biodiversity integrity of insects (Table 5.3). This is on account of their megadiversity, trophic diversity (which includes granivory, nectarivory, carnivory and herbivory), their role in plant propagation including pollination and seed dispersal and their role as a food source, especially for reptiles and some birds. Ants are also soil engineers, but not as important in this role as termites. Termites were considered to be the second most important group on account of their greater role in decomposition and soil engineering than the other groups, as well as their serving as a food source for a wide range of organisms. Dung beetles were perceived to be considerably less important than ants and moderately less important than termites as indicators of biodiversity integrity.

In terms of serving as indicators of biodiversity integrity, a clear rank hierarchy was recorded for bird groups (Table 5.3). Cranes, korhaans, bustards and kestrels were considered to be the most important. Larks, pipits and longclaws were ranked less valuable as indicators because they are capable of persisting under most land uses, provided natural grassland remains. The blue swallow was not considered as part of the swallow and martin group because of its restricted range and specialized habitat requirements.

Mammal groups differed markedly in their suitability to serve as indicators of biodiversity integrity (Table 5.3). Their usefulness as indicators of biodiversity integrity was inversely related to their perceived ability to persist in landscapes affected by transformation and the weaker indicators were considered to be groups that are relatively lightly affected by transformation. Shrews are influenced the least by transformation, while moles and mole-rats are weakly influenced.

Small grassland-dependent antelope were considered to be very good indicators because they respond to a larger scale of transformation and cannot persist unless a sound functioning grassland system is in place. Their importance was

emphasized in the heavily transformed moist sub-biome because of the high conservation profile of oribi. Larger predators were also considered to be good indicators, because they integrate trophic relationships over a large area or a broader suite of organisms. Jackal and caracal are, however, relatively opportunistic species with wide habitat ranges and good tolerance to disturbance and were, therefore, not considered to be priority indicators.

(iii) Alien plants

The relative importance of the threat of herbaceous and woody aliens was considered to vary across the Grassland Biome. The impact of woody aliens on biodiversity was ranked as being considerably greater than that of herbaceous alien species (Table 5.3).

5.4.2. Impact of land uses on biodiversity

(a) Ranking of land uses

The relative influence of land uses on landscape structure (Figure 5.1; Table 5.4), landscape functioning (Figure 5.2; Table 5.4) and landscape composition (Figure 5.3; Table 5.3) are relatively consistent with one another and with an overall statement for biodiversity integrity (Figure 5.4; Table 5.8).

The overall rank hierarchy among land uses in the moist sub-biome is in the order of (least to most impact) conservation estate, game farming, livestock ranching, tourism and recreation, dryland cropping, irrigated cropping, rural settlement, dairy farming, timber production and finally urban settlement (Figure 5.4; Table 5.8). Conservation estate emerges, as expected, as the standard by

which the impact of other land uses can be assessed. The other nine land uses vary from “biodiversity friendly” to “biodiversity write-off”.

(b) Profile of individual land uses

Land uses vary from relatively untransformed in the case of conservation to almost complete transformation of the natural asset in the case of urban development. Urban development was considered to have an extreme negative impact on biodiversity integrity throughout the biome, which is expressed at all levels of evaluation. There is near complete transformation in urban environments with only isolated fragments of natural asset remaining. This environment also has grossly disrupted ecosystem functioning in the form of dramatically perturbed fire and grazing regimes, biogeochemical processes and hydrological functioning. Urban environments also have elevated soil erosion, with extreme loss of habitat and species, and an increase in the presence of alien plants.

As expected, the “biodiversity friendly” land uses were considered to be livestock ranching and game farming. Although these two land uses negatively affect a large proportion of the indicators, impacts associated with them are generally thought to be slight.

Although tourism or recreation properties were considered to have a substantial negative impact on biodiversity integrity, this is not at the scale of production activities. This impact derives mainly from transformation of natural asset for infrastructure development in a pattern of greater than average fragmentation, reduced fire and grazing management of the remaining asset, increased human density and attendant problems of outputs and disturbance and finally an increase in the threat of alien plants. Difficulties in assessing this land use were related to the definition of a norm for developments of this nature.

Rural settlement were considered to have a very strong negative impact on biodiversity integrity for reasons that relate to the nature of agricultural activity as much as to patterns of transformation. Although rural areas are possibly less transformed than most production areas, fragmentation is high and the impact of grazing on rangelands is significant. The scale of soil erosion from both rangelands and croplands, the effects of this on biogeochemical processes, hydrological functioning and unregulated use of water resources were considered to be important.

Croplands (dryland or irrigated), dairy farming and plantation forestry are associated with virtually complete transformation of natural asset. Contributing factors to the severe impact of irrigated cropping and dairy farming on biodiversity integrity are their influences on fauna and on ecosystem functioning, especially fire and grazing regimes, nutrient leakage and hydrological functioning. By contrast, timber estates were considered to have less of an effect on ecosystem processes, although soil erosion associated with this land use is considerable and fire regimes are totally disrupted.

(c) Impact on landscape composition

The influence of a land use on the biodiversity integrity of any of the five terrestrial habitats depends on the importance of a habitat for biodiversity and the extent of impact (Table 5.5). Grassland, which was considered to be the most important habitat for biodiversity, is transformed not only by urban development and rural settlements, but by production of timber, crops, and milk. The other habitats were perceived to be of lesser importance for biodiversity integrity. Urban and rural settlements together with dams for irrigation cropping and dairy farming were considered to pose the greatest threat for direct loss of wetland and riparian habitat. Riparian habitat is also subject to impact from urban and rural

settlements, timber plantations, croplands and dairy farms. On account of their topographic position and protected status, there are very little direct impacts on forests by commercial production properties, but forests are unsustainably exploited in some rural areas.

The highest impact on birds and mammals was associated with urban and rural settlement areas and timber plantations. Most grassland-dependent birds and mammals will be excluded from urban areas on account of the extent and nature of transformation, and on account of human impact. In rural settlements, hunting pressure is an important factor. The impact of transformation for production systems on birds and mammals is acute in timber estates on account of their extent and impact on physiognomy. Despite maintaining a fair amount of natural asset, tourism and recreation properties were not considered to be benign on account of high human disturbance. Livestock ranching and game farming were ranked as the most benign land uses for maintaining biodiversity integrity. Game farming was ranked marginally more beneficial although this could reflect perception more than reality. All participants stressed, however, that the impact of livestock ranching and game farming depended on the quality of management.

All three insect groups were significantly negatively impacted by timber production, dairy farming, dryland cropping, irrigated cropping and urban development (Table 5.5). By contrast, livestock ranching and game farming were considered to have a slight to moderate negative impact on ants and virtually no impact on dung beetles and termites. Intermediate between these two groups, rural settlement was considered to be beneficial for termites but slightly or moderately harmful for dung beetles and ants respectively. Tourism

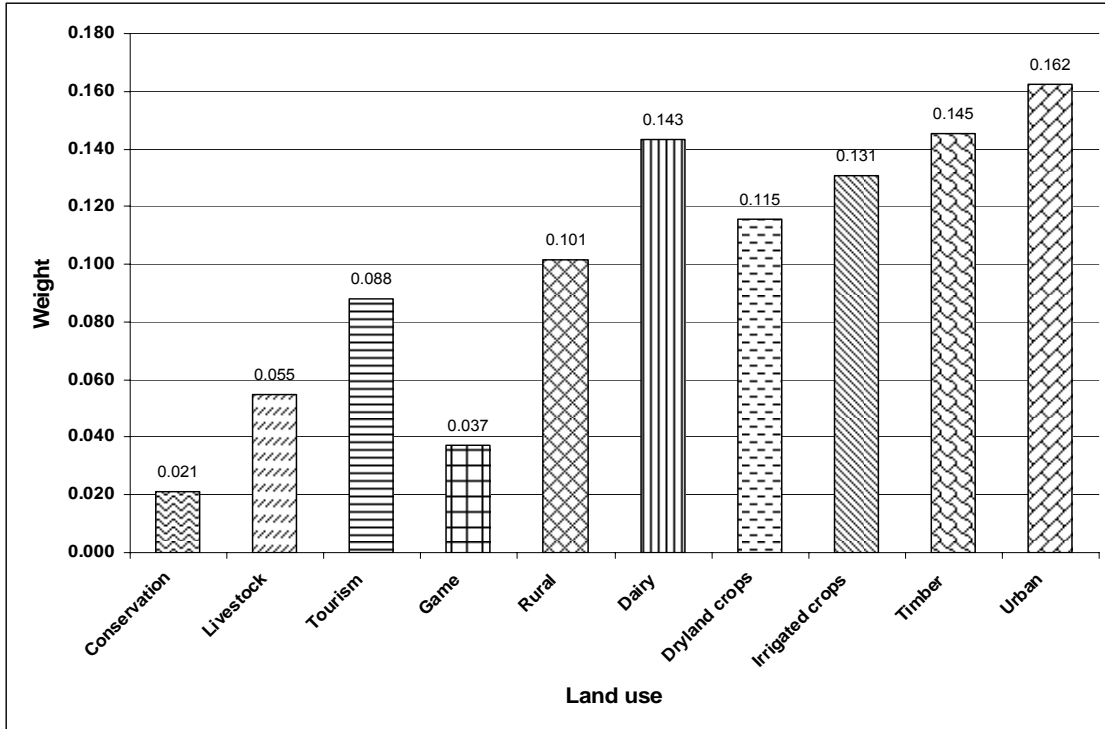


Figure 5.1: Relative impact of land use on landscape structure in the moist sub-biome of the Grassland Biome.

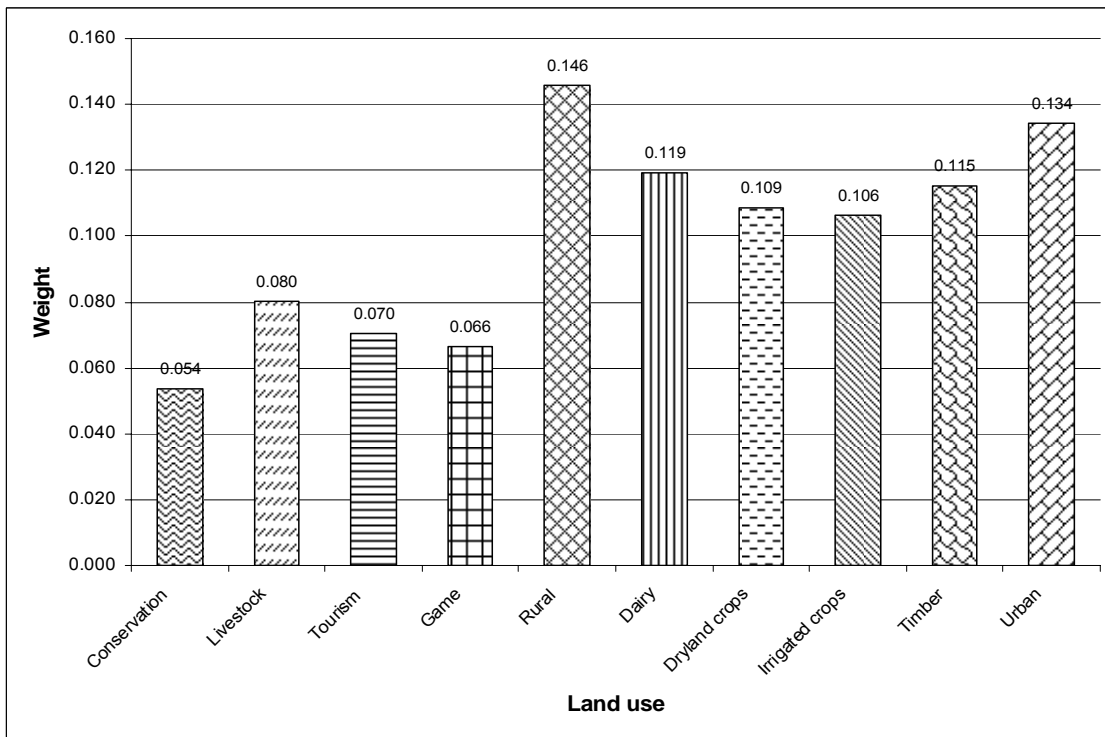


Figure 5.2: The relative impact of land use on landscape function in the moist sub-biome of the Grassland Biome.

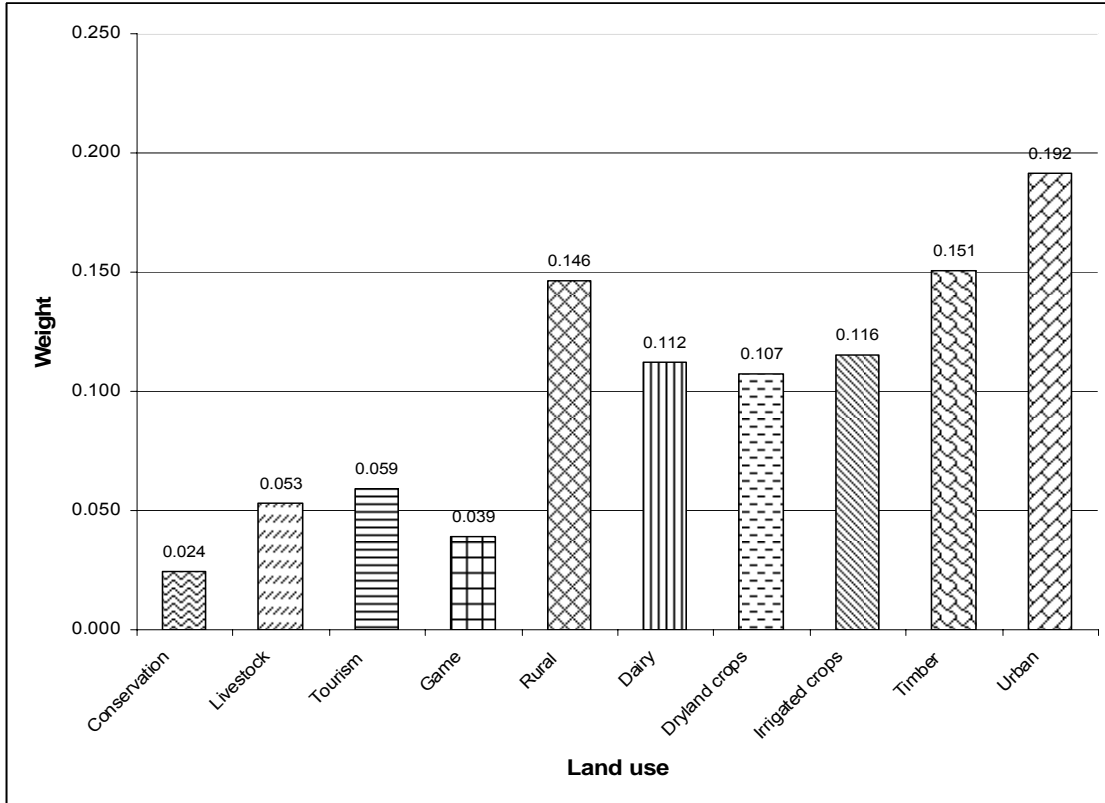


Figure 5.3: The relative impact of land use on landscape composition in the moist sub-biome of the Grassland Biome.

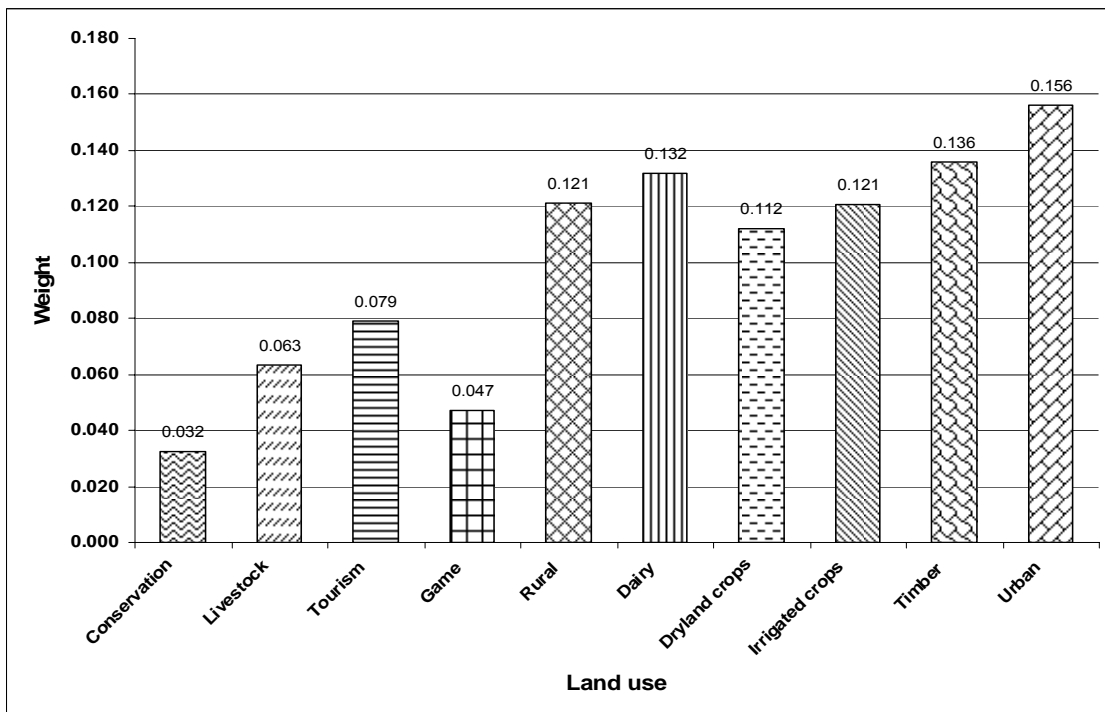


Figure 5.4: The relative impact of land use on overall biodiversity integrity for the moist sub-biome of the Grassland Biome.

and recreation was considered to have a slight negative impact on termites and a moderate impact on ants and dung beetles.

Alien plants are an increasing threat to indigenous biodiversity. Gardens in towns and on tourism and recreation estates are primary sources of alien vegetation. Urban and peri-urban developments, together with croplands (both dryland and irrigated) and timber estates were considered the land uses that most encouraged the establishment of aliens.

5.4.3. Recommendations for land uses

(a) Conservation estate

As the benchmark for biodiversity conservation, a conservation estate is of obvious benefit for maintaining grassland biodiversity integrity. Respondents, however, indicated that very few conservation areas in the grassland biome had been promulgated with the objective of conserving biodiversity. A protected area network designed for biodiversity conservation is worthy of investigation and formal policy and legislation in this regard is essential.

(b) Livestock ranching and game farming

Livestock ranching and game farming are the obvious means by which to maintain grassland biodiversity in a production landscape. However, the effectiveness of livestock ranching or game farming in maintaining biodiversity depends more upon management than upon the grazing system or animal type. Game farming is, however, a commercial enterprise and may be based on highly selective herd-forming grazers, some of which are aliens and have a negative

impact on their environment. Mixes of species that are biodiversity-friendly, a combination of grazers and browsers and different stocking strategies may be worth investigating in a dual ecological and economic context. A spatially explicit formulation of grassland conservation by means of livestock and game ranching would recognize areas in which extensive ranches could be consolidated, preferably in association with core reserve areas. Commercially viable approaches by means of which this could be achieved need to be evaluated.

(c) Dairy farming

Dairy farming should not be promoted for its contribution to maintaining biodiversity, although opportunities for expansion are climatically, edaphically and physiographically constrained. The issue should be to intervene in order to ameliorate effects mainly on ecosystem functioning, especially nutrient leakage.

Dairy farms would invariably have a proportion of their asset that cannot be transformed. Maintaining the connectivity of this asset to the natural asset in the region should be a primary goal, which would ideally be achieved through biodiversity planning at the municipal or macro-landscape level.

(d) Crop farming (dryland and irrigation)

Dryland or irrigated cropping does not have considerable potential for expansion because of limited water supplies and arable soils, but increases in both types of cropping are ongoing. A key issue is the positioning of future crop developments, which could be predicted on the basis of soil maps of arable land and climate information.

Whether the crop is irrigated or not is also important. Although dryland cropping is of greater benefit to biodiversity integrity than irrigated cropping, the latter can produce two crops per annum whereas dryland cropping produces only one. It can accordingly be argued that extensive irrigation would reduce the need for continuing land transformation in meeting food production demands.

(e) Tourism and recreation

Impacts associated with tourism and recreation was difficult to assess because of the diverse array of activities that are included in this land use. This land use could make some contribution to maintaining biodiversity integrity, but the perceived norm of such development is that it serves as a diluted form of urban expansion in rural settings. The manner in which this land use is conducted through the biome first needs to be understood in terms of the full range of activities and the relative importance of each. Activities that are likely to be important for maintaining biodiversity are probably a small proportion of the total set or of demand. The general perception was that it should not be adopted as a vehicle for maintaining biodiversity.

Tourism and recreation developments in rural settings would not necessarily be a preferable alternative to agricultural uses. They are also likely to act as a catalyst in further fragmenting the regional landscape and may be accompanied by the establishment of low density up-market residential developments.

(f) Timber plantations

By contrast, timber estates have considerable potential for expansion, especially as breeding programmes have produced varieties that can be grown at lower rainfall. It is also perceived politically to be a vehicle for economic development of rural areas. The extent of fragmentation is large and the landscape becomes extremely fragmented. Timber estates make a limited contribution to biodiversity conservation because a portion of an estate remains unplanted. However, this benefit is small and is offset by severe impacts on landscape functioning, specifically soil erosion, nutrient leakage, and hydrological functioning. In addition, timber estates are a main focus for the spread and expansion of both woody and herbaceous alien plants.

The contribution of timber estates relates mainly to maintaining connectivity at this greater scale, as well as to maintaining any obvious priority conservation assets. The large areas of land that the industry claims are effectively under conservation need to be assessed for their conservation value in terms of connectivity, geometry and porosity. The core areas of natural asset need to be identified and the isolated fragments discounted.

The contribution to connectivity of these estates rests largely upon the viability of remaining corridors, which in many instances are too narrow and poorly managed to be effective. Potential exists for mitigation of impacts of plantation forestry through limiting access infrastructure, better control of erosion from access infrastructure and limiting the impact of harvesting. Planting should be limited to those areas that can be properly accessed and to slopes which are permissible for planting. In addition, herbaceous and woody alien plants must be controlled and the burning of slash must be prevented. To maximize the conservation benefit of the remaining natural asset within timber estates, the

larger spatial scale of the industry needs to be recognized because large areas within targeted catchments are usually developed.

(g) Rural settlement

Rural settlement in its current form of practice does not contribute much towards maintaining biodiversity, nor does it offer much opportunity unless practices change. Key interventions that could make a difference would be closely regulated harvesting activities, especially of medicinal plants, a drastic decline in the hunting pressure of humans and domestic animals and cropping practices that ensure soil conservation. Livestock impacts and the need for a reduction in stock densities are also important areas to concentrate on.

(h) Urban settlement

Although urban developments are effectively a biodiversity “write-off”, a critical issue is the management of the natural asset left behind in these environments. It is suggested that planning actions in urban environments must contain the urban “footprint” and that expansion must be limited to the areas least important for the maintenance of biodiversity integrity (Zipperer, Wu, Pouyat and Pickett 2000). Urban expansion in the guise of rural development should be critically reviewed, while the role of municipalities and the Development Facilitation Tribunal in promoting urban sprawl should be questioned.

Urban areas can maintain a degree of connectivity with adjacent undisturbed areas through the planning of biodiversity corridors and can conserve priority biodiversity assets. The current environmental management plan requirements for Integrated Development Plans (IDPs) of municipalities can contribute to the achievement of goals for biodiversity conservation within urban areas.

CHAPTER 6

EVALUATION OF PROPOSED METHODOLOGY AND APPLICATION FOR LAND USE DECISIONS

6.1. Evaluation of methodology

6.1.1. The Analytic Hierarchy Process

The following may be considered to be essential stages for a procedure that includes the Analytic Hierarchy Process (AHP) and group decision-making as employed for the evaluation of land use impacts on landscape biodiversity integrity in the Mistbelt Grassland (Section 4.2) and the Grassland Biome (Section 5.2):

- (1) The establishment of clear terms of reference for the evaluation.
This must include details of land use alternatives to be evaluated.
- (2) The identification of experts in biodiversity and other fields, and essential role-players to participate in the evaluation procedure in accordance with the fields of specialization or nature of input that is required.
- (3) Application of the AHP and decision-making by a group of experts and key role-players to:
 - i Establish an appropriate hierarchy of decisions with a clear goal for each level in the hierarchy.
 - ii Identify and describe a set of criteria to evaluate the alternatives at each level of the hierarchy with respect to the goal for that level. This may include a set of indicators of the integrity of a biodiversity component in accordance with the goal for a specific hierarchical level.

- iii Undertake comparative judgements to rank indicator criteria for each level in the hierarchy.
 - iv Undertake comparative judgements to rank alternatives with respect to each indicator criterion for each level in the hierarchy.
- (4) Obtaining of relative weights for alternatives at each level of the hierarchy and overall relative weights for the evaluation (final ranking).

(a) Combined workshop and interview process

The structured approach offered by the methodology allows for input by a range of experts to decision-making in the AHP. This process can be seen as participative, transparent and non-biased, rather than subjective and obscure. What is important is that individuals can participate in a decision-making process in a manner which allows for qualified input and the development of trust. Diverse viewpoints can be debated and integrated into decisions before consensus is reached. The process therefore ensures that all participants have made input to decisions which determine the final results.

Experience gained in this study indicates that more than one day will be required to hold a workshop at which a comprehensive evaluation of impacts of land use on all components of biodiversity using the AHP is conducted. Accordingly, three individual workshops were held to examine compositional, functional and structural components of biodiversity (Section 4.4). It was also difficult to set a date for a full-day workshop at short notice (less than one month) that suited all the potential participants.

To expedite the evaluation procedure, the following process which incorporates a relatively short workshop (about half a day) followed by personal interviews is proposed (Section 4. 2; Section 5.2):

- (1) Potential participants with the necessary expertise must be identified and arrangements made for a half-day workshop.

- (2) A background information document must be supplied to all participants to enable them to prepare for the workshop. This document must contain sufficient information regarding the terms of reference for the evaluation, the procedure, details on alternatives (such as land uses, plans or programmes) and a possible list of indicator criteria (such as environmental indicators) for the assessment of the alternatives in accordance with the expected hierarchy of decisions.

- (3) The following must be undertaken at the workshop:
 - i Discuss the background information document and clarify any uncertainties by presenting sufficient supporting information.
 - ii Identify and describe the alternatives to be evaluated.
 - iii Discuss the AHP and the hierarchy of decisions as appropriate to the evaluation. Identify the objectives for each level of the hierarchy in accordance with that for the exercise.
 - iv Identify and describe appropriate indicator criteria for the evaluation of the alternatives at each level of the hierarchy.
 - v Explain the decision-making process for the ranking of indicators criteria and alternatives with respect to indicators to obtain relative weights for land uses at each level.
 - vi Describe consistency in scoring and what the consequence of inconsistent scoring is.

- (4) Follow up with personal interviews with each participant to undertake the following for each level of the hierarchy and record the reasons for participant's decisions:
 - i Rank criteria for each level of the evaluation; and
 - ii Rank alternatives with respect to each criterion for each level.

- (5) Identify any inconsistent scores and arrange for further interviews with the participants to re-examine these scores and clarify uncertainties. This process is repeated until all scores are consistent.

- (6) Complete the calculations for the relative weights indicator criteria and alternatives with respect to each indicator for each level to obtain relative weights for the overall impact of alternatives. Inform all participants and relevant interested parties about the outcome of the evaluation.

It is important that consensus is reached at the workshop regarding alternatives and criteria for the evaluation of these alternatives and that the reasons for decisions in this regard are understood by all participants.

The procedure as described allows for the participative decision-making process in the AHP to be expedited. Adequate opportunity is provided in a workshop environment for an examination of indicator criteria and the evaluation process.

Experience at the workshops and personal interviews conducted during this study (Section 4.2.2; Section 5.2.2) indicate that the following are the advantages of a process that includes personal interviews rather than a workshop environment for decision-making in the AHP:

- i Participants are not intimidated by the viewpoints of other group members and find it easier to supply reasons for their decisions, based on personal experience;
- ii “Group-think” and the loss of individual opinion does not occur; and
- iii Problems with interpretation of the various situations implied in the ranking procedure are easier to identify and clarify in personal interviews rather than workshops.

Results from the combined workshop and personal interview procedure are readily accepted by participants because the reasons for individual scoring during the ranking process is not seen as compromising the consensus reached during the workshop. This evaluation procedure is considered to be rapid and cost-effective and most participants are more readily available for a short workshop followed by interviews than a prolonged workshop.

(b) Group decision- making

The lack of group discussions and interactions during the ranking procedure in the AHP and the use of personal interviews for this phase are not considered to be a drawback to the process (Section 5.2). A clear understanding of each indicator element and the various land use alternatives is essential and these should be discussed during the workshop so that the answers obtained during interviews provide a statement that reflects the participant’s personal experience and understanding of the subject and one that is free of any influences due to the opinions of other participants and the problems of “group-think”. In addition, scoring at workshops in which group discussions were allowed for all rankings, rather than personal interviews, did not show improved consistency (Section 4.2). It is a process that emphasizes individual contributions and not merely general participation that will ensure consensus regarding outcomes.

(c) Rating scale of the Analytic Hierarchy Process

Application of the linear nine-point continuous rating scale for the ranking of two elements in the AHP can be problematic and needs to be conducted with caution. During the application of the AHP in this study (Section 4.2; Section 5.2) it was evident that participants seldom thought linearly about impacts during the ranking process. Over- or underemphasis of ratings was common and “strongly more” or “strongly less important” were frequently over- or underrated to “extremely more” or “extremely less important” (Table 3.1). It was therefore essential to assist participants so that they could retain a clear perspective over the entire range of situations or conditions that would be associated with each point on the rating scale. This problem should be discussed with participants during the workshop and prior to scoring to ensure that it is taken into account during all rankings.

6.1.2. Level of application

(a) Landscape-level evaluation

In an assessment of the impacts of land use on biodiversity integrity in the Mistbelt Grassland at the landscape-level, a simple hierarchy of decisions with respect to impacts at two levels was undertaken (Section 4.2). Accordingly, a single set of indicators for landscape composition, structure and function was used to rank land uses with respect to these components. Components were ranked to provide overall relative weights for land uses with respect to their impacts on biodiversity. Results indicate that the application of the AHP and decision-making by biodiversity experts can provide a clear ranking of land uses with respect to their impact on each component and an overall statement of their impact on biodiversity integrity (Section 4.3). In accordance with the profile of

indicators selected, this simple evaluation can indicate where broad intervention strategies to address land use impacts on biodiversity integrity should be directed (Section 4.4).

(b) Biome-level evaluation

An evaluation of impacts of land use on biodiversity integrity of the moist sub-biome of the Grassland Biome indicates that the methodology employed for the Mistbelt Grassland study can be expanded to that of a biome-level evaluation (Section 5.2). An increase in the number of levels in the hierarchy of decisions and an expansion of indicators of biodiversity integrity to include those for species, habitats and processes, provide a more detailed evaluation of land use impacts (Section 5.2). Accordingly, 52 indicators at 3 levels of enquiry were selected to evaluate the relative impacts of 10 land uses.

Results obtained for the Grassland Biome evaluation indicates that, as for the Mistbelt Grassland study, a clear and consistent ranking of land uses is obtained for the various components of biodiversity at the various levels of evaluation in the hierarchy and that an overall statement of their impact on biodiversity integrity can be obtained (Section 5.3). These results indicate that land uses are associated with varying relative impacts, which land uses should be promoted and for which further investigation is required to mitigate impacts on biodiversity. Details of ranking of land uses with respect to impacts on each indicator element at each level in the hierarchy provide information on impacts on biodiversity components and assistance regarding intervention strategies. Although intervention strategies will primarily depend on the weights allocated to the impacts of land use alternatives on indicators of biodiversity integrity, further investigation may be required to determine what the impacts are at lower organizational levels (population, species or genetic). Further refinement of

intervention strategies or mitigation measures may be required to accommodate results obtained at these levels.

An expansion of the hierarchy of decisions, as for the Grassland Biome study, therefore allows for the inclusion of elements that are biodiversity indicators for a range of organizational levels. It also allows for an expansion of the decision-making process to enable a more detailed evaluation of the relative impact of land use alternatives. Results also provide information regarding the nature and organizational level at which intervention strategies must be directed. The inclusion of biodiversity indicators from lower organizational levels will accordingly provide credibility to biodiversity management decisions at the macro-level or landscape level.

6.1.3. Selection of indicators

In the evaluation procedure used for this study, indicators for each of the structural, functional and compositional components of biodiversity integrity, as appropriate to the landscape evaluated, were selected (Section 4.2; Section 5.2). It is important that indicators, irrespective of which organizational level they represent, must be sensitive enough to provide an early warning of any changes in biodiversity integrity and must be representative of the area to be evaluated. The importance of choosing appropriate indicators that have real value for the exercise is fundamental to its success, because it is the strength of indicators that will reinforce the relative weights scored for land uses (Section 4.3; Section 5.3). Clearly, the value of indicators must be determined from empirical information and their status must be well established. Where such information is not readily available, or is lacking, input by experts, as applied in this study is appropriate. Changes to the status of biodiversity indicators will occur in time, and it is essential to re-evaluate this if the procedure is repeated for the same study area at a later date.

As an evaluation is expanded to further hierarchical levels within the AHP, the refinement of information on indicators may be required. It is critical to take into consideration the level of decision-making that is required, as dictated by the terms of reference for an assessment, when indicators are selected. Accordingly, it may be more appropriate to select the status of a habitat rather than individual species as an indicator for a strategic assessment. It is also important that impacts on indicators are readily discernable for the entire range of land uses in the study area and that indicators are not influenced by topographic or geographic factors. It would therefore not be appropriate to use an indicator species that has a limited geographic range within a given study area.

Biological systems operate within the constraints of the biosphere and are directly or indirectly linked. Confounding of indicators to a greater or lesser extent will therefore always occur and should be appropriately managed. The most effective mechanism to manage confounding is a very precise description of the indicator as applied to the evaluation. This description must define the boundaries of application of the indicator, to clearly indicate its application within a specific component of landscape biodiversity. As an example, transformation of vegetation as an indicator of landscape structure may be defined as the net loss of natural asset such as communities and habitats in the landscape, rather than geometric or spatial changes that may best be defined under fragmentation. It is important that indicators are described within a workshop to ensure that there is consensus regarding their definition, so that uncertainties in this regard do not influence scoring.

6.1.4. General comments

Application of the AHP and decision-making by experts clearly has value in natural resource management decisions that require the consideration of issues

across many disciplines, where such empirical information is not readily available. The flexibility of the methodology as proposed for the evaluation of land use impacts on biodiversity integrity in the Mistbelt Grassland and Grassland Biome has particular value when applied to management decisions where input is required from a diverse range of experts and interested parties and where solutions must be acceptable to many stakeholders. This study has indicated that, although the methodology has value in decision-making at a strategic level and where objectives are to inform broad intervention strategies (Section 4.4.3; Section 5.4.3), an expansion of the hierarchy of decisions can accommodate information regarding the impacts of land use on biodiversity integrity at the habitat and species levels (Section 5.2.5; Section 5.4.1). The relative weights for land use impacts at these levels may guide decisions regarding the mitigation of biodiversity impacts at a micro-level or site specific level.

Integrating decisions regarding natural resource management with legal, social and economic considerations can be time-consuming and costly and, to be acceptable, requires an extensive process that provides for input from a range of specialists, role players and interested parties. The AHP evaluation procedure applied in this study is flexible and may be expanded to encompass an extensive hierarchy of managerial and planning tasks in a single cost-effective exercise. This procedure allows for the integration of biodiversity, institutional and socio-economic concerns and participative decision-making by multiple role-players to facilitate consensus regarding natural resource management.

What is important is that the process as described allows for a group decision-making exercise which nonetheless emphasizes individual contributions within a framework, that promotes the systematic and rational examination of a problem and generates quantitative information for which there is accountability and acceptance.

6.2. The Land Use Evaluation Model

In accordance with the objectives for this study (Section 1.3), and the methodology employed and insights obtained in the evaluation of impacts of land use on biodiversity integrity in the Mistbelt Grassland (Section 4.2) and the Grassland Biome (Section 5.2), the Land Use Evaluation Model (LUEM) is proposed for the assessment and management of land use impacts on the biodiversity integrity.

(a) Stages of the LUEM

The following stages are proposed for the LUEM (Figure 6.1):

- Terms of reference;
- Assessment;
- Implementation;
- Monitoring; and
- Re-evaluation.

Important process requirements for each stage in the LUEM are the following:

- (1) Terms of reference:
 - i Identify the need for the evaluation and specific instructions regarding the objectives for the exercise. These objectives can be related to land use or biodiversity management or conservation in a specific area.
 - ii Identify and describe the study area and review geographic, topographic and geophysical information regarding it.

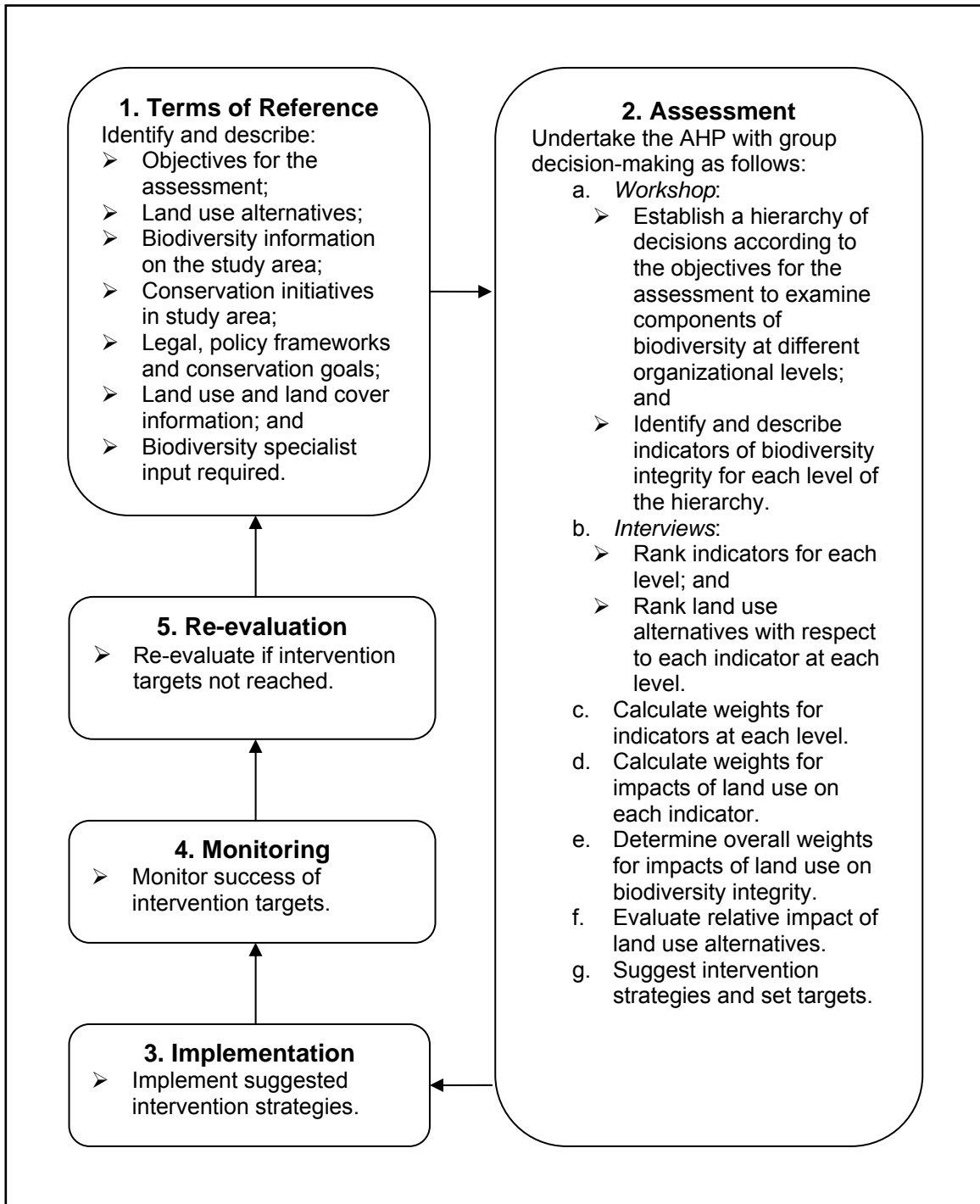


Figure 6.1: Proposed Land Use Evaluation Model for the assessment and management of impacts of land use on biodiversity.

- iii Compile and review any information on the biodiversity status of the area to be assessed. This includes details on existing conservation initiatives in the study area.
- iv Identify the land use alternatives and land-cover information applicable to the level of investigation proposed (spatial level of enquiry) for the study area.
- v Examine existing legal, policy or other frameworks and goals for the management and conservation of biodiversity in the study area (this includes environmental and town planning legislation and frameworks).
- vi Identify the nature of biodiversity specialist input that will be required in the decision-making process and identify participants.

(2) Assessment:

- i Apply the AHP in a group decision-making exercise employing biodiversity experts at a workshop and establish a hierarchy of decisions with respect to the objectives for the evaluation. The various levels in the hierarchy may evaluate impacts of land use on specific biodiversity organizational levels as required for the formulation of management strategies. The hierarchy of decisions will be established in accordance with the terms of reference and may include an evaluation at levels from population/ species through to community/ ecosystem to the landscape level for compositional, functional and structural components of biodiversity.
- ii Identify and define criteria as indicators of the integrity of the compositional, functional and structural components of biodiversity for various organizational levels in accordance with the hierarchy of decisions that has been established.

Accordingly, indicators may be identified for the population/ species, as well as community/ ecosystem levels.

- iii Apply the AHP in personal interviews with workshop participants to make the following:
 - Comparative judgements to rank indicator criteria for each level of the hierarchy;
 - Comparative judgements to rank land use alternatives with respect to impacts on each indicator criterion for each level;
 - Determination of relative weights for impacts of land uses for each level of the hierarchy; and
 - Determination of overall relative weights for impacts of land use on components of biodiversity and overall weights for impacts on biodiversity integrity of the landscape.
- iv Determine, in accordance with the objectives for the evaluation as described in the terms of reference, areas for intervention and suggest appropriate strategies for the mitigation of land use impacts on biodiversity integrity. Areas for intervention will be determined by the relative weights recorded for impacts on biodiversity indicators in the various organizational levels. It is expected that weights for impacts on indicators at lower levels (such as population and species levels) will expand on the nature of impacts at higher levels and inform intervention strategies at that level. Intervention strategies are determined through an evaluation of the significance of relative weights recorded for land use impacts on indicator criteria at a specific hierarchical level.
- v Set suggested targets and goals to facilitate biodiversity conservation as determined by the significance of impacts of

land use on biodiversity indicators, the terms of reference for the study and conservation targets for the study area.

(3) Implementation:

- i Implement the suggested intervention strategies for the mitigation of land use impacts as proposed in the assessment phase.
- ii Apply intervention strategies at a strategic, local or site specific level.

(4) Monitoring:

- i Monitor the success of the implementation of intervention strategies; this will indicate to what extent the targets that have been set for biodiversity conservation during the assessment stage have been achieved.

(5) Re-evaluation:

- i Re-initiate the evaluation strategy, if targets that have been set in the intervention strategies for biodiversity conservation during the assessment stage have not been achieved. Accordingly, a re-examination of the terms of reference for the study will be essential and the process will have to be followed through to monitoring and implementation of amended or additional intervention strategies.
- ii Re-examine indicator criteria for biodiversity integrity and extend the hierarchy of decisions to accommodate further levels of investigation, if intervention strategies are found to be unsuccessful. A more detailed assessment of the nature of impacts on biodiversity integrity can be made if indicator criteria for each component of biodiversity are expanded. Accordingly, more comprehensive recommendations

regarding interventions for impacts of land use on specific components of biodiversity should be formulated and new targets in this regard should be set.

6.3. Application of the Land Use Evaluation Model

6.3.1. Integrated environmental management

Taking the definition of integrated environmental management (IEM) into account (DEAT 2004a) (Section 2.4.1), the proposed LUEM can be expanded to become a tool that will inform decision-making regarding the management of environmental impacts associated with alternative policies, plans or programmes associated with any stage of the planning and development cycle for a project (i.e. project life cycle). Expansion of the hierarchy of decisions in the AHP allows for the establishment of limitless levels of enquiry in the LUEM and for the investigation of impacts on the biophysical, social and economic components of the environment (Section 6.2) as related to alternative plans or programmes. Accordingly, indicator criteria for the standards of evaluation for a number of environmental components can be integrated in a single evaluation process that is time-saving and cost-effective. Expansion of the hierarchy, therefore, allows for the evaluation of issues related to various phases of the project life cycle. The LUEM can be extended to also incorporate information obtained from other IEM tools such as screening or environmental impact assessment reports and environmental management or monitoring plans, to further support decisions regarding the significance and mitigation of environmental impacts. The assessment stage of the LUEM also makes explicit provision for stakeholder engagement in an open and transparent process that can facilitate the

credibility of decision-making at all levels of evaluation and during all phases of an activity as underwritten by IEM for sustainable development.

(a) The LUEM as an integrated environmental management tool

Essential stages in the LUEM (Section 6.2) may be expanded to include the assessment of alternative policies, plans or programmes on any one or more components (biophysical, social or economic) of the environment to facilitate IEM as follows (Figure 6.1):

(1) Terms of reference

- i The terms of reference for a study may be expanded to evaluate the impact of alternative development policies, plans or programmes associated with any stage in the life cycle of a project on any biophysical, social or economic component or combination of components of the environment. For example, a study may be undertaken to determine the impacts of various land use plans on the social and economic status of a community.
- ii A review of available empirical information for a proposed project may include a review of IEM tools such as (DEAT 2004a):
 - Screening reports;
 - Environmental impact assessments;
 - Biodiversity and cultural-historical conservation plans;
 - Social impact assessments;
 - Specialist reports on environmental quality;
 - Environmental management plans;
 - Strategic impact assessment reports; or

- State of environment reports.
- iii Key specialists and other interested parties that are required to participate in the decision-making process must be identified. For the socio-economic impacts of land use options, interested parties may include community organizations and non-government organizations.
- iv Existing legal, policy or other frameworks and goals for the management and conservation of the environment, as applicable to the project, must be examined (this includes environmental and town planning legislation and frameworks).

(2) Assessment

- i The objectives for the evaluation must be defined in accordance with the terms of reference for the study. A hierarchy of decisions must be established and must reflect all stages or levels of evaluation and essential issues that must be resolved at each level with respect to the objectives for the study. Typically, decisions regarding various potential impacts of alternative plans at a stage in the life cycle on a component or sub-component of the environment, (biophysical, social or economic) may be associated with a specific level in the hierarchy.
- ii Criteria that serve as indicators of the integrity of the environmental component or components must be defined for each level in the hierarchy of decisions. The indicator elements must reflect the standards to be set for an evaluation of alternatives with respect to the objectives for the evaluation. Indicators must be applicable to the entire study area, sensitive enough to reflect any changes or trends in the

integrity of the environment and easy to measure and verify during monitoring.

- iii Ranking of indicators for each level and alternative policies, plans or programmes with respect to indicators for that level will yield relative weights for the respective levels. Relative weights with respect to impacts on environment components or sub-components may be integrated to provide overall relative weights for various alternatives.
- iv The relative impact of alternatives must be evaluated for each level of assessment and suggestions for intervention must be based on the significance of impacts on individual or groups of indicators.
- v Targets for the intervention strategies must be set in accordance with the significance of impacts and goals for the management or conservation of environmental components that have been established for the study area.

(3) Implementation

- i The various intervention strategies, as suggested for land use impacts on the environmental component or components, must be implemented in the way suggested in the assessment stage.

(4) Monitoring

- i Monitoring of the success of intervention strategies will indicate if the targets set for the mitigation of environmental impacts have been achieved. If not, the evaluation process may need to be repeated and indicators expanded to facilitate

a more detailed assessment of impacts and a refinement of intervention strategies.

6.3.2. The strategic environmental assessment

The definition and aims of a strategic environmental assessment (SEA) is outlined in Section 2.4.3. An SEA is essentially a systematic process that evaluates the environmental consequences of alternative plans or programmes at a strategic rather than a site specific level. The aims of an SEA are to provide decision-makers and affected stakeholders with information on the potential environmental impacts and to suggest mitigation in a pro-active manner (CSIR 2003; DEAT 2004b).

(a) The LUEM in strategic environmental assessment

The proposed LUEM as described in Section 6.2 and applied as an IEM tool (Section 6.3.1) can accommodate the aims of a strategic environment assessment to facilitate decisions regarding the implementation of alternative plans and programmes. The LUEM can be applied within the framework of an SEA (DEAT 2000) to evaluate the relative impacts of these alternatives on the integrity of one or more components of the environment as follows (Figure 6.2):

(i) Programme alternatives and screening

The overall purpose of an assessment study must be defined and the primary objectives, identified as for the screening process in an SEA, can be included in the terms of reference of the LUEM. Alternative plans or programmes to be evaluated must be identified and described in this stage and the legal and policy frameworks in this regard must be examined. The study area must be clearly

defined and key specialists and interested and affected parties required for participation in the evaluation must be identified.

(ii) Scoping, situation assessment and assessment of alternatives

The scoping and situation assessment stages and an identification of sustainability parameters in the SEA process can be accommodated under the assessment stage of the LUEM (Figure 6.2). A group decision-making process that includes the AHP can facilitate input from key specialists as well as interested and affected parties and can facilitate a hierarchy of decisions formulated with regard to the levels of enquiry required to assess alternatives. Indicator criteria for environmental integrity must be identified and defined to set the standards for the evaluation at each level of the hierarchy. Application of the AHP in order to rank indicator criteria and alternatives with respect to indicators at each level of the hierarchy will establish overall weights for alternatives. The LUEM supports a transparent and participative decision-making process that provides for input by environmental specialists, as well as key interested parties and facilitates the reaching of consensus and effective public participation within the SEA process. Through the use of clearly defined indicator criteria, the LUEM establishes explicit and verifiable standards for the evaluation of alternatives within the SEA process. Suggestions regarding mitigation can be made after examination of the relative weights for the ranking of alternative plans and programmes against indicator criteria for the various levels of investigation. Relative weights for alternatives will provide a quantitative indication of the significance of potential environmental impacts associated with them and will guide mitigation measures and intervention strategies required.

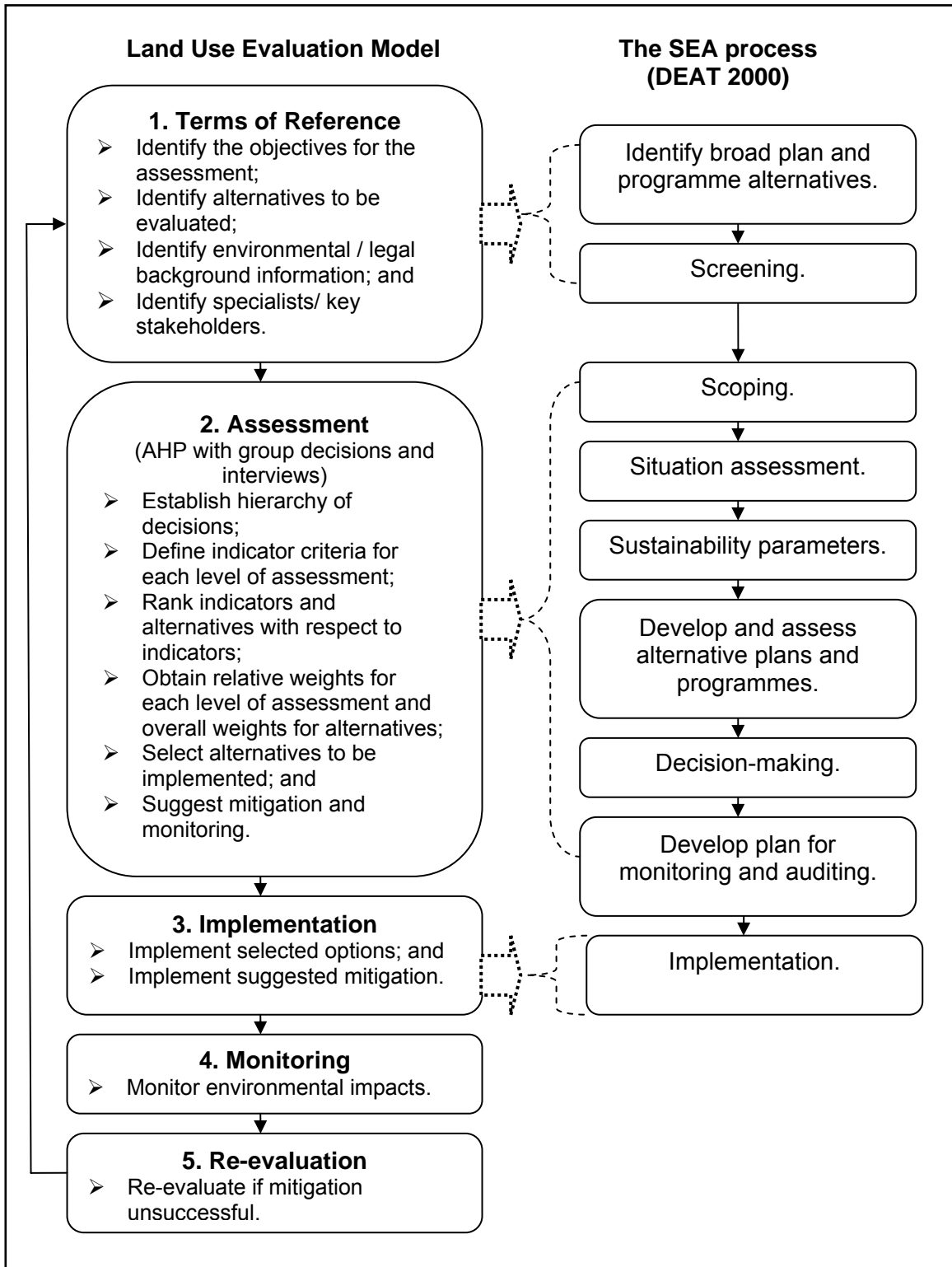


Figure 6.2: Land Use Evaluation Model applied to the framework of a strategic environmental assessment

(iii) Implementation

Selection of an alternative plan or programme and suggested mitigation of environmental impacts will be guided by the overall relative weights assigned during the assessment stage.

(iv) Monitoring

Although this is not an explicit phase of an SEA, monitoring of the success of mitigation measures is critical to ensure that environmental impacts associated with selected plans or programmes are adequately managed. Targets set with regard to the management of environmental impacts will be determined during the assessment stage and will inform monitoring plans.

(v) Re-evaluation

A repeat of the LUEM evaluation procedure within the framework of an SEA will be required if the mitigation of impacts identified during the assessment is not successful. If targets set for the management of environmental impacts associated with selected alternatives are not achieved, the terms of reference for the study must be re-examined. Input from additional specialists may be required and the hierarchy of decisions may have to be expanded to inform further levels of investigation. A more detailed assessment of the significance of the impacts of alternative plans or programmes may be required and suggestions for mitigation may have to be amended to establish new targets for the management of environmental impacts.

6.3.3. The environmental impact assessment

The environmental impact assessment (EIA) process in terms of the requirements of the Environment Conservation Act (Act 73 of 1989) (ECA) is described in Section 2.4.2. Although the LUEM as described in Section 6.2 is primarily proposed to help facilitate strategic decisions regarding land use, it can be applied as an IEM tool to inform the EIA process for project proposals that are site specific.

(a) Facilitation of environmental impact assessment

Key elements of the EIA process can be facilitated through the application of the LUEM as described in Figure 6.3. The LUEM can be adapted to evaluate alternatives within the EIA process in order to provide essential supporting information regarding the relative desirability, or not, of the alternatives.

(i) Plan of study for scoping

The LUEM can be adopted to examine site or process alternatives prior to the commencement of the EIA process so as to provide information that will guide the scoping and EIA phases. Application of the LUEM to facilitate the SEA process (Section 6.3.2) can provide background information regarding the relative significance of environmental impacts associated with land use or project alternatives at a strategic level, prior to the commencement of the EIA process. Strategic environmental information can be used to evaluate site specific project alternatives at a macro-level or landscape-level at the project planning stage. This information can be incorporated in a background information document and the plan of study for scoping and can include information on desirable project alternatives to accordingly facilitate the scoping process.

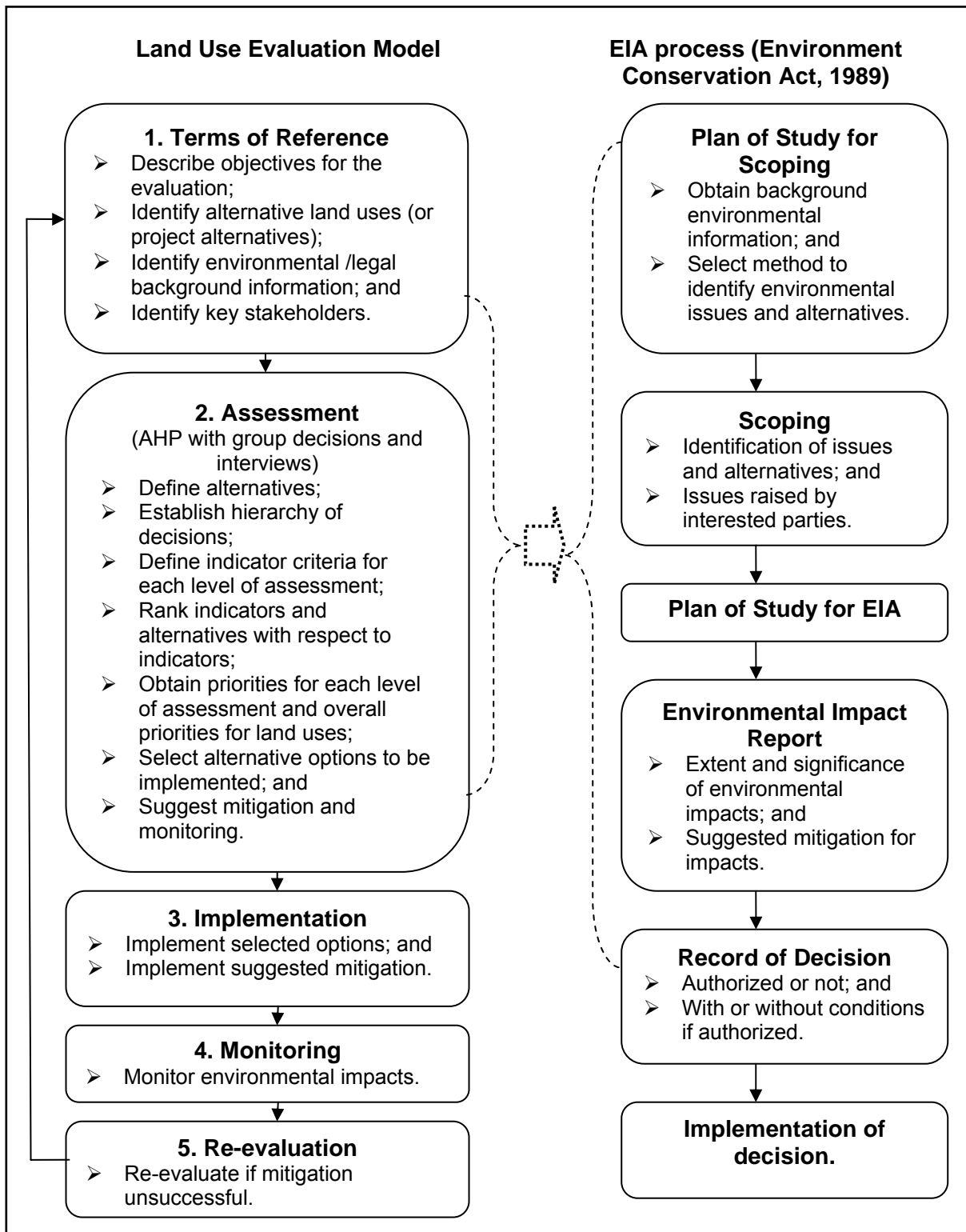


Figure 6.3: Land Use Evaluation Model applied to facilitate the environmental impact assessment process.

Application of the methodology as proposed in the assessment stage of the LUEM can also facilitate the identification of environmental issues and alternatives as required in the plan of study for scoping.

(ii) Scoping

Application of a group decision-making exercise and the AHP in the assessment stage of the LUEM, to identify and evaluate the relative desirability of project alternatives associated with a development can facilitate the scoping process. Indicator criteria for the evaluation of project alternatives can be selected so as to inform site specific management of environmental impacts. Within the framework of IEM, indicator criteria may be chosen for impacts on biophysical, social or economic elements as appropriate. The relative impact of the project alternatives on environmental indicator criteria will also provide an indication of the relative significance of environmental impacts and details in this regard can assist in the identification of feasible alternatives that have a lower environmental risk. Relative impacts of alternatives will also identify environmental issues that may require further investigation and assessment.

(iii) Plan of study for EIA and the environmental impact report

Application of the LUEM to evaluate the relative environmental impact of a project can provide the plan of study for EIA with a description of the most feasible project alternatives in terms of environmental impacts and environmental issues which may require further investigation during the EIA phase (Figure 6.3). An indication of which environmental issues will require further investigation during the EIA phase to determine the significance of environmental impacts will also be provided by the ranking of indicators against project alternatives in the assessment stage of the LUEM.

(iv) Record of decision

Use of strategic environmental information for an assessment of project alternatives in the LUEM during the project planning stage can provide an indication of the nature of cumulative environmental impacts associated with a site specific project at the landscape level. Accordingly, suggestions regarding the mitigation of cumulative impacts can inform conditions of authorization and requirements for environmental management plans in the records of decision for site specific projects.

6.3.4. Integrated development planning

The objectives, methodologies and application of the process of integrated development planning (IDP) for municipalities in KwaZulu-Natal are described in Section 2.4.4. An examination of the essential components of the proposed LUEM and its application as an IEM tool within the framework of an SEA process, indicates that it may be expanded to facilitate the IDP process as follows (Figure 6.4):

(1) Phase 1 of the IDP process

The terms of reference stage in the LUEM includes the essential elements of Phase 1 (analysis phase) of the IDP process and can be readily adopted in the IDP process. The primary objectives of the LUEM equate to the primary objectives for the IDP project and must be aligned with strategic objectives of the municipality. The IDP process is considered to be a strategic tool (DAEA 2003) and the need for projects is determined by the town planning objectives of a

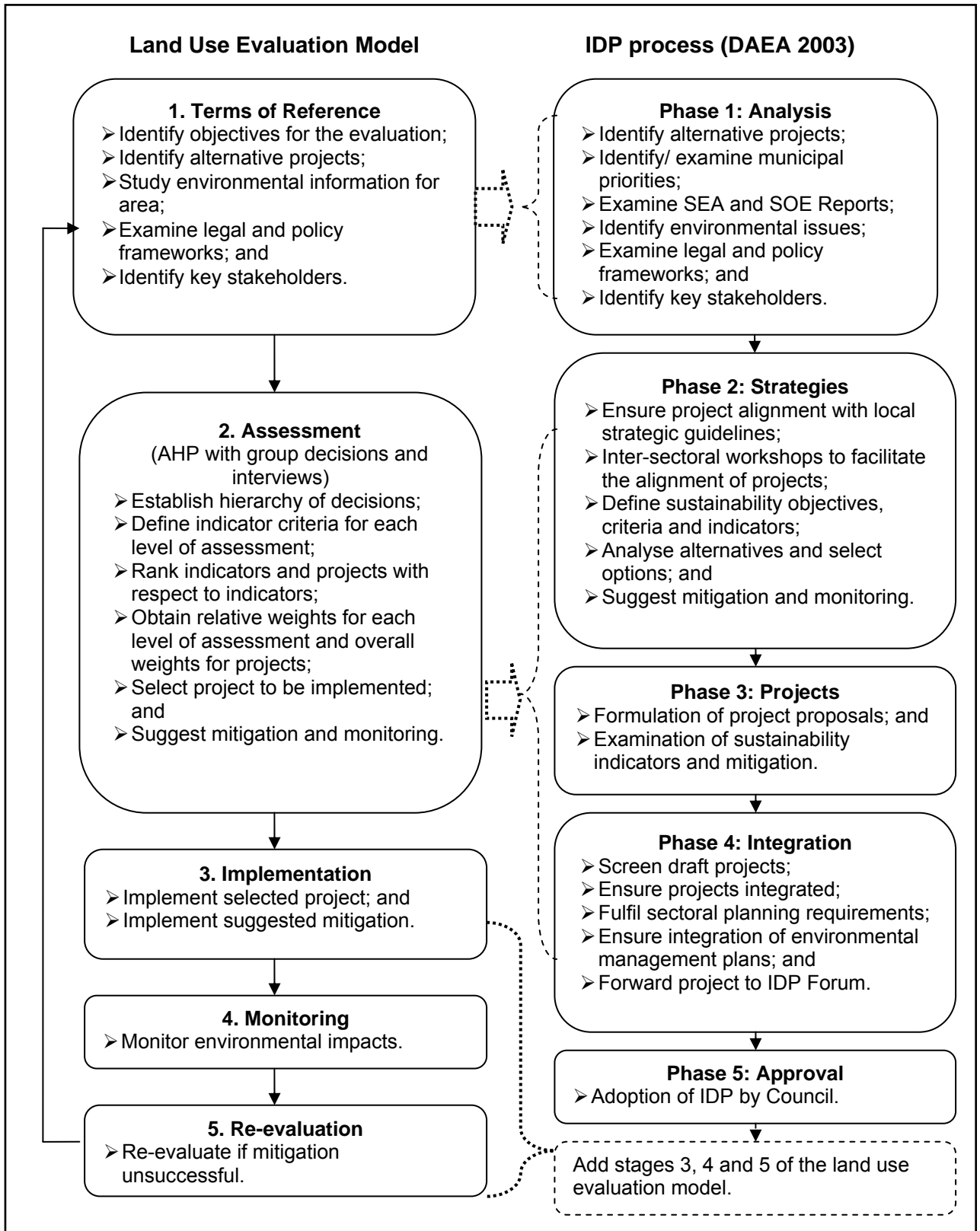


Figure 6.4: Land Use Evaluation Model applied to facilitate the integrated development planning process.

municipality. Alternative project options to be evaluated must be identified. The input of strategic environmental information in Phase 1 of the IDP process and the examination of legal and policy frameworks that relate to the implementation of the project are elements that are also included in the terms of reference for the LUEM. The identification of key stakeholders is important during the first stage of the IDP process and is also considered to be essential in the LUEM. Key specialists and other interested parties (within government, the private sector and general public) must be identified early in the IDP process to ensure effective participation in decision-making.

(2) Phases 2, 3 and 4 of the IDP process

The assessment stage of the LUEM can make a significant contribution to the IDP process. This stage essentially covers Phase 2 (Strategy Phase) of the IDP process and will facilitate and expand its objectives as follows:

- i Application of the AHP in a group decision-making exercise will facilitate participation of key stakeholders such as government and local authority representatives, community representatives and specialists. Participation of key stakeholders in an integrated decision-making process will afford greater credibility to and acceptability of its outcomes.
- ii Objectives for the evaluation will be defined in accordance with strategic planning objectives of the municipality and take appropriate legal and policy frameworks into consideration. Environmental sustainability can be identified as the overall objective of the evaluation.
- iii The alternative projects to be evaluated as identified in Phase 1 of the IDP process will be described in more detail in this Phase and will be clearly defined.

- iv The hierarchy of decisions in the LUEM can be established so as to consider the various strategic objectives of the IDP process and will allow for the evaluation of issues related to biodiversity, social and economic components of the environment in a single, integrated decision-making exercise.
- v Within a group decision-making exercise the evaluation model allows key stakeholders to participate in the identification and evaluation of indicator criteria for each level in the hierarchy of decisions and in the evaluation of alternatives at each level. Key stakeholders can, therefore, provide input into the selection of indicators that, while being aligned with the strategic environmental objectives or policies of the municipality, will also determine the standards for environmental quality for their communities.
- vi Mitigation measures will be determined from the relative weights recorded for the ranking of alternative projects against indicators. Higher ranking will signal a concern and will determine the significance of impacts on indicator criteria and will determine areas for intervention. The significance of environmental impacts and the nature of mitigation required will determine monitoring requirements and will inform environmental management plans for projects. Participation of interested parties in the AHP process will also provide an opportunity for them to comment on mitigation measures and monitoring strategies.

(3) Implementation, Monitoring and Re-evaluation

Although the implementation, monitoring and re-evaluation stages of the LUEM are not described in the IDP process, it is suggested that they be added after Phase 5 (approval phase) of the process. Reasons for this suggestion are as follows:

- i Implementation as a stage is required to give effect to the approval phase in the IDP process. This is the stage at which the selected project (or projects) is implemented together with suggested mitigation and conditions of implementation as determined by the municipal council. Implementation could be in phases and with appropriate mitigation.
- ii The monitoring of environmental impacts associated with projects is an essential consequence of implementation and the stage during which mitigation measures as proposed in environmental management plans in the IDP process must be evaluated to determine their success. Monitoring of environmental impacts will determine if targets with regard to environmental quality have been achieved and if further evaluation may be required to reassess the nature of impacts.
- iii Re-evaluation of environmental impacts associated with projects may be required if monitoring indicates that mitigation measures for the management of such impacts have been unsuccessful.

CHAPTER 7

CONCLUSIONS

7.1. Achievements of this study

In accordance with the broad objectives for this study, as set out in Section 1.3 of Chapter 1, it can be concluded that this study has achieved the following:

- (i) A methodology for the evaluation of land use impacts on biodiversity integrity of landscapes has been developed;
- (ii) This methodology has been applied in the assessment of land use impacts on biodiversity integrity for the Mistbelt Grassland (vegetation-type level) and moist sub-biome of the Grassland Biome (biome-level);
- (iii) Recommendations for the maintenance of biodiversity integrity for the Mistbelt Grassland and Grassland Biome have been made;
- (iv) In accordance with the methodology developed, the Land Use Evaluation Model (LUEM) for the evaluation of land use impacts on biodiversity has been proposed; and
- (v) The application of the LUEM to facilitate integrated environmental management and the model's application in strategic environmental assessments, environmental impact assessments and integrated development has been examined.

7.1.1. Evaluation of land use impacts on biodiversity

(a) Development of methodology

The Analytic Hierarchy Process (AHP) in a group decision-making exercise with input by a team of experts was proposed for an evaluation of the impacts of land

use on biodiversity integrity at the landscape level. The procedure allows for the establishment of a hierarchy of decisions regarding the objectives of the exercise and the procedure incorporates the use of appropriate indicator criteria for the evaluation of the integrity of the structural, functional and compositional components of landscape biodiversity at each level of decision-making. Therefore, indicators set clear standards for the evaluation of the integrity of each level in the hierarchy. Comparative judgements, by a team of experts, of the impacts of land uses on the integrity of each indicator allowed for the calculation of relative weights for land use alternatives at each level of the hierarchy and calculation of overall relative weights with respect to their impact on the integrity of landscape biodiversity.

(b) Application of methodology

Evaluation of the impacts of land use on biodiversity integrity was conducted for the Mistbelt Grassland at the vegetation type level (Section 4) and the moist sub-biome of the Grassland Biome at the biome level (Section 5). Application of the AHP allowed for the establishment of a hierarchy of decisions with respect to the evaluation of land use impacts for each study and allowed for the selection of indicator criteria for various levels of enquiry as appropriate for maintenance of the biodiversity integrity at that level.

(i) Biodiversity indicators

Landscape composition, structure and function, as the three indicator sets that defined biodiversity integrity, fell into a clear rank in terms of what was considered to be their relative importance (Section 4.4.1; Section 5.4.1). Landscape structure was considered to be of primary importance as the dynamics of the transformed landscape are responsible for the integrity of

biodiversity that will be maintained. The long-term viability and functioning of the remaining natural asset of the landscape will depend on the integrity of the key ecosystem processes that remain. Properly functioning ecosystem processes should ensure the persistence of the compositional elements and a greater proportion of the original biota in a transformed landscape. Accordingly, landscape composition is rated secondary to landscape functioning.

(ii) *Impact of land uses on biodiversity*

The relative impact of land uses was consistent with respect to impacts on landscape composition, structure and function, and provided an unambiguous statement with respect to land use's overall impact on biodiversity integrity of the Mistbelt Grassland (Section 4.4) and moist sub-biome of the Grassland Biome (Section 5.4). In the Mistbelt Grassland, urban settlement had the greatest overall impact on biodiversity, while those of timber plantations, crops, pasture and rural settlement were also considerable. Measured against the benchmark of conservation, only a slightly negative impact was associated with livestock ranching.

Although a greater number of land uses were evaluated in the Grassland Biome, the trends for impacts on biodiversity integrity were similar (Section 5.4.2). Urban settlements were considered to have the greatest negative impact, while those for timber plantations, dairy farming, croplands and rural settlements were also considered to be high. Against the benchmark of conservation, game ranching, livestock ranching and tourism were considered to have only slight impacts on biodiversity integrity.

For both the Mistbelt Grassland and Grassland Biome evaluations, the impacts of land uses were considered to be mainly on landscape structure and primarily associated with extent of transformation and fragmentation (Section 4.4.2;

Section 5.4.2). The integrity of grassland habitat was considered to be important for landscape composition, while nutrient leakage and fire regime were considered to be important for landscape function in the Mistbelt Grassland and Grassland Biomes respectively.

(iii) Recommendations for land uses

Relative weights for land use impacts on indicators of biodiversity integrity for the various levels of enquiry selected for the Mistbelt Grassland and Grassland Biome evaluations, provide a clear indication of the nature of land use impacts, where intervention strategies must be directed and what they must involve (Section 4.4.3; Section 5.4.3). Land uses vary from being relatively untransformed for conservation to being an almost complete transformation of natural asset in urban environments. Urban developments are associated with an extreme negative impact on biodiversity integrity at all levels of enquiry for both the Mistbelt Grassland and Grassland Biome studies. There is nearly complete transformation associated with this land use and only isolated fragments of the natural landscape asset remain. It is suggested that intervention strategies for urban development must be directed at consolidation of this land use, rather than further fragmentation, and that higher density settlements must be encouraged. Urban developments must be evaluated within a regional context and provision must be made for necessary linkages and for the limitation of impacts on the biodiversity integrity of surrounding areas.

Impacts of timber plantations on landscape biodiversity integrity were ranked second to urban developments for both the Mistbelt Grassland and Grassland Biome studies, while impacts for dairy farming, rural settlements and croplands were also considered to be high. While these land uses contribute very little to the maintenance of biodiversity integrity, their spatial orientation and ability to maintain regional connectivity in the landscape is considered to be important.

With formal conservation as the benchmark, livestock ranching on natural vegetation was judged to have the lowest impact on all components of biodiversity in both studies and should therefore be encouraged for the maintenance of biodiversity integrity.

7.1.2. The Land Use Evaluation Model

In accordance with the methodology employed in the evaluation of impacts of land use on landscape biodiversity in the Mistbelt Grassland and the moist sub-biome of the Grassland Biome, the LUEM is proposed as a framework (Section 6.2). The five stages suggested for the LUEM provide an explicit procedure that incorporates the establishment of terms of reference, an assessment stage, an implementation phase, monitoring and re-evaluation.

The assessment stage includes the application of the AHP in a group decision-making exercise. Within a single integrated evaluation procedure, the hierarchy of decisions in the AHP can be expanded to include a limitless number of indicator criteria as standards for the evaluation of land use alternatives. This approach is transparent, time-saving and cost-effective and makes provision for input by a range of experts and key stakeholders. Ranking of the impacts of land use alternatives against indicator criteria provides essential information on the significance of impacts and a clear indication as to where intervention strategies should be directed.

(a) Application of the Land Use Evaluation Model

(i) Integrated environmental management

Expansion of the hierarchy of decisions in the AHP allows for the establishment of limitless levels of enquiry and the application of the LUEM for the investigation of impacts on the biophysical or social or economic components of the environment. Accordingly, it is proposed that the LUEM can be expanded into an integrated environmental management (IEM) tool for the evaluation of alternative plans and programmes associated with any stage of the development cycle for a project. The process will involve a single evaluation exercise that is cost-effective and makes explicit provision for engagement of specialists and stakeholders in an open and transparent exercise that facilitates the credibility of decision-making and ensures that development is environmentally sustainable.

(ii) Strategic environmental assessment

An examination of the LUEM indicates that it has the essential components that would enable it to be applied as an IEM tool to facilitate the strategic environmental assessment (SEA) process (Section 6.3.2). The flexibility afforded by the AHP allows for the participation of specialists and key stakeholders in an integrated evaluation procedure in which the impacts of alternative plans or programmes or projects on the biophysical or social or economic components of the environment can be assessed. The model supports participative decision-making in a transparent process that facilitates consensus among key stakeholders and interested parties.

Application of the AHP within a strategic environmental assessment provides for an examination of alternative plans or programmes at various levels of decision-

making and the integration of information from a range of IEM tools such as environmental impact assessments, social impact assessments or other specialist environmental assessment reports. The identification of clearly defined indicator criteria allows for the establishment of explicit and verifiable standards for the evaluation of the alternatives. The relative weights scored for the impacts of the alternatives provide details on their significance and direction for mitigation and intervention strategies. In a single exercise, the LUEM therefore supports the integration of decisions regarding the mitigation of impacts of alternative plans or projects on a spectrum of environmental issues to ensure sustainable development.

(iii) Environmental impact assessment

The LUEM can be applied to facilitate the environmental impact assessment (EIA) process as prescribed by the Environment Conservation Act (Act 73 of 1989). Application of the LUEM to evaluate site specific or process alternatives at a strategic level, (as proposed for an SEA application in Section 6.3.2) will facilitate the EIA process and assist decision-making during especially the pre-scoping and scoping phases (Section 6.3.3). A hierarchy of strategic environmental indicators (including biodiversity or social or economic criteria) may be used to assess the relative impact of site specific project alternatives and accordingly may provide background information to facilitate pre-scoping decisions regarding alternatives that are acceptable in terms of existing macro-environmental or strategic environmental conditions. Accordingly, information regarding existing environmental conditions in the broader landscape can assist with the identification of cumulative impacts and can be included to facilitate decisions regarding site specific impacts. Unacceptable, high risk alternatives can be identified at an early stage and the significance of impacts that can be tolerated for the broader landscape can be further investigated during the EIA process. The recognition of alternatives that are strategically more acceptable at

an early stage of the EIA process can therefore allow greater focus on those alternatives in the EIA phase that are more acceptable and that will have less significant strategic impacts. Environmental indicators used during the application of the LUEM will also provide valuable direction with respect to the evaluation of site specific environmental issues. For example, impacts of project alternatives on indicators of the integrity of biodiversity at a strategic level will provide direction for the evaluation of site specific impacts and will indicate which elements of biodiversity at a micro-level are at risk due to a specific alternative.

(iv) Integrated development planning

As an IEM tool, the LUEM can be expanded to facilitate the integrated development planning (IDP) process for municipalities as proposed by the KwaZulu-Natal Department of Agriculture and Environmental Affairs (DAEA 2003). The hierarchy of decisions in the assessment phase of the LUEM provides for a clear framework in which alternative IDP projects can be evaluated for alignment with other municipal projects and with important strategic municipal priorities. The group decision-making process in the LUEM also supports essential public participation and stakeholder engagement within the IDP process and ensures integrated decision-making that will afford greater credibility and consensus regarding the outcome of decisions. Participation by key stakeholders in the selection of indicators that are aligned with strategic environmental objectives or policies of a municipality will allow input by key stakeholders into the determination of standards for environmental quality in communities and will facilitate environmentally sustainable development.

REFERENCES

- Acocks, J.P.H. 1975. Veld types of South Africa (Second Edition). *Memoirs of the Botanical Survey of South Africa* **40**: 1-128.
- Andersen, A.N., Hoffmann, B.D., Muller, W.J. and Griffiths, A.D. 2002. Using ants as bioindicators in land management: simplifying assessment of ant community responses. *Journal of Applied Ecology* **39**: 8-17.
- Angermeier, P.L. and Karr, J.R. 1994. Biological integrity versus biological diversity as policy directives. *BioScience* **44**: 690-697.
- Armstrong, A.J., Benn, G., Bowland, A.E., Goodman, P.S., Johnson, D.N., Maddock, A.H. and Scott-Shaw, C.R. 1998. Plantation Forestry in South Africa and its Impact on Biodiversity. *Southern African Forestry Journal* **182**: 59-65
- Bell, R.H.V. 1982. The effect of soil nutrient availability on community structure in African ecosystems. In: B.J. Huntley and B.J. Walker (eds.) *Ecology of Tropical Savannas*, pp: 193-216. Springer-Verlag, Berlin, Germany.
- Benn, G. 2000. Identification of important landscapes. In: P.S. Goodman (ed.), *Determining the conservation value of land in KwaZulu-Natal*, pp: 5-11. Biodiversity Division, KwaZulu-Natal Nature Conservation Service, Cascades, Pietermaritzburg.
- Bromilow, C. 1995. *Problem Plants of South Africa*. Briza Publications, Arcadia, Pretoria.

- Camp, K.G. 1997. The Bioresource Groups of KwaZulu-Natal. *Cedara Report No. N/A/97/6*. Natural Resource Section, KZN Department of Agriculture and Environmental Affairs, Cedara, Pietermaritzburg.
- Chapin, F.S. III, Sala, O.E., Burke, I.C., Grime, J.P., Hooper, D.U., Lauenroth, W.K., Lombard, A., Mooney, H.A., Mosier, A.R., Naeem, S., Pacala, S.W., Roy, J., Steffen, W.L. and Tilman, D. 1998. Ecosystem consequences of changing biodiversity: Experimental evidence and a research agenda for the future. *BioScience* **48**(1): 45-52.
- Chuntharpursat, A. 2000. *Using multi-criteria decision making in developing a decision support system for land suitability with regard to natural resource management*. Master of Science dissertation, Centre for Environment and Development, University of Natal, Pietermaritzburg.
- Cooperrider, A. 1991. Conservation of biodiversity on Western Rangelands. In: W.E. Hudson (ed.) *Landscape linkages and biodiversity*, pp: 40-53. Island Press, Washington D.C.
- Council for Scientific and Industrial Research (CSIR) 2003. *Strategic Environmental Assessment Resource Document: Introduction to the Process, Principles and Application of SEA*. (Version 3). CSIR Report ENV-S-C 2002-073. CSIR Environmentek, Pretoria.
- Cowan, G.I. (ed.) 1996. *Wetlands of South Africa*. Department of Environmental Affairs and Tourism, Pretoria.

Crist, M.R., Wilmer, B. and Aplet, G.H. 2005. Assessing the value of roadless areas in a conservation reserve strategy: biodiversity and landscape connectivity in the northern Rockies. *Journal of Applied Ecology* **42**: 181-191.

Dalton, H. and Brand-Hardy, R. 2003. Nitrogen: the essential public enemy. *Journal of Applied Ecology* **40**: 771-781.

Department of Agriculture, Conservation and Land Affairs, Gauteng (DACEL) 2003. *National Grasslands Initiative: Concept Document* (Compiled by: Reyers, B. and Tosh, C.A.), Gauteng Department of Agriculture, Conservation and Land Affairs, Johannesburg.

Department of Agriculture and Environmental Affairs, KwaZulu-Natal (DAEA) 2001. *Land cover information for KwaZulu-Natal*. Natural Resources Component, KZN Department of Agriculture and Environmental Affairs, Pietermaritzburg.

Department of Agriculture and Environmental Affairs, KwaZulu-Natal (DAEA) 2002. *KwaZulu-Natal Provincial Government Environmental Implementation Plan (First Edition: May 2002)*. KZN Department of Agriculture and Environmental Affairs, Pietermaritzburg.

Department of Agriculture and Environmental Affairs, KwaZulu-Natal (DAEA) 2003. *The Municipal Integrated Development Planning Process (Guideline Document, January 2002)*. Chief Directorate Environmental Management, KZN Department of Agriculture and Environmental Affairs, Pietermaritzburg.

Department of Environmental Affairs and Tourism (DEAT) 1998a. *Agenda 21: an agenda for sustainable development into the 21st century*. Department of Environmental Affairs and Tourism, Pretoria.

Department of Environmental Affairs and Tourism (DEAT) 1998b. *EIA Regulations: Implementation of sections 21, 22 and 26 of the Environment Conservation Act* (Guideline Document). Department of Environmental Affairs and Tourism, Pretoria.

Department of Environmental Affairs and Tourism (DEAT) 1999. *White paper on Environmental Management Policy for South Africa*. Department of Environmental Affairs and Tourism, Pretoria.

Department of Environmental Affairs and Tourism (DEAT) 2000. *Strategic Environmental Assessment in South Africa*. Department of Environmental Affairs and Tourism, Pretoria.

Department of Environmental Affairs and Tourism (DEAT) 2004a. Overview of Integrated Environmental Management. *Integrated Environmental Management, Information Series: 0*. Department of Environmental Affairs and Tourism, Pretoria.

Department of Environmental Affairs and Tourism (DEAT) 2004b. Strategic Environmental Assessment. *Integrated Environmental Management, Information Series: 10*. Department of Environmental Affairs and Tourism, Pretoria.

Department for Transport, Local Government and the Regions, United Kingdom. (DTLR) 2002. *Multi Criteria Analysis: A Manual*. <http://www.dtlr.gov.uk/about/multicriteria/05.htm>

- Downing, B.H. 1978. Environmental consequences of agricultural expansion in South Africa since 1850. *South African Journal of Science* **74**: 420-422.
- Eastman, J.R. 2003. *IRIDISI Kilimanjaro. Guide to GIS and Image Processing*. Clark University, Worcester, MA, USA.
- Ezemvelo KZN Wildlife (EKZNW) 2005. *Data on the transformation and degradation of grasslands of KwaZulu-Natal*. Biodiversity Division, Ezemvelo KZN Wildlife, Cascades, Pietermaritzburg.
- Fairbanks, D.H.K. and Benn, G.A. 2000. Identifying regional landscapes for conservation planning: a case study from KwaZulu-Natal, South Africa. *Landscape and Urban Planning* **50**: 237-257.
- Fairbanks, D.H.K., Thompson, M.W., Vink, D.E., Newby, T.S., van den Berg, H.M. and Everhard, D.A. 2000. The South African Land –cover characteristics database: a synopsis of the landscape. *South African Journal of Science* **96**: 69-82.
- Fischer, J., Lindenmayer, D.B. and Cowling, A. 2004. The challenge of managing multiple species at multiple scales: reptiles in an Australian grazing landscape. *Journal of Applied Ecology* **41**: 32-44.
- Forman, R.T.T. 1981. Interactions among landscape elements: a core of landscape ecology. In: S.P. Tjallingii and A.A. de Veer (eds.), *Perspectives in Landscape Ecology*, pp: 35-48. Proceedings of the International Congress of Landscape Ecology, Veldhoven. Pudoc Publ., Wageningen, The Netherlands.
- Forman, R.T.T. and Godron, M. 1986. *Landscape Ecology*. 1st Edition. John Wiley and Sons, New York.

- Franklin, J.F. 1988. Structural and functional diversity in temperate forests. In: E.O Wilson (ed.) *Biodiversity* pp: 166-175. National Academic Press, Washington, D.C.
- Goodman, P.S. 2000a. Executive summary. In: P.S Goodman (ed.), *Determining the conservation value of land in KwaZulu-Natal (Final Report)*, pp: i-ii. KwaZulu-Natal Nature Conservation Service, Cascades, Pietermaritzburg.
- Goodman, P.S. 2000b. Introduction. In: P.S. Goodman (ed.), *Determining the conservation value of land in KwaZulu-Natal (Final Report)*, pp: 1-4. KwaZulu-Natal Nature Conservation Service, Cascades, Pietermaritzburg.
- Goodman, P.S. (Co-ordinator) 2003. *Non-marine Biodiversity Conservation Targets for KwaZulu-Natal –non technical summary*. Ezemvelo KZN Wildlife, Pietermaritzburg.
- Hamer, K.C., Hill, J.K., Benedick, S., Mustaffa, N., Sherratt, T.N., Maryati, M. and Chey, V.K. 2003. Ecology of butterflies in natural and selectively logged forests of northern Borneo: the importance of habitat heterogeneity. *Journal of Applied Ecology* **40**: 150-162.
- Hockey, P.A.R., Dean, W.R.J. and Ryan, P.G. 2005. *Roberts Birds of Southern Africa VIIth Edition*. The Trustees of the John Voelcker Bird Book Fund, Cape Town.
- Hutchings, A. 1996. *Zulu Medicinal Plants. An Inventory*. University of Natal Press, Pietermaritzburg.

International Service for National Agricultural Research (ISNAR) 2003. *Information and Discussion Forum on Priority Setting in Agricultural Research: Analytical Hierarchy: Methods*. <http://www.isnar.cgiar.org/fora/priority/MeAnalit.htm>.

International Union for the Conservation of Nature (IUCN) 1991. *Definition of biodiversity*. <http://www.jsdnp.org.jm/biodef.htm>.

Kahn, M., von Riesen, A. and Jewell, P. (eds.) 2001. *KwaZulu-Natal Land-Use Management System. Guideline Manual*. Town and Regional Planning Commission, Pietermaritzburg (Main Series, Vol.92).

Kamada, M. and Nakagoshi, N. 1996. Landscape structure and the disturbance regime at three rural regions in Hiroshima Prefecture, Japan. *Landscape Ecology* 11: 15-25.

Keeney, R.L. and Raiffa, H. 1976. *Decisions with Multiple Objectives: Preferences and Value Tradeoffs*, John Wiley, New York. (Reprint 1993: Cambridge University Press).

Knapp, A.K., Briggs, J.M., Blair, J.M., and Turner, C.L. 1998. Patterns and controls of aboveground net primary production in tallgrass prairie. In: AK Knapp, JM Briggs, DC Hartnett and SL Collins (eds.), *Grassland Dynamics. Long-term Ecological Research in the Tallgrass Prairie*, pp: 193-221. Oxford University Press, New York.

KwaZulu-Natal Provincial Government (KZNPG) 2004. *KwaZulu-Natal Provincial Growth and Development Strategy (PGDS): Summit 2004*. Provincial Government of KwaZulu-Natal, Pietermaritzburg.

- Lombard, A.T. 1995. Introduction to an evaluation of the protection status of South Africa's vertebrates. *South African Journal of Zoology* **30**: 71-82.
- Low, A.B. and Rebelo, A. (eds.) 1996. *Vegetation of South Africa, Lesotho and Swaziland*. Department of Environmental Affairs and Tourism, Pretoria.
- Mander, M. 1998. *Marketing of indigenous medicinal plants in South Africa. A case study in Kwazulu-Natal*. Food and Agricultural Organization of the United Nations, Rome.
- Margules, C.R. and Pressey, R.L. 2000. Systematic conservation planning. *Nature* **405**: 243-253.
- Mentis, M.T. and Tainton, N.M. 1984. The effects of fire on forage production and quality. In: P. de V. Booysen and N.M. Tainton (eds.), *Ecological Effects of Fire in South African Ecosystems*, pp. 245-254. Springer-Verlag, Berlin.
- Mwasi, B. 2001. *Land use conflicts resolution in a fragile ecosystem using multi-criteria evaluation (MCE) and a GIS-based decision support system (DSS)*. International Conference on Spatial information for Sustainable Development, Nairobi, Kenya (2-5 October 2001).
- Noss, R.F. 1983. A regional landscape approach to maintaining diversity. *BioScience* **33**(11): 700-706.
- Noss, R.F. 1990. Indicators for monitoring biodiversity. *Conservation Biology* **4**(4): 355-364.
- Noss, R.F. 1996. Ecosystems as conservation targets. *Trends in Ecology and Evolution* **11**(8): 351.

- O' Connor, T.G. and Bredenkamp, G.J. 1997. Grassland. In: R.M. Cowling, D.M. Richardson and S.M. Pierce (eds.), *Vegetation of South Africa*, pp: 215-257. Cambridge University Press, Cambridge.
- O'Connor, T.G., Morris C.D. and Marriott, D.J. 2003. Change in land use and botanical composition of KwaZulu-Natal's grasslands over the past fifty years: Acocks' sites revisited. *South African Journal of Botany* **69(1)**: 105-115.
- O'Connor, T.G. 2005. Influence of land use on plant community composition and diversity in Highland Sourveld grassland in the southern Drakensberg, South Africa. *Journal of Applied Ecology* **42**: 975 – 988.
- O'Connor, T.G. and Kuyler, P. 2005. *National Grasslands Initiative: Identification of compatible land uses for maintaining compatible biodiversity integrity*. South African National Biodiversity Institute (unpublished report) 128 pp.
- O' Neill, R.V., De Angelis, D.L., Waide, J.B. and Allen, T.F.H. 1986. *A hierarchical concept of ecosystems*. Princeton University Press, Princeton, New Jersey.
- O'Reagain, P.J. and Turner, J.R. 1992. An evaluation of the empirical base for grazing management recommendations for rangeland in southern Africa. *Journal of the Grassland Society of Southern Africa* **6**: 71-76.
- Partidario, M.R. 2000. Elements of an SEA framework – improving the added-value of SEA. *Environmental Impact Assessment Review* **20**: 647-663.

- Partidario, M.R. 2003. *Strategic Environmental Assessment (SEA): Current practices, future demands and capacity-building needs (Course Manual)*. International Association for Impact Assessment (IAIA) Training Courses, Lisbon, Portugal.
- Patil, G.P. 2002. *Characterization, evaluation and validation of ecosystem health and its measurement at landscape scale*. Centre for Statistical Ecology and Environmental Statistics, Pennsylvania State University, University Park, PA, U.S.A.
- Peterson D.L. and Schmoltdt, D.L. 1999. Using analytical tools for decision making and program planning in natural resources: breaking the fear barrier. In: D. Harmon (ed.), *On the frontiers of conservation: Proceedings of the tenth conference on research and resource management in parks and public lands*, pp: 256-262. The George Wright Society, Hancock, Michigan.
- Poiani, K.A., Richter, B.D., Anderson, M.G. and Richter, H.E. 2000. Biodiversity conservation at multiple scales: functional sites, landscapes, and networks. *BioScience* **50**(2): 133-146.
- Pott, R.McC. 1997. Plantation forestry in South Africa and its impact on biodiversity and water. *Southern African Forestry Journal* **180**: 45-48.
- Proctor, W. 1999. A practical application of multi criteria analysis to forest planning in Australia. *Theory to practice –Gaps and solutions in managerial ecosystems economics and accounting in forestry*. IUFRO International Symposium (May 13-15 1999), Czech University of Agriculture, Prague.

- Reynolds, K.M. and Hessburg, P.F. 2005. Decision support for integrated landscape evaluation and restoration planning. *Forest Ecology and Management* **207**: 263-278.
- Rogelberg, S.G., Barnes-Farrell, J.L. and Lowe, C.A. 1992. The stepladder technique: An alternative group structuring facilitating effective group decision making. *Journal of Applied Psychology* **77**: 730-737.
- Rosenberg, D.M., Danks, H.V. and Lehmkuhl, D.M. 1986. Importance of insects in environmental impact assessment. *Environmental Management* **10**: 773-783.
- Roux, P.W. 1980. Elements of the trampling factor in stock. *Karoo Agric* **1**(2): 9-12.
- Rowe-Rowe, D.T. and Scotcher, J.S.B. 1986. Ecological carrying capacity of the Natal Drakensberg for wild ungulates. *South African Journal of Wildlife Research* **16**(1): 12-16.
- Saaty, T.L. 1977. A Scaling Method for Priorities in Hierarchical Structures. *Journal of Mathematical Psychology* **15**: 234-281.
- Saaty, T.L. 1980. *The Analytic Hierarchy Process*. McGraw-Hill, New York.
- Sadler, B. and Verheem, R. 1996. *Strategic Environmental Assessment: Status, Challenges and Future Directions*. Ministry of Housing and Spatial Planning (VROM) Report No. 53, Zoetemeer, The Netherlands.

- Sandwith, T. 2002: Introduction. In: S.M. Pierce, R.M. Cowling, T. Sandwith and K. MacKinnon (eds.), *Mainstreaming Biodiversity in Development: Case Studies from South Africa*, pp: 1-4. Environment Department, The World Bank, Washington D.C., U.S.A.
- Seastedt T.R., Hayden B.P., Owensby C.E. and Knapp A.K. 1998. Climate change, elevated CO₂, and predictive modeling. Past and future climate change scenarios for the Tallgrass prairie. In: A.K. Knapp, J.M. Briggs, D.C. Hartnett and S.L. Collins (eds.), *Grassland Dynamics. Long-term Ecological Research in the Tallgrass Prairie*, pp: 283-300. Oxford University Press, New York.
- Schlapfer, F., Pfisterer, A.B. and Schmid, B. 2005. Non-random species extinction and plant production: implications for ecosystem functioning. *Journal of Applied Ecology* **42**: 13-24.
- Schmoldt, D.L. and Peterson, D.L. 1997. Using the Analytic Hierarchy Process for Decision-Making in Ecosystem Management. *Analysis Notes of the W/O Ecosystems Management Analysis Centre, Fort Collins, Colorado, USA : Vol. 7, Issue 1*: 17-22.
- Schmoldt, D.L. and Peterson, D.L. 2000. Analytical group decision making in natural resources: Methodology and application. *Forest Science* **46**(1): 62-75.
- Schmoldt, D.L. and Peterson, D.L. 2001. Efficient group decision making in workshop settings. In: D.L. Schmoldt, J. Kangas, G.A. Mendoza and M. Pesonen (eds.), *The Analytic Hierarchy Process in Natural Resource and Environmental Decision Making*, pp: 97-114. Kluwer Academic Publications, Dordrecht, The Netherlands.

- Schmoldt, D.L., Kangas, J. and Mendoza, G.A. 2001a. Basic Principles of Decision Making in Natural Resources and the Environment. In: D.L. Schmoldt, J. Kangas, G.A. Mendoza and M. Pesonen (eds.), *The Analytic Hierarchy Process in Natural Resource and Environmental Decision Making*, pp: 1-13. Kluwer Academic Publications, Dordrecht, The Netherlands.
- Schmoldt, D.L., Mendoza, G.A. and Kangas, J. 2001b. Past Developments and Future Directions for the AHP in Natural Resources. In: D.L. Schmoldt, J. Kangas, G.A. Mendoza and M. Pesonen (eds.), *The Analytic Hierarchy Process in Natural Resource and Environmental Decision Making*, pp: 289-305. Kluwer Academic Publications, Dordrecht, The Netherlands.
- Schmoldt, D.L., Peterson, D.L. and Smith, R.L. 2001c. The Analytic Hierarchy Process and participatory decision making. In: J.M. Power, M. Strome and T.C. Daniel (eds.), *Proceedings: Decision Support 2001 (Vol 1)*, pp: 129-143. 17th Annual Geographic Information Seminar and the Resource Technology '94 Symposium, Toronto.
- Scholes, R.J. and Biggs, R. 2005. A biodiversity intactness index. *Nature* **434** (03 March 2005): 45-49.
- Scotcher, J.S.B. 1982. *Interrelations of Vegetation and Eland (Taurotragus oryx Pallas) in Giant's Castle Game Reserve, Natal*. Ph.D. thesis, University of the Witwatersrand, Johannesburg.
- Short, A., O'Connor, T.G. and Hurt, C.R. 2003. Medium-term changes in grass composition and diversity of Highland Sourveld grassland in the southern Drakensberg in response to fire and grazing. *African Journal of Range and Forage Science* **20**: 1-10.

- Tainton, N.M. (ed.) 1999. *Veld Management in South Africa*. University of Natal Press, Pietermaritzburg.
- Tapson, D. 1993. Biological sustainability in pastoral systems: the KwaZulu case. In: H. Behnke, I. Scoones and C. Kerven (eds.), *Range Ecology at Disequilibrium*, pp: 118-135. Overseas Development Institute, London, UK.
- Turner, M.G. 1989. Landscape ecology: the effect of pattern on process. *Annual Review of Ecology and Systematics* **20**: 171-197.
- Turner, M.G. and Gardner R.H. (eds.) 1992. *Quantitative Methods in Landscape Ecology: An Introduction*. Springer-V. New York.
- Turner, M.G., Romme, W.H., Gardner, R.H., O'Neill, R.V. and Kratz, T.K. 1993. A revised concept of landscape equilibrium: disturbance and stability on scaled landscapes. *Landscape Ecology* **8**: 213-227.
- Turner, M.G., Gardener, R.H. and O'Niell R.V. 1995. Ecological dynamics at broad scales. *BioScience* **45** (supplement): 29-35.
- United Nations (UN) 1999. *Earth Summit: Agenda 21: The United Nations Programme of Action from Rio*. United Nations Department of Public Information. United Nations, Geneva (reprint).
- United Nations Environment Programme (UNEP) 2005. *Convention on Biological Diversity (Rio de Janeiro, 05 June 1992)*, Secretariat of the Convention on Biological Diversity, United Nations Environment Programme, Montreal, Canada (<http://www.biodiv.org/convention>).

- Urban, D.L., O'Neill, R.V. and Shugart, H.H. 1987. Landscape Ecology: A hierarchical perspective can help scientists understand spatial patterns. *BioScience* **37**(2): 119-127.
- Watkins, A.R. and Ormerod, S.J. 2001. Grasslands, grazing and biodiversity: editor's introduction. *Journal of Applied Ecology* **38**: 233-237.
- Wischmeier, W.H. and Smith, D.D. 1978. *Predicting rainfall erosion losses – a guide to conservation planning*. US Department of Agriculture handbook No. 537.
- Woods, D.B. 1997. *Siting artificial water points in Mkuzi Game Reserve using GIS*. Master of Science dissertation, School of Environment and Development, University of Natal, Pietermaritzburg.
- White, D., Preston, E.M., Freemark, K.E. and Kiester, A.R. 1999. A hierarchical framework for conserving biodiversity. In: J.M. Klopatek and R.H. Gardner (eds.) *Landscape ecology analysis: issues and applications*, pp: 127-153. Springer-Verlag, New York.
- Wu, J. and Hobbs, R. 2002. Key issues and research priorities in landscape ecology: An idiosyncratic synthesis. *Landscape Ecology* **17**: 355-365.
- Zipperer, W.C., Wu, J., Pouyat, R.V., and Pickett, S.T.A. 2000. The application of ecological principles to urban and urbanizing landscapes. *Ecological Applications*, **10**: 685-688.

APPENDIX A

LIST OF PARTICIPANTS

1. Mistbelt Grassland study

➤ *Workshop participants:*

Botha, C.
Cowden, G.
Felton, I.
Goodman, P.
Green-Govender, J.
Jennings, P.
O'Connor, T.
Pillay, K.
Short, A.

2. Grassland Biome study

➤ *Interviewees:*

Adie, H.	Krueger, S.
Armstrong, A.	Manson, A.
Avenant, N.	Marchant, A.
Bezuidenhout, S.	Maze, K.
Blackmore, A.	McConnachie, A.
Botha, C.	McKean, S.
Carbutt, C.	Miles, N.
Dickens, C.	Morris, C.
du Toit, J.	Owen-Smith, R.N.
Everson, C.	Rowe-Rowe, D.
Everson, T.	Rushworth, I.
Fish, L.	Scott-Shaw, R.
Fynn, R.	Smit, N.
Goodall, J.	Snyman, H.
Goodman, P.	Steyn, L.
Graham, M.	Swanepoel, D.
Henderson, L.	van Wyk, E.
Hoare, D.	Villiers, J.
Hurt, R.	Wakelin, J.
Jewitt, G.	Winter, P.
Kirkman, K.	Witkowski, E.
Kotze, D.	

APPENDIX B

IMPACT OF LAND USE ON BIODIVERSITY OF THE MISTBELT GRASSLAND

- Analytic Hierarchy Process matrices were calculated in Microsoft Excel and Poptools was used to determine dominant eigenvalues.
- All workshops were held at the Head Office of the KwaZulu-Natal Department of Agriculture and Environmental Affairs at Cedara near Pietermaritzburg.

1. Pilot workshop results

1.1. Ranking of biodiversity indicators

(a) Landscape composition

Workshop: 18 November 2003

n=5 matrix

Indicator	Forest	Grassland	Wetland	Riparian	Fauna
Forest	1	0.333	0.500	0.667	1.000
Grassland	3.000	1	1.502	2.000	3.003
Wetland	2.000	0.666	1	1.333	2.000
Riparian	1.500	0.500	0.750	1	3.030
Fauna	1.000	0.333	0.500	0.330	1

Normalized matrix:

Indicator	Forest	Grassland	Wetland	Riparian	Fauna	Weight
Forest	0.118	0.118	0.118	0.125	0.100	0.116
Grassland	0.353	0.353	0.353	0.375	0.299	0.347
Wetland	0.235	0.235	0.235	0.250	0.199	0.231
Riparian	0.176	0.177	0.176	0.188	0.302	0.204
Fauna	0.118	0.118	0.118	0.062	0.100	0.103
	1.000	1.000	1.000	1.000	1.000	1.000

CI=	0.015
CI/RI_n= (<i>n=5</i>)	0.013

(b) Landscape function

Workshop: 12 December 2003

n=5 matrix

Indicator	Disturbance	Geomorphic	Nutrient	Hydrologic	Reproductive
Disturbance	1	3.003	0.500	0.667	2.000
Geomorphic	0.333	1	0.167	0.333	0.667
Nutrient	2.000	6.000	1	1.333	4.000
Hydrologic	1.500	3.000	0.750	1	3.003
Reproductive	0.500	1.500	0.250	0.333	1

Normalized matrix:

Indicator	Disturbance	Geomorphic	Nutrient	Hydrologic	Reproductive	Weight
Disturbance	0.188	0.207	0.188	0.182	0.187	0.190
Geomorphic	0.062	0.069	0.063	0.091	0.062	0.069
Nutrient	0.375	0.414	0.375	0.364	0.375	0.380
Hydrologic	0.281	0.207	0.281	0.273	0.281	0.265
Reproductive	0.094	0.103	0.094	0.091	0.094	0.095
	1.000	1.000	1.000	1.000	1.000	1.000

CI=	0.005
CI/RI _n =	0.004
(n=5)	

(c) Landscape structure

Workshop: 16 April 2004

n=3 matrix

Indicator	Transformation	Fragmentation	Physiognomy
Transformation	1	3.003	3.003
Fragmentation	0.333	1	1.000
Physiognomy	0.333	1.000	1

Normalized matrix:

Indicator	Transformation	Fragmentation	Physiognomy	Weight
Transformation	0.600	0.600	0.600	0.600
Fragmentation	0.200	0.200	0.200	0.200
Physiognomy	0.200	0.200	0.200	0.200
	1.000	1.000	1.000	1.000

CI=	0.000
CI/RI_{n=} <i>(n=3)</i>	0.000

1.2. Ranking of land uses with respect to indicators

(a) Landscape composition

Workshop: 18 November 2003

(i) Indicator: Integrity of forest

n=5 matrix

Land use	Livestock	Conservation	Timber	Crops	Urban
Livestock	1	3.003	0.143	0.200	0.111
Conservation	0.333	1	0.111	0.111	0.111
Timber	7.000	9.000	1	3.030	0.333
Crops	5.000	9.000	0.330	1	0.200
Urban	9.000	9.000	3.000	5.000	1

Normalized matrix:

Land use	Livestock	Conservation	Timber	Crops	Urban	Weight
Livestock	0.045	0.097	0.031	0.021	0.063	0.052
Conservation	0.015	0.032	0.024	0.012	0.063	0.029
Timber	0.313	0.290	0.218	0.324	0.190	0.267
Crops	0.224	0.290	0.072	0.107	0.114	0.161
Urban	0.403	0.290	0.654	0.535	0.570	0.491
	1.000	1.000	1.000	1.000	1.000	1.000

CI=	0.103
CI/RIn=	0.092
(n=5)	

(ii) Indicator: Integrity of grassland

n=5 matrix

Land use	Livestock	Conservation	Timber	Crops	Urban
Livestock	1	3.003	0.111	0.167	0.111
Conservation	0.333	1	0.111	0.111	0.111
Timber	9.000	9.000	1	3.003	1.000
Crop	6.000	9.000	0.333	1	1.000
Urban	9.000	9.000	1.000	1.000	1

Normalized matrix:

Land use	Livestock	Conservation	Timber	Crops	Urban	Weight
Livestock	0.039	0.097	0.043	0.032	0.034	0.049
Conservation	0.013	0.032	0.043	0.021	0.034	0.029
Timber	0.355	0.290	0.391	0.569	0.310	0.383
Crops	0.237	0.290	0.130	0.189	0.310	0.231
Urban	0.355	0.290	0.391	0.189	0.310	0.307
	1.000	1.000	1.000	1.000	1.000	1.000

CI=	0.061
CI/RI_n= (<i>n</i> =5)	0.054

(iii) Indicator: Integrity of wetlands

n=5 matrix

Land use	Livestock	Conservation	Timber	Crops	Urban
Livestock	1	3.003	0.143	0.200	0.111
Conservation	0.333	1	0.111	0.143	0.111
Timber	7.000	9.000	1	3.003	0.333
Crops	5.000	7.000	0.333	1	0.200
Urban	9.000	9.000	3.000	5.000	1

Normalized matrix:

Land use	Livestock	Conservation	Timber	Crops	Urban	Weight
Livestock	0.045	0.104	0.031	0.021	0.063	0.053
Conservation	0.015	0.034	0.024	0.015	0.063	0.030
Timber	0.313	0.310	0.218	0.321	0.190	0.271
Crops	0.224	0.241	0.073	0.107	0.114	0.152
Urban	0.403	0.310	0.654	0.535	0.570	0.494
	1.000	1.000	1.000	1.000	1.000	1.000

CI=	0.092
CI/RIn=	0.082
(<i>n=5</i>)	

(iv) Indicator: Integrity of riparian areas

n=5 matrix

Land use	Livestock	Conservation	Timber	Crops	Urban
Livestock	1	3.003	0.167	0.143	0.111
Conservation	0.333	1	0.111	0.143	0.111
Timber	6.000	9.000	1	3.003	0.333
Crops	7.000	7.000	0.333	1	0.500
Urban	9.000	9.000	3.000	2.000	1

Normalized matrix:

Land use	Livestock	Conservation	Timber	Crops	Urban	Weight
Livestock	0.043	0.104	0.036	0.023	0.054	0.052
Conservation	0.014	0.034	0.024	0.023	0.054	0.030
Timber	0.257	0.310	0.217	0.478	0.162	0.285
Crops	0.300	0.241	0.072	0.159	0.243	0.203
Urban	0.386	0.310	0.651	0.318	0.486	0.430
	1.000	1.000	1.000	1.000	1.000	1.000

CI=	0.099
CI/RIn=	0.088
(<i>n=5</i>)	

(v) Indicator: Status of indigenous fauna

n=5 matrix

Land use	Livestock	Conservation	Timber	Crops	Urban
Livestock	1	3.003	0.143	0.250	0.111
Conservation	0.333	1	0.111	0.167	0.111
Timber	7.000	9.000	1	3.003	0.500
Crops	4.000	6.000	0.333	1	0.500
Urban	9.000	9.000	2.000	2.000	1

Normalized matrix:

Land use	Livestock	Conservation	Timber	Crops	Urban	Weight
Livestock	0.047	0.107	0.040	0.039	0.050	0.057
Conservation	0.016	0.036	0.031	0.026	0.050	0.032
Timber	0.328	0.321	0.279	0.468	0.225	0.324
Crops	0.188	0.214	0.093	0.156	0.225	0.175
Urban	0.422	0.321	0.558	0.312	0.450	0.412
	1.000	1.000	1.000	1.000	1.000	1.000

CI=	0.053
CI/RIn=	0.047
(<i>n=5</i>)	

(b) Landscape function

Workshop: 12 December 2003

(i) Indicator: Disturbance processes

n=5 matrix

Land use	Livestock	Conservation	Timber	Crops	Urban
Livestock	1	3.003	0.143	0.250	0.111
Conservation	0.333	1	0.111	0.111	0.111
Timber	7.000	9.000	1	0.333	0.500
Crops	4.000	9.000	3.000	1	0.333
Urban	9.000	9.000	2.000	3.000	1

Normalized matrix:

Land use	Livestock	Conservation	Timber	Crops	Urban	Weight
Livestock	0.047	0.097	0.023	0.053	0.054	0.055
Conservation	0.016	0.032	0.018	0.024	0.054	0.029
Timber	0.328	0.290	0.160	0.071	0.243	0.219
Crops	0.188	0.290	0.480	0.213	0.162	0.267
Urban	0.422	0.290	0.320	0.639	0.486	0.432
	1.000	1.000	1.000	1.000	1.000	1.000

CI=	0.106
CI/RIn=	0.095
(<i>n=5</i>)	

(ii) Indicator: Geomorphic processes

n=5 matrix

Land use	Livestock	Conservation	Timber	Crops	Urban
Livestock	1	3.003	3.003	0.200	0.143
Conservation	0.333	1	0.333	0.143	0.111
Timber	0.333	3.000	1	0.333	0.200
Crops	5.000	7.000	3.000	1	0.500
Urban	7.000	9.000	5.000	2.000	1

Normalized matrix:

Land use	Livestock	Conservation	Timber	Crops	Urban	Weight
Livestock	0.073	0.131	0.243	0.054	0.073	0.115
Conservation	0.024	0.043	0.027	0.039	0.057	0.038
Timber	0.024	0.130	0.081	0.091	0.102	0.086
Crops	0.366	0.304	0.243	0.272	0.256	0.288
Urban	0.512	0.391	0.405	0.544	0.512	0.473
	1.000	1.000	1.000	1.000	1.000	1.000

CI=	0.082
CI/RIn=	0.074
(<i>n=5</i>)	

(iii) Indicator: nutrient leakage

n=5 matrix

Land use	Livestock	Conservation	Timber	Crops	Urban
Livestock	1	5.000	0.200	0.333	0.143
Conservation	0.200	1	0.143	0.143	0.111
Timber	5.000	7.000	1	5.000	0.500
Crops	3.000	7.000	0.200	1	0.333
Urban	7.000	9.000	2.000	3.000	1

Normalized matrix:

Land use	Livestock	Conservation	Timber	Crops	Urban	Weight
Livestock	0.062	0.172	0.056	0.035	0.068	0.079
Conservation	0.012	0.034	0.040	0.015	0.053	0.031
Timber	0.309	0.241	0.282	0.528	0.240	0.320
Crops	0.185	0.241	0.056	0.106	0.160	0.150
Urban	0.432	0.310	0.565	0.317	0.479	0.421
	1.000	1.000	1.000	1.000	1.000	1.000

CI=	0.108
CI/RIn=	0.096
(<i>n=5</i>)	

(iv) Hydrological processes

n=5 matrix

Land use	Livestock	Conservation	Timber	Crops	Urban
Livestock	1	3.003	0.167	0.200	0.125
Conservation	0.333	1	0.111	0.143	0.111
Timber	6.000	9.000	1	4.000	0.500
Crops	5.000	7.000	0.250	1	0.500
Urban	8.000	9.000	2.000	2.000	1

Normalized matrix:

Land use	Livestock	Conservation	Timber	Crops	Urban	Weight
Livestock	0.049	0.104	0.047	0.027	0.056	0.057
Conservation	0.016	0.034	0.031	0.019	0.050	0.030
Timber	0.295	0.310	0.283	0.545	0.224	0.331
Crops	0.246	0.241	0.071	0.136	0.224	0.184
Urban	0.393	0.310	0.567	0.272	0.447	0.398
	1.000	1.000	1.000	1.000	1.000	1.000

CI=	0.078
CI/RIn=	0.070
(<i>n=5</i>)	

(v) Indicator: Reproductive processes

n=5 matrix

Land use	Livestock	Conservation	Timber	Crops	Urban
Livestock	1	5.000	0.143	0.250	0.125
Conservation	0.200	1	0.111	0.125	0.111
Timber	7.000	9.000	1	2.000	0.500
Crops	4.000	8.000	0.500	1	0.500
Urban	8.000	9.000	2.000	2.000	1

Normalized matrix:

Land use	Livestock	Conservation	Timber	Crops	Urban	Weight
Livestock	0.050	0.156	0.038	0.047	0.056	0.069
Conservation	0.010	0.031	0.030	0.023	0.050	0.029
Timber	0.347	0.281	0.266	0.372	0.224	0.298
Crops	0.198	0.250	0.133	0.186	0.224	0.198
Urban	0.396	0.281	0.533	0.372	0.447	0.406
	1.000	1.000	1.000	1.000	1.000	1.000

CI=	0.072
CI/RIn=	0.064
(<i>n=5</i>)	

(c) Landscape structure

Workshop: 16 April 2004

(i) Indicator: Transformation of grassland

n=5 matrix

Land use	Livestock	Conservation	Timber	Crops	Urban
Livestock	1	3.003	0.143	0.200	0.143
Conservation	0.333	1	0.143	0.143	0.111
Timber	7.000	7.000	1	3.030	0.333
Crops	5.000	7.000	0.330	1	0.333
Urban	7.000	9.000	3.000	3.000	1

Normalized matrix:

Land use	Livestock	Conservation	Timber	Crops	Urban	Weight
Livestock	0.049	0.111	0.031	0.027	0.074	0.059
Conservation	0.016	0.037	0.031	0.019	0.058	0.032
Timber	0.344	0.259	0.217	0.411	0.174	0.281
Crops	0.246	0.259	0.071	0.136	0.174	0.177
Urban	0.344	0.333	0.650	0.407	0.521	0.451
	1.000	1.000	1.000	1.000	1.000	1.000

CI=	0.090
CI/RIn=	0.080
(<i>n=5</i>)	

(ii) Indicator: Fragmentation of grassland

n=5 matrix

Land use	Livestock	Conservation	Timber	Crops	Urban
Livestock	1	3.003	0.143	0.143	0.143
Conservation	0.333	1	0.111	0.111	0.143
Timber	7.000	9.000	1	1.000	0.333
Crops	7.000	9.000	1.000	1	0.333
Urban	7.000	7.000	3.000	3.000	1

Normalized matrix:

Land use	Livestock	Conservation	Timber	Crops	Urban	Weight
Livestock	0.045	0.104	0.027	0.027	0.073	0.055
Conservation	0.015	0.034	0.021	0.021	0.073	0.033
Timber	0.313	0.310	0.190	0.190	0.171	0.235
Crops	0.313	0.310	0.190	0.190	0.171	0.235
Urban	0.313	0.241	0.571	0.571	0.512	0.442
	1.000	1.000	1.000	1.000	1.000	1.000

CI=	0.090
CI/RIn=	0.081
(<i>n=5</i>)	

(iii) Indicator: Physiognomic (structural) change of grassland

n=5 matrix

Land use	Livestock	Conservation	Timber	Crops	Urban
Livestock	1	3.003	0.143	0.200	0.111
Conservation	0.333	1	0.111	0.143	0.111
Timber	7.000	9.000	1	1.000	0.333
Crops	5.000	7.000	1.000	1	0.200
Urban	9.000	9.000	3.000	5.000	1

Normalized matrix:

Land use	Livestock	Conservation	Timber	Crops	Urban	Weight
Livestock	0.045	0.104	0.027	0.027	0.063	0.053
Conservation	0.015	0.034	0.021	0.019	0.063	0.031
Timber	0.313	0.310	0.190	0.136	0.190	0.228
Crops	0.224	0.241	0.190	0.136	0.114	0.181
Urban	0.403	0.310	0.571	0.681	0.570	0.507
	1.000	1.000	1.000	1.000	1.000	1.000

CI=	0.080
CI/RIn=	0.072
(<i>n=5</i>)	

1.3. Final ranking of land uses

1.3.1. Impact on biodiversity components

(a) Landscape composition

	Indicator:	Forest	Grassland	Wetland	Riparian	Fauna	
	Weight:	0.116	0.347	0.231	0.204	0.103	Weight
Land use	Livestock	0.052	0.049	0.053	0.052	0.057	0.052
	Conservation	0.029	0.029	0.030	0.030	0.032	0.030
	Timber	0.267	0.383	0.271	0.285	0.324	0.318
	Crop	0.161	0.231	0.152	0.203	0.175	0.193
	Urban	0.491	0.307	0.494	0.430	0.412	0.408
		1.000	1.000	1.000	1.000	1.000	1.000

(b) Landscape function

	Indicator:	Disturbance	Geomorphic	Nutrient	Hydrological	Reproductive	
	Weight:	0.190	0.069	0.380	0.265	0.095	Weight
Land use	Livestock	0.055	0.115	0.079	0.057	0.069	0.070
	Conservation	0.029	0.038	0.031	0.030	0.029	0.031
	Timber	0.219	0.086	0.320	0.331	0.298	0.285
	Crop	0.267	0.288	0.150	0.184	0.198	0.195
	Urban	0.432	0.473	0.421	0.398	0.406	0.419
		1.000	1.000	1.000	1.000	1.000	1.000

(c) Landscape structure

		Indicator:	Transformation	Fragmentation	Physiognomy	
		Weight:	0.600	0.200	0.200	Weight
Land use	Grazing	0.059	0.055	0.053	0.057	
	Conservation	0.032	0.033	0.031	0.032	
	Timber	0.281	0.235	0.228	0.261	
	Crops	0.177	0.235	0.181	0.190	
	Urban	0.451	0.442	0.507	0.460	
		1.000	1.000	1.000	1.000	

1.3.2. Overall impact on biodiversity

(a) Ranking of biodiversity components:

COMPONENT:	Composition	Function	Structure
Composition	1.000	0.333	0.200
Function	3.000	1.000	0.600
Structure	5.000	1.667	1.000
	9.000	3.000	1.800

Normalized matrix:

COMPONENT:	Composition	Function	Structure	Weight
Composition	0.111	0.111	0.111	0.111
Function	0.333	0.333	0.333	0.333
Structure	0.556	0.556	0.556	0.556
	1.000	1.000	1.000	1.000

CI=	0
CI/RIn=	0

(n=3)

(b) Ranking of land uses:

	COMPONENT: WEIGHT:	Composition 0.111	Function 0.333	Structure 0.556	WEIGHT
LAND USE:	Livestock	0.052	0.070	0.057	0.061
	Conservation	0.030	0.031	0.032	0.031
	Timber	0.318	0.285	0.261	0.275
	Crop	0.193	0.195	0.190	0.192
	Urban	0.408	0.419	0.460	0.441
		1.000	1.000	1.000	1.000

2. Formal workshop results

Workshop: 06 April 2005

2.1. Ranking of biodiversity indicators

(a) Landscape composition

Indicator	Forest	Grassland	Wetland	Riparian	Fauna
Forest	1.00	0.20	0.50	3.03	3.03
Grassland	5.00	1.00	2.00	14.29	15.15
Wetland	2.00	0.50	1.00	5.88	6.06
Riparian	0.33	0.07	0.17	1.00	1.00
Fauna	0.33	0.07	0.17	1.00	1.00

Normalized
matrix:

Indicator	Forest	Grassland	Wetland	Riparian	Fauna	Weight
Forest	0.12	0.11	0.13	0.12	0.12	0.118
Grassland	0.58	0.54	0.52	0.57	0.58	0.558
Wetland	0.23	0.27	0.26	0.23	0.23	0.246
Riparian	0.04	0.04	0.04	0.04	0.04	0.040
Fauna	0.04	0.04	0.04	0.04	0.04	0.039
	1.00	1.00	1.00	1.00	1.00	1.000

CI=	0.001
CI/RIn=	0.001
(n=5)	

(b) Landscape function

Indicator	Disturbance	Geomorphic	Nutrient	Hydrologic	Extinction
Disturbance	1	4.55	1.03	1.00	2.00
Geomorphic	0.22	1	0.22	0.22	0.50
Nutrient	0.97	4.50	1	1.00	2.00
Hydrologic	1.00	4.50	1.00	1	2.00
Extinction	0.50	2.00	0.50	0.50	1

Normalized matrix:

Indicator	Disturb	Geomorphic	Nutrient	Hydrologic	Extinction	Weight
Disturbance	0.271	0.275	0.275	0.269	0.267	0.271
Geomorphic	0.060	0.060	0.059	0.060	0.067	0.061
Nutrient	0.263	0.272	0.266	0.269	0.267	0.267
Hydrologic	0.271	0.272	0.266	0.269	0.267	0.269
Extinction	0.136	0.121	0.133	0.134	0.133	0.131
	1.000	1.000	1.000	1.000	1.000	1.000

CI=	0.000
CI/RIn=	0.000
<i>(n=5)</i>	

(c) Landscape structure

Indicator	Transformation	Fragmentation	Physiognomy	Heterogeneity
Transformation	1.000	1.053	2.128	2.326
Fragmentation	0.950	1.000	2.000	0.667
Physiognomy	0.470	0.500	1.000	1.053
Heterogeneity	0.430	1.500	0.950	1.000

Normalized matrix:

Indicator	Transformation	Fragmentation	Physiognomy	Heterogeneity	Weights
Transformation	0.351	0.260	0.350	0.461	0.355
Fragmentation	0.333	0.247	0.329	0.132	0.260
Physiognomy	0.165	0.123	0.165	0.209	0.165
Heterogeneity	0.151	0.370	0.156	0.198	0.219
	1.000	1.000	1.000	1.000	1.000

Consistency:

CI=	0.059
CI/RI_n=	0.066
<i>(n=4)</i>	

2.2. Ranking of land use with respect to indicators

(a) Landscape composition

(i) Indicator: Integrity of forest

n=6 matrix:

Land use	Livestock	Timber	Crops	Pasture	Rural	Urban
Livestock	1	0.23	0.64	1.15	0.18	0.18
Timber	4.33	1	3.45	3.03	0.37	0.64
Crops	1.56	0.29	1	1.49	0.23	0.25
Pasture	0.87	0.33	0.67	1	0.21	0.21
Rural	5.67	2.67	4.33	4.67	1	0.41
Urban	5.67	1.56	4.00	4.67	2.44	1

Consistency:

CI=	0.041
CI/RIn=	0.033
<i>(n=6)</i>	

Normalized matrix:

Land use	Livestock	Timber	Crops	Pasture	Rural	Urban	Weight
Livestock	0.052	0.038	0.045	0.072	0.040	0.066	0.052
Timber	0.227	0.164	0.245	0.189	0.084	0.238	0.191
Crops	0.082	0.048	0.071	0.093	0.052	0.093	0.073
Pasture	0.046	0.054	0.048	0.062	0.048	0.080	0.056
Rural	0.297	0.439	0.307	0.292	0.225	0.152	0.285
Urban	0.297	0.257	0.284	0.292	0.550	0.372	0.342
	1.000	1.000	1.000	1.000	1.000	1.000	1.000

(ii) Indicator: Integrity of grassland

n=6 matrix:

Land use	Livestock	Timber	Crops	Pasture	Rural	Urban
Livestock	1	0.12	0.13	0.20	0.20	0.12
Timber	8.33	1	1.12	2.04	3.85	0.43
Crops	8.00	0.89	1	3.70	3.85	0.25
Pasture	5.00	0.49	0.27	1	1.12	0.19
Rural	5.00	0.26	0.26	0.89	1	0.17
Urban	8.67	2.33	4.00	5.33	6.00	1

Normalized matrix:

Land use	Livestock	Timber	Crops	Pasture	Rural	Urban	Weight
Livestock	0.028	0.024	0.018	0.015	0.012	0.054	0.025
Timber	0.231	0.196	0.166	0.155	0.240	0.200	0.198
Crops	0.222	0.175	0.148	0.281	0.240	0.116	0.197
Pasture	0.139	0.096	0.040	0.076	0.070	0.087	0.085
Rural	0.139	0.051	0.038	0.068	0.062	0.078	0.073
Urban	0.241	0.458	0.590	0.405	0.375	0.465	0.422
	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Consistency:

CI=	0.061
CI/RI<i>n</i>=	0.049
(<i>n</i> =6)	

(iii) Indicator: Integrity of wetlands

n=6 matrix:

Land use	Livestock	Timber	Crops	Pasture	Rural	Urban
Livestock	1.000	0.258	0.226	0.268	0.214	0.137
Timber	3.882	1.000	0.871	1.217	1.125	0.351
Crops	4.416	1.148	1.000	1.889	0.684	0.331
Pasture	3.728	0.822	0.529	1.000	0.549	0.299
Rural	4.682	0.889	1.461	1.821	1.000	0.474
Urban	7.277	2.853	3.022	3.346	2.112	1.000

Normalized matrix:

Land use	Livestock	Timber	Crops	Pasture	Rural	Urban	Weight
Livestock	0.040	0.037	0.032	0.028	0.038	0.053	0.038
Timber	0.155	0.143	0.122	0.128	0.198	0.135	0.147
Crops	0.177	0.165	0.141	0.198	0.120	0.128	0.155
Pasture	0.149	0.118	0.074	0.105	0.097	0.115	0.110
Rural	0.187	0.128	0.206	0.191	0.176	0.183	0.178
Urban	0.291	0.409	0.425	0.351	0.372	0.386	0.372
	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Consistency:

CI=	0.017
CI/RI _n =	0.013
(n=6)	

(iv) Indicator: Integrity of riparian areas

n=6 matrix:

Land use	Livestock	Timber	Crops	Pasture	Rural	Urban
Livestock	1.000	0.380	0.438	0.549	0.272	0.147
Timber	2.630	1.000	0.950	2.261	0.889	0.228
Crops	2.281	1.052	1.000	1.915	0.840	0.234
Pasture	1.821	0.442	0.522	1.000	0.658	0.206
Rural	3.680	1.125	1.191	1.519	1.000	0.336
Urban	6.804	4.384	4.282	4.856	2.977	1.000

Normalized matrix:

Land use	Livestock	Timber	Crops	Pasture	Rural	Urban	Weight
Livestock	0.055	0.045	0.052	0.045	0.041	0.068	0.051
Timber	0.144	0.119	0.113	0.187	0.134	0.106	0.134
Crops	0.125	0.126	0.119	0.158	0.127	0.109	0.127
Pasture	0.100	0.053	0.062	0.083	0.099	0.096	0.082
Rural	0.202	0.134	0.142	0.126	0.151	0.156	0.152
Urban	0.374	0.523	0.511	0.401	0.449	0.465	0.454
	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Consistency:

CI=	0.015
CI/RI<i>n</i>=	0.012
(<i>n</i>=6)	

(v) Indicator: Status of indigenous fauna

n=6 matrix:

Land use	Livestock	Timber	Crops	Pasture	Rural	Urban
Livestock	1.000	0.143	0.178	0.349	0.169	0.132
Timber	6.971	1.000	1.553	2.788	1.284	0.566
Crops	5.619	0.644	1.000	2.854	0.635	0.341
Pasture	2.862	0.359	0.350	1.000	0.320	0.213
Rural	5.909	0.779	1.574	3.129	1.000	0.389
Urban	7.595	1.766	2.932	4.690	2.572	1.000

Normalized matrix:

Land use	Livestock	Timber	Crops	Pasture	Rural	Urban	Weight
Livestock	0.033	0.031	0.023	0.024	0.028	0.050	0.032
Timber	0.233	0.213	0.205	0.188	0.215	0.214	0.211
Crops	0.188	0.137	0.132	0.193	0.106	0.129	0.147
Pasture	0.096	0.076	0.046	0.068	0.053	0.081	0.070
Rural	0.197	0.166	0.208	0.211	0.167	0.147	0.183
Urban	0.254	0.377	0.386	0.317	0.430	0.379	0.357
	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Consistency:

CI=	0.020
CI/RI<i>n</i>=	0.016
(<i>n</i>=6)	

(b) Landscape function

(i) Indicator: Disturbance processes

n=6 matrix:

Land use	Livestock	Timber	Crops	Pasture	Rural	Urban
Livestock	1.000	0.134	0.162	0.254	0.562	0.122
Timber	7.454	1.000	1.626	2.765	3.251	0.639
Crops	6.160	0.615	1.000	1.859	2.001	0.393
Pasture	3.936	0.362	0.538	1.000	1.312	0.278
Rural	1.778	0.308	0.500	0.762	1.000	0.225
Urban	8.207	1.565	2.548	3.600	4.448	1.000

Normalized matrix:

Land use	Livestock	Timber	Crops	Pasture	Rural	Urban	Weight
Livestock	0.035	0.034	0.025	0.025	0.045	0.046	0.035
Timber	0.261	0.251	0.255	0.270	0.259	0.241	0.256
Crops	0.216	0.154	0.157	0.182	0.159	0.148	0.169
Pasture	0.138	0.091	0.084	0.098	0.104	0.105	0.103
Rural	0.062	0.077	0.078	0.074	0.080	0.085	0.076
Urban	0.288	0.393	0.400	0.352	0.354	0.377	0.360
	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Consistency:

CI=	0.011
CI/RI_n=	0.009
(<i>n</i>=6)	

(ii) Indicator: Geomorphic processes

n=6 matrix:

Land use	Livestock	Timber	Crops	Pasture	Rural	Urban
Livestock	1.000	0.325	0.301	0.752	0.281	0.201
Timber	3.080	1.000	0.765	2.159	1.017	0.556
Crops	3.327	1.308	1.000	2.179	1.171	0.644
Pasture	1.330	0.463	0.459	1.000	0.427	0.343
Rural	3.557	0.983	0.854	2.340	1.000	0.831
Urban	4.965	1.800	1.552	2.913	1.204	1.000

Normalized matrix:

Land use	Livestock	Timber	Crops	Pasture	Rural	Urban	Weight
Livestock	0.058	0.055	0.061	0.066	0.055	0.056	0.059
Timber	0.178	0.170	0.155	0.190	0.199	0.155	0.175
Crops	0.193	0.222	0.203	0.192	0.230	0.180	0.203
Pasture	0.077	0.079	0.093	0.088	0.084	0.096	0.086
Rural	0.206	0.167	0.173	0.206	0.196	0.232	0.197
Urban	0.288	0.306	0.315	0.257	0.236	0.280	0.280
	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Consistency:

CI=	0.005
CI/RI_n=	0.004
(<i>n</i>=6)	

(iii) Indicator: Nutrient leakage

n=6 matrix:

Land use	Livestock	Timber	Crops	Pasture	Rural	Urban
Livestock	1.000	0.184	0.159	0.251	0.359	0.130
Timber	5.439	1.000	0.731	2.253	2.451	0.568
Crops	6.293	1.368	1.000	2.000	2.028	0.684
Pasture	3.984	0.444	0.500	1.000	1.058	0.309
Rural	2.783	0.408	0.493	0.945	1.000	0.294
Urban	7.707	1.760	1.461	3.234	3.405	1.000

Normalized matrix:

Land use	Livestock	Timber	Crops	Pasture	Rural	Urban	Weight
Livestock	0.037	0.036	0.037	0.026	0.035	0.043	0.036
Timber	0.200	0.194	0.168	0.233	0.238	0.190	0.204
Crops	0.231	0.265	0.230	0.207	0.197	0.229	0.227
Pasture	0.146	0.086	0.115	0.103	0.103	0.104	0.110
Rural	0.102	0.079	0.113	0.098	0.097	0.098	0.098
Urban	0.283	0.341	0.336	0.334	0.331	0.335	0.327
	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Consistency:

CI=	0.008
CI/RI<i>n</i>=	0.007
<i>(n</i> =6)	

(iv) Indicator: Hydrological processes

n=6 matrix:

Land use	Livestock	Timber	Crops	Pasture	Rural	Urban
Livestock	1.000	0.150	0.211	0.302	0.217	0.122
Timber	6.654	1.000	2.245	3.204	2.028	0.663
Crops	4.729	0.445	1.000	1.832	1.000	0.369
Pasture	3.310	0.312	0.546	1.000	0.508	0.321
Rural	4.606	0.493	1.000	1.968	1.000	0.408
Urban	8.207	1.507	2.711	3.118	2.449	1.000

Normalized matrix:

Land use	Livestock	Timber	Crops	Pasture	Rural	Urban	Weight
Livestock	0.035	0.038	0.027	0.026	0.030	0.042	0.033
Timber	0.233	0.256	0.291	0.280	0.282	0.230	0.262
Crops	0.166	0.114	0.130	0.160	0.139	0.128	0.139
Pasture	0.116	0.080	0.071	0.088	0.071	0.111	0.089
Rural	0.162	0.126	0.130	0.172	0.139	0.142	0.145
Urban	0.288	0.386	0.351	0.273	0.340	0.347	0.331
	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Consistency:

CI=	0.011
CI/RI<i>n</i>=	0.009
<i>(n</i> =6)	

(v) Indicator: Extinction rates

n=6 matrix:

Land use	Livestock	Timber	Crops	Pasture	Rural	Urban
Livestock	1.000	0.169	0.224	0.298	0.359	0.147
Timber	5.916	1.000	1.802	1.702	2.038	0.663
Crops	4.472	0.555	1.000	2.001	1.565	0.396
Pasture	3.350	0.588	0.500	1.000	1.045	0.307
Rural	2.783	0.491	0.639	0.957	1.000	0.301
Urban	6.817	1.507	2.523	3.253	3.320	1.000

Normalized matrix:

Land use	Livestock	Timber	Crops	Pasture	Rural	Urban	Weight
Livestock	0.041	0.039	0.033	0.032	0.039	0.052	0.039
Timber	0.243	0.232	0.269	0.185	0.218	0.236	0.231
Crops	0.184	0.129	0.150	0.217	0.168	0.141	0.165
Pasture	0.138	0.136	0.075	0.109	0.112	0.109	0.113
Rural	0.114	0.114	0.096	0.104	0.107	0.107	0.107
Urban	0.280	0.350	0.377	0.353	0.356	0.355	0.345
	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Consistency:

CI=	0.011
CI/RI<i>n</i>=	0.009
(<i>n</i> =6)	

(c) Landscape structure

(i) Indicator: Transformation of grassland

n=6 matrix:

Land use	Livestock	Timber	Crops	Pasture	Rural	Urban
Livestock	1.000	0.126	0.135	0.166	0.230	0.126
Timber	7.937	1.000	0.931	1.733	2.530	0.809
Crops	7.416	1.074	1.000	1.414	2.281	0.731
Pasture	6.031	0.577	0.707	1.000	1.457	0.541
Rural	4.356	0.395	0.438	0.686	1.000	0.442
Urban	7.937	1.237	1.369	1.848	2.264	1.000

Normalized matrix:

Land use	Livestock	Timber	Crops	Pasture	Rural	Urban	Weight
Livestock	0.029	0.029	0.029	0.024	0.024	0.035	0.028
Timber	0.229	0.227	0.203	0.253	0.259	0.222	0.232
Crops	0.214	0.244	0.218	0.207	0.234	0.200	0.219
Pasture	0.174	0.131	0.154	0.146	0.149	0.148	0.150
Rural	0.126	0.090	0.096	0.100	0.102	0.121	0.106
Urban	0.229	0.280	0.299	0.270	0.232	0.274	0.264
	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Consistency:

CI=	0.005
CI/RI_n=	0.004
(n=6)	

(ii) Indicator: Fragmentation of grassland

n=6 matrix:

Land use	Livestock	Timber	Crops	Pasture	Rural	Urban
Livestock	1.000	0.130	0.148	0.161	0.236	0.122
Timber	7.707	1.000	1.265	1.375	2.559	0.728
Crops	6.735	0.790	1.000	1.089	2.412	0.520
Pasture	6.192	0.727	0.918	1.000	2.061	0.432
Rural	4.229	0.391	0.415	0.485	1.000	0.302
Urban	8.207	1.374	1.923	2.317	3.310	1.000

Normalized matrix:

Land use	Livestock	Timber	Crops	Pasture	Rural	Urban	Weight
Livestock	0.029	0.029	0.026	0.025	0.020	0.039	0.028
Timber	0.226	0.227	0.223	0.214	0.221	0.235	0.224
Crops	0.198	0.179	0.176	0.169	0.208	0.168	0.183
Pasture	0.182	0.165	0.162	0.156	0.178	0.139	0.164
Rural	0.124	0.089	0.073	0.075	0.086	0.097	0.091
Urban	0.241	0.311	0.339	0.360	0.286	0.322	0.310
	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Consistency:

CI=	0.009
CI/RI_n=	0.007
(<i>n</i>=6)	

(iii) Indicator: Physiognomy of grassland

n=6 matrix:

Land use	Livestock	Timber	Crops	Pasture	Rural	Urban
Livestock	1.000	0.122	0.155	0.280	0.273	0.131
Timber	8.207	1.000	1.616	3.007	3.501	0.841
Crops	6.447	0.619	1.000	2.000	2.515	0.577
Pasture	3.568	0.333	0.500	1.000	1.136	0.427
Rural	3.663	0.286	0.398	0.880	1.000	0.676
Urban	7.637	1.189	1.732	2.340	1.480	1.000

Normalized matrix:

Land use	Livestock	Timber	Crops	Pasture	Rural	Urban	Weight
Livestock	0.033	0.034	0.029	0.029	0.028	0.036	0.031
Timber	0.269	0.282	0.299	0.316	0.353	0.230	0.292
Crops	0.211	0.174	0.185	0.210	0.254	0.158	0.199
Pasture	0.117	0.094	0.093	0.105	0.115	0.117	0.107
Rural	0.120	0.081	0.074	0.093	0.101	0.185	0.109
Urban	0.250	0.335	0.321	0.246	0.149	0.274	0.263

1.000 1.000 1.000 1.000 1.000 1.000 1.000

Consistency:

CI=	0.021
CI/RI<i>n</i>= (<i>n</i> =6)	0.017

(iv) Indicator: Heterogeneity of grassland

n=6 matrix:

Land use	Livestock	Timber	Crops	Pasture	Rural	Urban
Livestock	1.000	0.134	0.154	0.162	0.281	0.127
Timber	7.454	1.000	1.296	1.296	2.982	0.789
Crops	6.514	0.772	1.000	1.000	2.475	0.610
Pasture	6.160	0.772	1.000	1.000	2.475	0.552
Rural	3.557	0.335	0.404	0.404	1.000	0.277
Urban	7.896	1.267	1.638	1.813	3.604	1.000

Normalized matrix:

Land use	Livestock	Timber	Crops	Pasture	Rural	Urban	Weight
Livestock	0.031	0.031	0.028	0.029	0.022	0.038	0.030
Timber	0.229	0.234	0.236	0.228	0.233	0.235	0.232
Crops	0.200	0.180	0.182	0.176	0.193	0.182	0.186
Pasture	0.189	0.180	0.182	0.176	0.193	0.164	0.181
Rural	0.109	0.078	0.074	0.071	0.078	0.083	0.082
Urban	0.242	0.296	0.298	0.319	0.281	0.298	0.289
	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Consistency:

CI=	0.005
CI/RI<i>n</i>= (<i>n</i> =6)	0.004

2.3. Final ranking of land uses

2.3.1. Impact on biodiversity components

(a) Landscape composition

	Indicator: Weight:	Forest	Grassland	Wetlands	Riparian	Fauna	Weight
Land use							
	Livestock	0.052	0.025	0.038	0.051	0.032	0.033
	Timber	0.191	0.198	0.147	0.134	0.211	0.183
	Crops	0.073	0.197	0.155	0.127	0.147	0.167
	Pasture	0.056	0.085	0.110	0.082	0.070	0.087
	Rural	0.285	0.073	0.178	0.152	0.183	0.131
	Urban	0.342	0.422	0.372	0.454	0.357	0.399

1.000

(b) Landscape function

	Indicator: Weight:	Disturbance	Geomorphic	Nutrient	Hydrologic	Extinction	Weight
Land use							
	Livestock	0.035	0.059	0.036	0.033	0.039	0.037
	Timber	0.256	0.175	0.204	0.262	0.231	0.235
	Crops	0.169	0.203	0.227	0.139	0.165	0.178
	Pasture	0.103	0.086	0.110	0.089	0.113	0.101
	Rural	0.076	0.197	0.098	0.145	0.107	0.112
	Urban	0.360	0.280	0.327	0.331	0.345	0.337

1.000

(c) Landscape structure

	Indicator:	Transformation	Fragmentation	Physiognomy	Heterogeneity	
	Weight:	0.355	0.260	0.165	0.219	Weight
Land use	Livestock	0.028	0.028	0.031	0.030	0.029
	Timber	0.232	0.224	0.292	0.232	0.240
	Crops	0.219	0.183	0.199	0.186	0.199
	Pasture	0.150	0.164	0.107	0.181	0.153
	Rural	0.106	0.091	0.109	0.082	0.097
	Urban	0.264	0.310	0.263	0.289	0.281

1.000

2.3.2. Overall impact on biodiversity

(a) Ranking of biodiversity components:

COMPONENT:	Composition	Function	Structure
Composition	1.000	0.333	0.200
Function	3.000	1.000	0.600
Structure	5.000	1.667	1.000
	9.000	3.000	1.800

Normalized matrix:

COMPONENT:	Composition	Function	Structure	Weight
Composition	0.111	0.111	0.111	0.111
Function	0.333	0.333	0.333	0.333
Structure	0.556	0.556	0.556	0.556
	1.000	1.000	1.000	1.000

CI=	0
CI/RIn=	0

(n=3)

(b) Ranking of land uses:

	COMPONENT:	Composition	Function	Structure	WEIGHT
	WEIGHT:	0.111	0.333	0.556	
LAND USE:	Livestock	0.033	0.037	0.029	0.032
	Timber	0.183	0.235	0.240	0.232
	Crops	0.167	0.178	0.199	0.189
	Pasture	0.087	0.101	0.153	0.129
	Rural	0.131	0.112	0.097	0.106
	Urban	0.399	0.337	0.281	0.313

1.000

APPENDIX C

IMPACT OF LAND USE ON BIODIVERSITY OF THE MOIST SUB-BIOME OF THE GRASSLAND BIOME

- Summary from Analytic Hierarchy Process matrices originally in Microsoft Excel spreadsheets.
- Procedure for the ranking of indicators of biodiversity integrity and land uses with respect to each indicator was as undertaken for the Mistbelt Grassland Study in Appendix B.

1. Final ranking of land uses (summary)

1.1. Impact on biodiversity components

(a) Landscape composition

(i) Indicator group: Alien vegetation

		Herbaceous aliens	Woody aliens	Overall Weights
Indicator:				
Weight:		0.167	0.833	
Land use	Conservation	0.028	0.021	0.022
	Livestock	0.076	0.063	0.065
	Tourism	0.073	0.063	0.064
	Game	0.051	0.021	0.026
	Rural	0.109	0.104	0.105
	Dairy	0.138	0.104	0.110
	Dryland crops	0.122	0.146	0.142
	Irrigated crops	0.140	0.146	0.145
	Timber	0.082	0.146	0.135
	Urban	0.182	0.188	0.187

1.000

(ii) Indicator group: Species

	Indicator: Weight:	Insects 0.111	Birds 0.333	Mammals 0.556	Overall Weight
Land use	Conservation	0.023	0.023	0.025	0.024
	Livestock	0.040	0.038	0.057	0.049
	Tourism	0.062	0.084	0.046	0.060
	Game	0.023	0.047	0.034	0.037
	Rural	0.054	0.157	0.170	0.153
	Dairy	0.161	0.113	0.106	0.115
	Dryland crops	0.138	0.092	0.110	0.107
	Irrigated crops	0.177	0.112	0.109	0.117
	Timber	0.175	0.149	0.135	0.144
	Urban	0.147	0.186	0.209	0.194

1.000

(iii) Indicator group: habitats

	Indicator:	Forest	Riparian	Aquatic	Wetland	Rocky	Grassland	Overall
	Weight:	0.081	0.071	0.056	0.186	0.163	0.443	Weights
Land use	Conservation	0.032	0.023	0.027	0.028	0.030	0.021	0.025
	Livestock	0.070	0.068	0.065	0.061	0.069	0.055	0.061
	Tourism	0.062	0.062	0.053	0.049	0.070	0.053	0.057
	Game	0.046	0.041	0.038	0.045	0.050	0.049	0.047
	Rural	0.213	0.154	0.150	0.147	0.147	0.123	0.142
	Dairy	0.073	0.115	0.130	0.126	0.084	0.113	0.109
	Dryland crops	0.090	0.100	0.084	0.101	0.056	0.117	0.099
	Irrigated crops	0.086	0.120	0.108	0.118	0.050	0.118	0.104
	Timber	0.141	0.137	0.161	0.143	0.222	0.173	0.170
	Urban	0.187	0.181	0.185	0.183	0.222	0.178	0.187
		1.000	1.000	1.000	1.000	1.000	1.000	1.000

(iv) Overall ranking for landscape composition

	Indicator:	Aliens	Species	Habitat	Overall Weight
	Weight:	0.071	0.286	0.643	
Land use	Conservation	0.022	0.025	0.024	0.024
	Livestock	0.065	0.061	0.049	0.053
	Tourism	0.064	0.057	0.060	0.059
	Game	0.026	0.047	0.037	0.039
	Rural	0.105	0.142	0.153	0.146
	Dairy	0.110	0.109	0.115	0.112
	Dryland crops	0.142	0.099	0.107	0.107
	Irrigated crops	0.145	0.104	0.117	0.116
	Timber	0.135	0.170	0.144	0.151
	Urban	0.187	0.187	0.194	0.192

1.000

(b) Landscape function

(i) Indicator group: Hydrological functioning

	Indicator:	Water quantity	Water quality	Seasonality	Overall Weight
	Weight:	0.144	0.564	0.292	
Land use	Conservation	0.031	0.029	0.033	0.030
	Livestock	0.057	0.085	0.068	0.076
	Tourism	0.064	0.056	0.070	0.061
	Game	0.042	0.054	0.049	0.051
	Rural	0.124	0.130	0.131	0.129
	Dairy	0.140	0.140	0.138	0.139
	Dryland crops	0.088	0.109	0.071	0.095
	Irrigated crops	0.168	0.142	0.162	0.152
	Timber	0.158	0.094	0.140	0.116
	Urban	0.130	0.161	0.138	0.150

1.000

(ii) Indicator group: Biogeochemical processes

	indicator:	Carbon storage	Nutrient loss	Primary production	Overall Weight
	Weight:	0.310	0.310	0.380	
Land use	Conservation	0.090	0.028	0.105	0.077
	Livestock	0.102	0.076	0.105	0.095
	Tourism	0.101	0.073	0.110	0.096
	Game	0.090	0.051	0.105	0.084
	Rural	0.105	0.109	0.110	0.108
	Dairy	0.101	0.138	0.086	0.106
	Dryland crops	0.106	0.122	0.091	0.106
	Irrigated crops	0.106	0.140	0.077	0.106
	Timber	0.090	0.082	0.100	0.091
	Urban	0.108	0.182	0.110	0.132

1.000

(iii) Indicator group: Fire

	Indicator:	Extent	Intensity	Frequency	Seasonality	Overall Weight
	Weight:	0.063	0.125	0.313	0.500	
Land use	Conservation	0.037	0.119	0.061	0.075	0.073
	Livestock	0.037	0.076	0.081	0.059	0.067
	Tourism	0.104	0.149	0.053	0.066	0.075
	Game	0.067	0.085	0.067	0.078	0.075
	Rural	0.079	0.070	0.203	0.216	0.185
	Dairy	0.115	0.072	0.113	0.059	0.081
	Dryland crops	0.067	0.075	0.061	0.071	0.068
	Irrigated crops	0.065	0.067	0.067	0.071	0.069
	Timber	0.211	0.136	0.178	0.117	0.144
	Urban	0.217	0.152	0.117	0.187	0.163
		1.000	1.000	1.000	1.000	1.000

(iv) Indicator group: Grazing

	Indicator:	Extent	Intensity	Frequency	Seasonality	Overall Weight
	Weight:	0.095	0.286	0.238	0.381	
Land use	Conservation	0.100	0.039	0.039	0.069	0.056
	Livestock	0.100	0.117	0.136	0.069	0.102
	Tourism	0.100	0.020	0.019	0.069	0.046
	Game	0.100	0.098	0.136	0.069	0.096
	Rural	0.100	0.234	0.234	0.069	0.158
	Dairy	0.100	0.156	0.175	0.276	0.201
	Dryland crops	0.100	0.176	0.117	0.138	0.140
	Irrigated crops	0.100	0.078	0.078	0.069	0.077
	Timber	0.100	0.078	0.058	0.069	0.072
	Urban	0.100	0.004	0.007	0.103	0.052
		1.000	1.000	1.000	1.000	1.000

(v) Indicator group: Biotic processes

	Indicator:	Medicinal	Crafts	Building	Overall Weight
	Weight:	0.455	0.091	0.455	
Land use	Conservation	0.017	0.023	0.028	0.023
	Livestock	0.086	0.070	0.009	0.050
	Tourism	0.069	0.093	0.112	0.091
	Game	0.086	0.070	0.009	0.050
	Rural	0.138	0.116	0.084	0.112
	Dairy	0.121	0.163	0.196	0.159
	Dryland crops	0.103	0.128	0.154	0.129
	Irrigated crops	0.121	0.151	0.182	0.151
	Timber	0.103	0.070	0.056	0.079
	Urban	0.155	0.116	0.168	0.158

1.000

(vi) Overall ranking for landscape function

	Indicator:	Hydrological functioning	Soil erosion	Biogeo-chemical	Fire	Grazing	Biotic processes	Overall Weight
	Weight:	0.043	0.191	0.213	0.298	0.128	0.128	
Land use	Conservation	0.030	0.021	0.077	0.073	0.056	0.023	0.054
	Livestock	0.076	0.091	0.095	0.067	0.102	0.050	0.080
	Tourism	0.061	0.041	0.096	0.075	0.046	0.091	0.070
	Game	0.051	0.029	0.084	0.075	0.096	0.050	0.066
	Rural	0.129	0.144	0.108	0.185	0.158	0.112	0.146
	Dairy	0.139	0.107	0.106	0.081	0.201	0.159	0.119
	Dryland crops	0.095	0.144	0.106	0.068	0.140	0.129	0.109
	Irrigated crops	0.152	0.145	0.106	0.069	0.077	0.151	0.106
	Timber	0.116	0.150	0.091	0.144	0.072	0.079	0.115
	Urban	0.150	0.129	0.132	0.163	0.052	0.158	0.134
		1.000	1.000	1.000	1.000	1.000	1.000	1.000

(c) Landscape structure

(i) Indicator group: Fragmentation

indicator:		Extent	Connectivity	Geometry	Porosity	Overall Weight
Weight:		0.560	0.099	0.112	0.229	
Land use	Conservation	0.020	0.022	0.023	0.023	0.021
	Livestock	0.039	0.038	0.041	0.039	0.039
	Tourism	0.088	0.084	0.091	0.073	0.085
	Game	0.034	0.044	0.041	0.039	0.037
	Rural	0.096	0.087	0.081	0.114	0.098
	Dairy	0.147	0.141	0.140	0.107	0.137
	Dryland crops	0.118	0.125	0.128	0.125	0.121
	Irrigated crops	0.138	0.141	0.128	0.143	0.138
	Timber	0.142	0.133	0.152	0.139	0.142
	Urban	0.177	0.185	0.175	0.199	0.183
		1.000	1.000	1.000	1.000	1.000

(ii) Overall ranking for landscape structure

	Indicator:	Transformation	Cover diversity	Fragmentation	Physiognomy	Overall Weight
	Weight:	0.564	0.103	0.230	0.103	
Land use	Conservation	0.020	0.026	0.021	0.022	0.021
	Livestock	0.059	0.079	0.039	0.044	0.055
	Tourism	0.083	0.110	0.085	0.099	0.088
	Game	0.034	0.053	0.037	0.038	0.037
	Rural	0.098	0.129	0.098	0.099	0.101
	Dairy	0.143	0.197	0.137	0.109	0.143
	Dryland crops	0.116	0.091	0.121	0.122	0.115
	Irrigated crops	0.132	0.118	0.138	0.122	0.131
	Timber	0.147	0.105	0.142	0.183	0.145
	Urban	0.167	0.092	0.183	0.161	0.162
		1.000	1.000	1.000	1.000	1.000

2. Overall impact on biodiversity

	Component:	Composition	Function	Structure	Weight
	Weight:	0.111	0.333	0.556	
Land use	Conservation	0.024	0.054	0.021	0.032
	Livestock	0.053	0.080	0.055	0.063
	Tourism	0.059	0.070	0.088	0.079
	Game	0.039	0.066	0.037	0.047
	Rural	0.146	0.146	0.101	0.121
	Dairy	0.112	0.119	0.143	0.132
	Dryland crops	0.107	0.109	0.115	0.112
	Irrigated crops	0.116	0.106	0.131	0.121
	Timber	0.151	0.115	0.145	0.136
	Urban	0.192	0.134	0.162	0.156
		1.000	1.000	1.000	1.000