ECOSYSTEM SERVICES IN A BIOSPHERE RESERVE CONTEXT: IDENTIFICATION, MAPPING AND VALUATION

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ABSTRACT

Despite their contribution to human well-being, ecosystem services (ES) are being destroyed by anthropogenic activities, taken for granted and often compromised during land use decision making. The question that often arises is, what value do ES have compared to other undertakings that are economically robust, such as mining? The vision of the Millenium Ecosystem Assessment (MA) was a world in which natural assets (including ES) are appreciated and integrated into decision-making. The biodiversity strategy of the Convention on Biological Diversity (CBD) also concerns the integration of natural assets into decision-making. Responding to challenges facing ES and their mainstreaming into decision-making has been constrained by lack of data and requires new tools and approaches.

Integrating natural assets into decision-making is very important for South Africa (SA), where ES have been a crucial part of human systems for decades, and also because of the country's commitment to the implementation of the CBD`s biodiversity strategy. With the aim of incorporating ES into decision-making in an integrated way, this study was conducted in two biosphere reserves (BRs), Vhembe and Waterberg, in Limpopo Province, SA. The aims of the study were the identification, mapping and valuation of ES following an integrated approach. In order to achieve these aims, the study attempted to address four key objectives: (1) to assess and evaluate the status of mapping and valuation of ES in SA, (2) to identify and quantify ES and their indicators, (3) to investigate and analyse the impact of land use/cover (LU/LC) change to ES and (4) to conduct valuation of selected ES.

Two separate literature reviews were undertaken to assess and evaluate the status of mapping and valuation of ES in SA, thus addressing study objective 1. Both reviews detected a significant research gap with regard to mapping and valuation of supporting services in SA. To identify ES and indicators provided by the two BRs and to assess the impact of LU/LC change and its effect on ES, a participatory scenario planning process was conducted under three different scenarios, namely ecological development, social development and economic development. It became clear that LU issues were diverse in nature and affected ES in a number of ways and that there were always trade-offs in the choice of LU. For example, yields of ES were best in the ecological development scenario and were affected negatively, together with agricultural commodity production, in the social development and economic development scenarios. A mapping exercise was undertaken to illustrate the spatial distribution of ES supply and demand, involving five ES and 15 indicators using existing datasets and the Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) mapping tool, again addressing objective 2 of the study.

Carbon storage and habitat quality were assessed, modelled and quantified and their values provided in biophysical terms using InVEST modelling tools, thus addressing objective 4 of the study. High quantities of carbon storage and high habitat quality were recorded in natural areas and low quantities were recorded in managed systems (cultivated, urban and plantation areas). InVEST was again applied to conduct an economic valuation of two provisioning ES, timber and firewood, by determining their net present values, attempting to address objective 4 of the study. Results revealed that, at 12% discount rate, the net present value (NPV) for timber production accounted for R23 317/ha in VBR and R57 304/ha in WBR. However, at lower discount rates (4 and 7%), the NPVs for timber were negative in VBR and positive in WBR. With regard to firewood production, the NPVs were negative against all three discount rates in both study areas.

I conclude by proposing a four-step integrated approach that can aid the successful incorporation of ES into decision-making: (1) maintain a balance between the social, economic and ecological aspects when making decisions on ES, (2) strive for an evidence-based approach to decision-making (use quantities and values), (3) apply integrated approaches (methods and techniques) to quantification and valuation, and (4) communicate all steps along the way. The results of this study will serve as a baseline for integration of ES into decision-making in SA.

Key words: ecosystem services; valuation; InVEST; biosphere reserve; spatially explicit; mapping; social; economic; ecological; ecosystem services indicators.

DECLARATION

I, **Ntshane Basane Claire** hereby declare that all the work contained in this document is my own original work, has not been submitted previously in any educational institution for the purpose of obtaining any qualification. All the quoted work and referred literature has been acknowledged accordingly with full references. This thesis is submitted in fulfilment of a PhD in Environmental Science in the Faculty of Science at Rhodes University, South Africa.

Signature: ________________________________

Date: _October 2016_________________________

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LIST OF ABBREVIATIONS

1. ARC Agricultural Resource Council
2. ARIES Artificial intelligence for Ecosystem Services
3. BR Biosphere reserve
4. CA Conservation area
5. CBD Convention on Biological Diversity
6. CICES Common International Classification of Ecosystem Services
7. COP Conference of the Parties
8. CSIR Council for Scientific and Industrial Research
9. CM Choice Modelling
10. CV Contingent Valuation
11. DAFF Department of Agriculture, Forestry & Fisheries
12. DEA Department of Environmental Affairs
13. DEAT Department of Environmental Affairs and Tourism
14. DEFRA Department for Environment Food & Rural Affairs
15. DME Department of Minerals & Energy
16. DWAF Department of water Affairs
17. EDS Ecosystem disservice
18. Eftec Economics for the Environmental Consultants
19. ES Ecosystem services
20. ESA Ecological Society of America
21. ESRI Environmental Systems Research Institute
22. EPWP Extended Public Works Programme
23. FAO Food and Agriculture Organization
24. GDP Gross Domestic Product
25. GOI Government of India
26. GHG Greenhouse effect
27. GUMBO Global Unified Metamodel of the Biosphere
28. HP Hedonic Pricing

29. ICMM	International Council on Mining & Metals
30. InVEST	Integrated Valuation of Ecosystem Services & Trade-offs
31. IPBES	Intergovernmental Platform on Biodiversity & Ecosystem Services
32. IPCC	Intergovernmental Panel on Climate Change
33. IUCN	International Union for the Conservation of Nature
34. KLF	Komatiland Forests
35. KNP	Kruger National Park
36. LC	Land cover
37. LDA	Limpopo Department of Agriculture
38. LGDS	Limpopo Growth & Development Strategy
39. LM	Local municipality
40. LSU	Large Stock Unit
41. LU	Land use
42. MA	Millennium Ecosystem Assessment
43. MAB	Man and Biosphere
44. MAI	Mean Annual Increment
45. MIMES	Multiscale Integrated Models of Ecosystem services
46. MNPMP	Marakele National Park Management Plan
47. NBSAP	National Biodiversity Strategy and Action Plan
48. NEMA	National Environmental Management Act
49. NEM:PAA	National Environmental Management: Protected Areas Act
50. NFA	National Forest Act
51. NLC	National Land Cover
52. NPF	National Park Forum
53. NPAES	National Protected Area Expansion Strategy
54. NSBA	National Spatial Biodiversity Assessment
55. NWRS	National Water Resource Strategy
56. OPAL	Offset Portfolio Analyzer and Locator
57. PA	Protected area
58. PAK	Protected areas in Kenya
59. PAWC	Plant Available Water Content
60. PGRC	Provincial Government Responsible for Conservation
61. PLOS	Private Land Owners

62. RIOS	Resource Investment Optimization System
63. SA	South Africa
64. SANBI	South African National Biodiversity Institute
65. SANParks	South African National Parks
66. SAMABNC	South African Man and Biosphere National Committee
67. SoIVES	Social Values for Ecosystem Services
68. StatsSA	Statistics South Africa
69. TAU	Transvaal Agricultural Union
70. TC	Travel Cost
71. TEEB	The Economics of Ecosystems and Biodiversity
72. TEV	Total Economic Value
73. TNPV	Total Net Present Value
74. UNEP	United Nations Environment Programme
75. UNFCCC	United Nations Framework Convention on Climate Change
76. UNESCO	United Nations Educational, Scientific and Cultural Organization
77. VBR	Vhembe Biosphere Reserve
78. VDMIDP	Vhembe District Municipality Integrated Development Plan
79. WACC	Weighted Average Cost of Capital
80. WBR	Waterberg Biosphere Reserve
81. WDMIDP	Waterberg District Municipality Integrated Development Plan
82. WMB	Waterberg Meander Brochure
83. WTTC	World Travel and Tourism Council

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DEDICATION

This work is dedicated to the Almighty, never forsaking God, who never abandoned me, but was always by my side throughout this journey and as always carried out His promise: 'I will never leave you, nor forsake you'-Hebrews 13:5.

To my beloved mother, Mphephu Sarah Ntshane (late) for your love and belief in me and being a source of inspiration on my academic journey.

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CHAPTER 1

CONCEPTUAL AND CONTEXTUAL SETTINGS

1.1 NTRODUCTION

An ecosystem is defined as “a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit at any given scale" (Convention on Biological Diversity (CBD) 1992). Ecosystems produce a wide range of goods and services that are crucial for human well-being, collectively called ecosystem services (ES) (Millennium Ecosystem Assessment (MA) 2005; Nelson et al. 2009). The term ES was first recorded during the 1960s (King 1966; Helliwell 1969). Since these early records, considerable efforts have been put into the definition of the concept of ES (Daily 1997; Binning et al. 2002; Brown et al. 2007; TEEB 2010). It is obvious from these definitions that the term ES means different things to different people, although there is strong connectedness of these definitions in terms of what they stand for. In the definitions of Daily (1997), Binning et al. (2002) and Brown et al. (2007), the concepts of ES, goods and services were separated. However, other researchers put these two concepts together (MA 2005; Costanza et al. 1997). So far, the most popular definition is that of the MA (2005), where ES are defined as the “benefits that people obtain from the ecosystems”. Another definition is that of de Groot et al. (2010) describing ES as a “subset of biophysical structures and processes that provide services.”

Just like the definitions of ES, many methods of classification of goods and services have been proposed (Costanza et al. 1997; Daily 1997; Bastian and Schreiber 1999; Wilson and Hoehn 2006; Brown et al. 2007; Mertz et al. 2007; Costanza 2008; de Groot et al. 2010; CICES 2011), with numerous differences in the way ES were grouped and named (TEEB 2010; CICES 2011; Hermann et al. 2011). These differences could be brought about by the complexity of the way in which ecosystems produce ES (Costanza 2008; TEEB 2010; CICES 2011; Hermann et al. 2011). Appendix 1A provides details of five selected ES frameworks/typologies.

While much research and debate on the term ES have taken place (Boyd and Banzhaf 2007; Wallace 2007; Costanza 2008; Fisher and Turner 2008; Haines-Young and Potschin 2009; TEEB 2010), it should be noted that ecosystems provide not only benefits, but also disservices to human well-being (O'Farrell et al. 2007; Zhang et al. 2007; Dunn 2010; TEEB 2010; Escobedo et al. 2011; von Döhren and Haase 2014). In simple terms, ecosystem disservices (EDS) are the opposite of ES in that they have a negative impact on human well-being, whereas an ES is beneficial (MA 2005). One of the earliest definitions of EDS is that of Lyytimäki and Sipilä (2009), who refer to EDS as "functions of an ecosystem that are perceived as negative for human well-being." Some examples of EDS include biophysical hazards (diseases, allergenic and poisonous organisms) and geophysical hazards (floods, heatwaves and storms) (Lyytimäki and Sipilä 2009; von Döhren and Haase 2014). In an attempt to understand the concept of EDS better, it is imperative to understand the context in which it is used. In the review done by von Döhren and Haase (2015), it was found that EDS were mostly associated with agricultural and urban environments. In their association with agriculture, EDS mainly result from negative activities pertaining to land use, such as the incorrect use of fertilizers and pesticides, biodiversity loss, soil and water pollution, or introduction of invasive species (O'Farrell et al. 2007; Power 2010; Escobedo et al. 2011; Firbank et al 2013; von Döhren and Haase 2015). In the urban setting, EDS are associated with disease-causing vectors, air and water pollution, infrastructure malfunctioning and spread of allergies (Lyytimäki et al. 2008; Arnold 2012; Dobbs et al. 2011; Escobedo et al. 2011; von Döhren and Haase 2015), among others.

1.2 RESEARCH RATIONALE

The MA (2005) formally put human beings in the central context of ES, reflecting that natural ecosystems provide humans with services that are indispensable to their well-being, although prior to this assessment other authors, e.g. Daily (1997), also recognised the linkage between ES and human well-being. Despite their contribution to human well-being, natural assets (including ES), are being destroyed by anthropogenic activities. What can be deduced from the contextual settings of the EDS concept above, is that it is linked to what the MA (2005) listed as some of the causes of the degradation of ES, of which agriculturally related activities are at the top of the list (MA 2005; Power 2010). At the rate that ES are suffering degradation, EDS will have equally negative impacts on human well-being. Although some are inflicted naturally, most EDS are human-induced (MA 2005) and linked to human population growth, among others (Tilman et al. 2002; Norris 2008). Figure: 1.1 illustrates the conceptual framework of ES (MA 2005), showing the linkages between ES and human well-being and the associated drivers of change, which are either natural or anthropogenic.

Other concerns are related to the fact that ES are grossly undervalued by society (Daily et al. 2009), not mainly because of lack of awareness of their link to human well-being, but because for ages, human society has undermined the services that are available for free, not formally traded in markets (MA 2005, Daily et al. 2009). Other challenges are that natural assets are poorly understood and rarely monitored (Heal 2000a; MA 2005, Mäler et al. 2008; Daily et al., 2009), and often compromised during land use decisions in favour of undertakings that are economically robust. Southern Africa is not an exception from the concerns raised above. According to the regional assessments regarding the links between ES and poverty alleviation conducted by Shackleton et al. (2008), ES such as fresh water provisioning, fodder provision, soil fertility, biodiversity, wild products (wild foods and medicinal resources), and cultural and spiritual value, among others, are being threatened and subjected to degradation by factors such as climate change, land transformation and poverty, among others (Shackleton et al. 2008). The degradation of ES in Southern Africa and elsewhere in the world is borne disproportionately by the poor (MA 2005; Shackleton et al. 2008).

Given the challenges faced by natural assets and the fact that both ES degradation and EDS could have long-term negative effects on human well-being, strategies were put in place to minimize further degradation of ES. Among these strategies are the establishment of protected areas (PAs) and socio-ecological systems such as biosphere reserves (BRs). BRs are defined as ecosystems of terrestrial and coastal nature, combining conservation and sustainable use of natural resources and concerned with the promotion of harmony between human beings and nature (UNESCO 2010).

In South Africa (SA), the BR concept was introduced in 1990 (Pool-Stanvliet 2013), when UNESCO's Man and Biosphere (MAB) programme was identified as an appropriate approach to a holistic conservation strategy to address the transformation and destruction of natural habitats in the fynbos biome (Burgers et al. 1990; Pool-Stanvliet 2013). However, SA was officially introduced to the MAB programme by the signing of an agreement with UNESCO in 1995. Implementation of bio-regional planning following the sustainable development approach of BRs in the Western Cape Province led to the designation of Kogelberg as the first BR in SA in 1998. Bioregional planning was a management system that formed the basis for spatial planning (Pool-Stanvliet 2013). Currently, there are six BRs in SA (Kogelberg, Cape West Coast, Waterberg, Kruger to Canyons, Cape Winelands and Vhembe) across three provinces (Western Cape, Limpopo and Mpumalanga).

Given their concern with the society, ecology and the economy, both the concepts of ES and socio-ecological systems such as BRs` principles are rooted in the promotion of sustainable development for human well-being (MA 2005; UNESCO 2010). According to the Bruntland report (Bruntland and WCED 1987), sustainable development is the development that meets the needs of the current generation without compromising the needs of the future generation. Given the complex nature of human-environment systems (Wiek et al. 2012), there is a need for research into sustainability. This study therefore falls under sustainability science, which is a discipline that is concerned with the needs of society and the sustainability of the life support system (Wiek et al. 2012).

The vision of the MA (2005) was that "ES are recognized and incorporated into decision making" (Daily et al. 2009). Similarly, the Convention on Biological Diversity (CBD 2010), of which approximately 200 countries, including SA, are signatories, requires that natural capital be incorporated into national accounting. Without this integration, natural assets are ignored and suffer immense degradation (MA 2005; Daily et al. 2009). However, the integration of ES into decision-making is mainly constrained by lack of data (Petter et al. 2013). In an attempt to address this challenge, this study aimed to identify, map and value ES in two BRs in Limpopo Province of SA.

According to Daily et al. (2009), five elements have to be addressed in order to integrate ES successfully into decision-making: (1) focus on other services beyond provisioning services, (2) an understanding of the interlinked production of services, (3) an understanding of the decision-making process of individual stakeholders, (4) integration of research into institutional design and policy implementation, and (5) introduction of evidence-based policy in performance evaluation and improvement over time. Furthermore, according to the MA (2005), in order to improve the effectiveness of decision-making in these contexts and the outcomes of decisions for human well-being, the decision-making process has to satisfy certain aspects, which include: (1) use of the best available information, including the quantities and values of ES, (2) transparency and stakeholder engagement, (3) recognising that not all ES values can be quantified, (4) assessment of trade-offs across different ES and (5) ensuring accountability by providing for regular monitoring and evaluation.

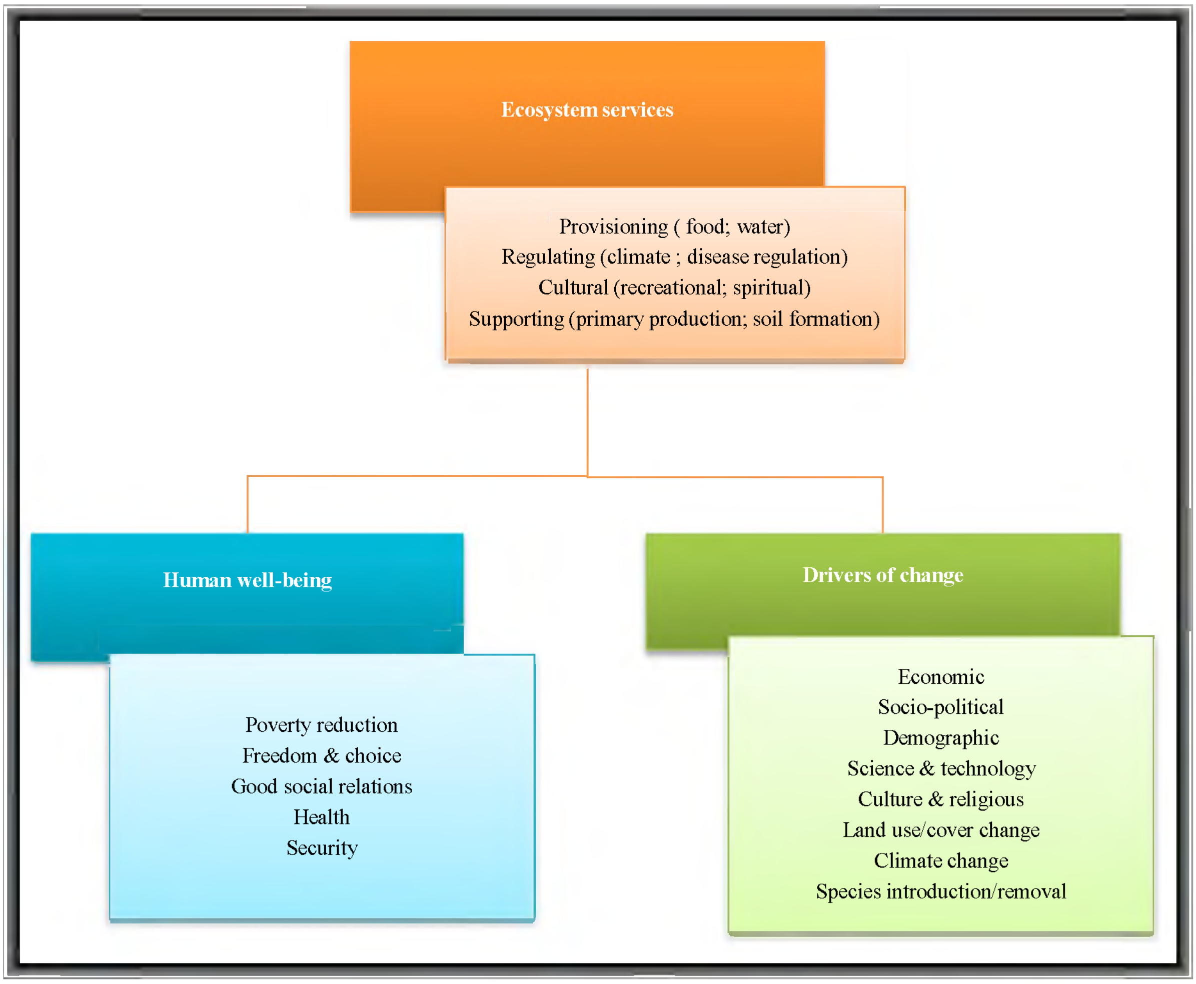

Figure 1.1 Ecosystem services conceptual framework (Source: MA 2005).

1.3 RESEARCH AIMS, OBJECTIVES AND KEY QUESTIONS

The aims of the study were the identification, mapping and valuation of ES. In order to achieve these aims, the study attempted to answer the following key questions: (1) What are different ES and their indicators provided by the study areas? (2) What are the impacts of land use/land cover (LU/LC) change on ES in the study areas? (3) What are the quantities of selected ES in the study areas? (4) What are the values of selected ES in the study areas? In order to answer the research questions mentioned above, the following objectives have been addressed: (1) to assess and evaluate the status of mapping and valuation of ES in SA, (2) to identify and quantify ES and their indicators in the study areas, (3) to investigate and analyse the impact of LU/LC change to ES in the study areas, and (4) to conduct valuation of selected ES in the study areas.

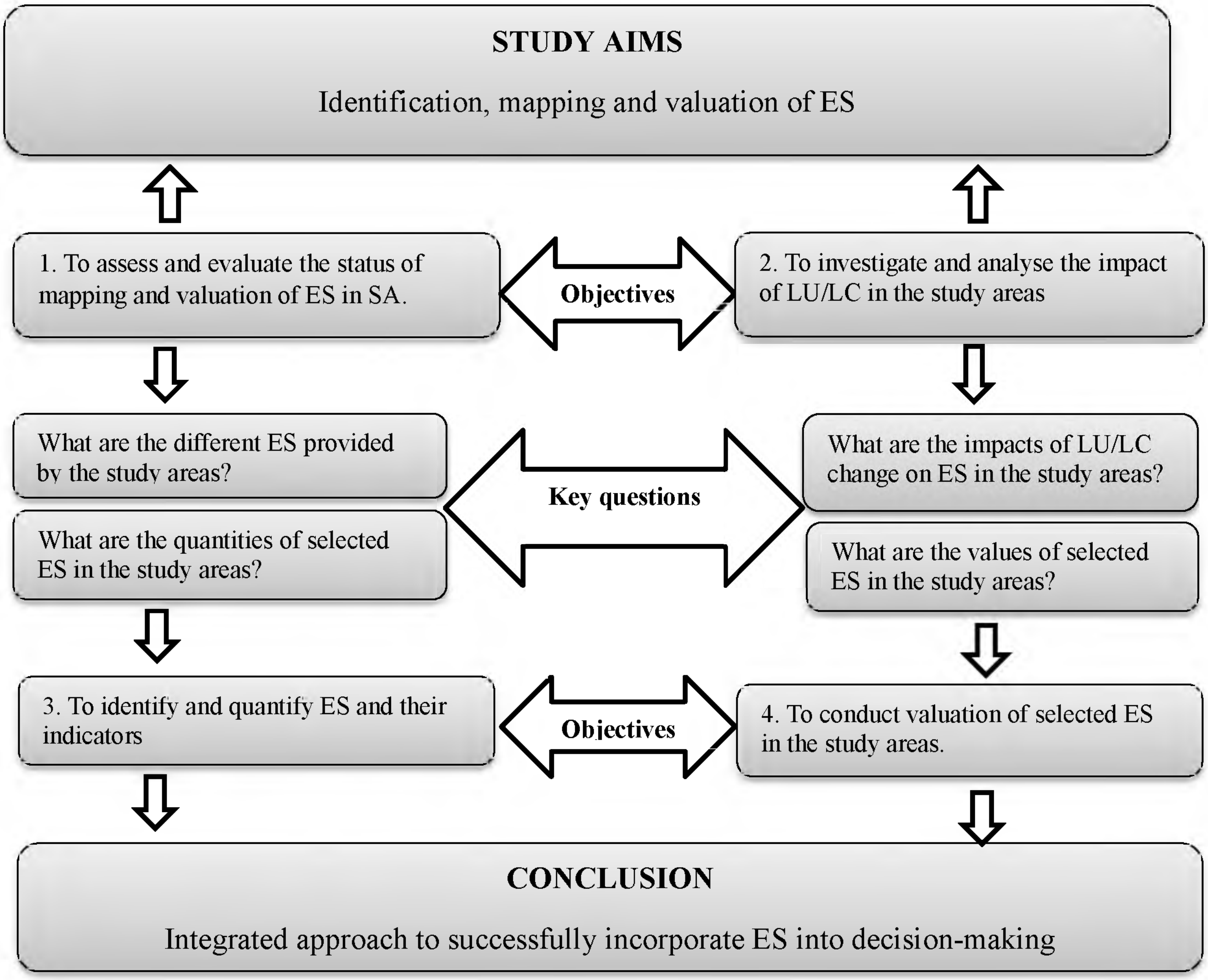

Figure 1.2 A schematic illustration of the key questions and objectives addressed in the core six chapters of this study.

1.4 GENERAL MATERIALS AND METHODS

1.4.1 MODELLING, MAPPING AND VALUATION APPROACH

1.4.1.1 Mapping of ecosystem services

1.4.1.1.1 What is mapping?

Given the importance of integrating ES into decisions (MA 2005; Nelson et al. 2009), the tools to aid this integration are crucial. Among the key tools to integrate ES in decision-making is mapping (Crossman et al. 2013; Martínez-Harms and Balvanera 2015). Mapping is a very useful method for spatially illustrating and quantifying ecosystem services in terms of supply and demand (Crossman et al. 2013). Mapping can also be used to estimate quantities biophysically, estimate benefits and trade-offs and establish trends (Daily et al. 2009; Deng et al. 2011; Tallis et al. 2011). Mapping is furthermore a very useful tool that can be used to support decision-making at various levels (Crossman et al. 2013; Martínez-Harms and Balvanera 2015).

1.4.1.1.2 Mapping approaches

There are different approaches to mapping ES, leading to inconsistency in quantifying and mapping them (Eppink et al. 2012; Crossman et al. 2013; Martínez-Harms and Balvanera 2015). However, a blueprint has recently been developed that will serve as a standardised approach (Crossman et al. 2013). Egoh et al. (2012) classify the methods used to map ES into three groups, which include the use of proxies and indicators, collection of primary data and the use of models with indicators as variables.

Just like the mapping approaches, a number of tools have also been developed to map ES. Among these is the Integrated Valuation of Ecosystem Services (InVEST) (Tallis et al. 2011). InVEST is an open access popular mapping tool and has been applied widely, including in this study (Nelson et al. 2009; Bai et al. 2011; Swetnam et al. 2011). Other popular mapping tools applicable to ES are the Artificial Intelligence for Ecosystem Services (ARIES), which is a web-based ES mapping tool (Villa et al. 2009); the Social Values for Ecosystem Services (SoIVES), which is a global information system (GIS) mapping tool that focuses mainly on social values such as recreation and aesthetic quality (Sherrouse et al. 2011) and the Global Unified Metamodel of the Biosphere (GUMBO), which applies a simulation model to model the interactions of human capital, built and social, with natural capital (Andrade et al. 2010; Crossman et al. 2013).

1.4.1.1 Valuation of ecosystem services

1.4.1.2.1 Values and valuation

Various values that human societies derive from nature (ecosystems/ES) are divided into use and non-use values (MA 2005, Haines-Young and Potschin 2009; TEEB 2010). Use values are associated with the utility that people derive from ES either directly (extractive) or indirectly (non-extractive) (MA 2005, Haines-Young and Potschin 2005; TEEB 2010). Use value approaches are divided into three types: (1) direct use, which results from direct use of

ES either in a consumptive format, e.g. wild fruit or timber, or a non-consumptive format, i.e. recreation; (2) indirect use, which implies those values derived from services performing regulating functions, i.e. climate regulation, flood control and prevention; and (3) option values, which are related to the importance that people attach to the sustainability of ES for the fulfilment of individual benefits, e.g. conserving ecosystems for future generations (MA 2005, Haines-Young and Potschin 2009; TEEB 2010) (see Appendix 1A).

Non-use values refer to values linked to things that people do not consume or use directly and are mainly based on ethical, socio-cultural, religious and philosophical considerations (MA, 2005). Non-use and existence values were formally introduced by Krutilla (1967) and are divided into three types: (1) bequest value, which is the value individuals attach to the future sustainability of ES benefits, i.e. conserving nature for the benefit of the next generations; (2) altruist value, which is the value individuals attach to the fact that some of the members of the current generation have access to benefits provided by species and ecosystems; and (3) existence value, which is related to the fulfilment that people derive from the continued existence of species and ecosystems.

Since ES affect human welfare (MA 2005; TEEB 2010), the value of their impact should be measured. Like the term ES, the term value inspires debate (TEEB 2010; Farber et al. 2002; MA 2005). According to Gómez-Baggethun et al. (2014), valuation is associated with value, importance or worth placement of an object and may be defined as "the act of assessing, appraising or measuring value, as value attribution, or as framing valuation." To illustrate the value chain discourse better, Haines-Young and Potschin (2009) have pointed out the importance of distinguishing benefits from values, as benefits may be constant, but values could be influenced by time.

1.4.1.2.2 Traditional valuation approaches

The existence of different definitions of ES and approaches to its classification (MA 2005; Brown et al. 2007; Boyd and Banzhaf 2006) resulted in various approaches and techniques (MA 2005; TEEB 2010; Haines-Young and Potschin 2010) that can be used to estimate both use and non-use values. It should be noted though that while ES definitions and typologies lack consistency and standards (MA 2005; Wallace 2007; Costanza 2008; Hermann et al. 2011), ES valuation approaches and techniques seem to be standardised (MA 2005; Haines-Young and Potschin 2010; TEEB 2010). Valuation of ES approaches can be divided into ecological, socio-cultural and economic ones (MA 2005; de Groot et al. 2002; Daily et al. 2009; Haines-Young and Potschin 2010; TEEB 2010; Gómez-Baggethun et al. 2014). Appendix 1A presents different ES typologies and the valuation methodologies that can be applied to different ES. It provides details of different valuation approaches (ecological, economic and socio-cultural), methods (direct market, indirect market - stated preference and revealed preference) as well as related techniques: travel cost (TC), hedonic pricing (HP); replacement cost, avoided cost, etc.). It also clarifies the concept of nature`s values (use and non-use), types of use values (direct/indirect use; consumptive use, e.g. food crops; non-consumptive use, e.g. recreation).

1.4.1.2.2.1 Ecological valuation approach

Ecological values, sometimes referred to as biophysical, encompass parameters such as the complexity, diversity and rarity of an ecosystem (de Groot et al. 2002; Gómez-Baggethun et al. 2014). Ecological values, e.g. the value of fires in nutrient recycling and tree species in controlling erosion (Hermann et al. 2011), are related to functions and ecological processes of the ecosystems (de Groot et al. 2002; Daily et al. 2009; Gómez-Baggethun et al. 2014), or of what the MA (2005) refers to as supporting ES or biodiversity (Gómez-Baggethun et al. 2014). The ecological valuation approach examines the importance in terms of quantities and qualities of attributes and characteristics related to nature (MA 2005; Gómez-Baggethun et al. 2014) and its values are mainly expressed in biophysical terms (Daily et al. 2009, Gómez-Baggethun et al. 2014). Given the fact that ecosystem processes and functions are interconnected, biophysical measurements are therefore necessary to determine how ES are generated (Haines-Young and Potschin 2009).

1.4.1.2.2.2 Socio-cultural valuation approach

Socio-cultural values, e.g. perceptions, ethics and equity, are linked to information functions (de Groot et al. 2002; Scholte et al. 2015). According to Gómez-Baggethun et al. (2014) socio-cultural values are also related to material, moral, spiritual, aesthetic and therapeutic values that people attach to the environment. The MA (2005) refers to socio-cultural values as non-material benefits people obtain from ecosystems of historical, aesthetic, cultural, spiritual, recreational and educational nature. According to Costanza et al. (1997), cultural values are associated with the aesthetic, artistic, educational, spiritual and/or scientific characteristics of ecosystems. The presence of the key words spiritual, aesthetic and moral/ethical in the definitions above suggests their importance and weight in association with cultural values. It can also be deduced from these definitions that values forming part of the socio-cultural category are rooted in the mind/perceptions of an individual. Cultural ES are therefore closely related to social science (Daily et al. 2009; Chan et al. 2012; Milcu et al. 2013). Social reasons play an important role in the identification of important environmental functions that contribute to human well-being, physical and mental health, education, cultural identity, spiritual and heritage values (English Nature 1994; de Groot et al. 2002). Natural systems also form an important source of indispensable non-material benefits necessary for the sustainability of human well-being (Norton 1987; de Groot et al. 2002).

1.4.1.2.2.3 Economic valuation approach

Economic valuation is an approach that seeks to determine the value of ES in financial terms (MA 2005; Haines-Young and Potschin 2010; TEEB 2010). Economic valuation, mainly the total economic value approach, is applied to value both use (direct and indirect) and non-use values. In this approach, values are derived from the direct market transactions, or indirectly from parallel markets associated with the goods to be valued, or values from hypothetical markets (TEEB 2010). Direct market valuation approaches are divided into (1) market price-based ones, used to obtain value (reflected in the market price) of most of the provisioning services that are sold in markets, e.g. agricultural crops; (2) cost-based approaches, which are based on estimating the costs associated with recreating the needed benefit/ES, e.g. restoration/mitigation cost of climate change; and (3) production function based approaches that estimate the contribution of a given ES to the delivery of another, e.g. the contribution of soil fertility to the production of a raw materials such as fodder and timber.

Indirect market approaches are used when surrogate markets do not exist (de Groot et al 2002; MA 2005; TEEB 2010). These are divided into stated and revealed preference approaches. Revealed preference approaches are based on observing individual choices related to the ES. This approach is divided into the Travel Cost (TC) method, which is mainly used to derive recreational value, and the Hedonic Pricing (HP) method, which is based on the implicit demand for an environmental attribute of marketed commodities, such as the proximity of a house to a nice landscape (de Groot et al 2002; MA 2005; TEEB 2010).

In stated preference approaches, individuals state their choices by means of a survey/questionnaire (de Groot et al. 2002; MA 2005; TEEB 2010). This approach is divided into the contingent valuation method, which uses questionnaires to ask people how much they are prepared to pay for the provisioning of a service, choice modelling, in which people are faced with two or more alternatives of a services to be valued with different attributes (including money to be paid for the service) and group valuation, which can be used to capture values that may escape individual-based surveys, i.e. non-human values or value pluralism (Spash 2008; TEEB 2010).

1.4.1.2.3 Limitations of the traditional valuation approaches

Although there seems to be consistency in the traditional valuation approaches (MA 2005; TEEB 2010, Haines-Young and Potschin 2010), there are limitations (MA 2005; Daily et al. 2009) as well. In cases where they were applied, it was noted that a great deal of attention was paid to capturing the value of direct use values and less attention was paid to non-use/indirect values (Chan et al. 2012; Gómez-Baggethun et al. 2014). Although traditional valuation approaches have the capacity to estimate values successfully, they have also been found to be more focused on capturing the value of a single service, concentrating mainly on the economic values of those services that are tradable on formal market platforms (MA 2005; Daily et al. 2009; TEEB 2010). The capability of capturing the value of multiple services simultaneously or in an integrated way, which is crucial in the quest to integrate ES in decision-making (MA 2005; Daily et al. 2009), is questionable for most of these approaches (MA 2005; Daily et al. 2009; Gómez-Baggethun et al. 2014). For example, in attempting to estimate the value of ES provided by a protected area, Travel Cost Method (TCM) will be used to determine the value of recreation, the willingness to pay method will be used to estimate the value of biodiversity separately and HP will be used to estimate the value of direct use values, e.g. timber, thatch.

Evidence also seems to suggest neglect of the determination of non-economic values (socio-cultural and ecological) (MA 2005; Daily et al. 2009; Gómez-Baggethun et al. 2014; Scholte et al. 2015), while compelling evidence exists that a great deal of attention was paid to capturing the economic value (MA 2005; Hein et al. 2006; Daily et al. 2009; Haines-Young and Potschin 2009; TEEB 2010; Hermann et al. 2011; Gómez-Baggethun et al. 2014). Cases where socio-cultural values were measured in economic terms involved recreational and sometimes educational benefits (Chan and Ruckelshaus 2010; Milcu et al. 2013). However, most of the ES in this category are difficult to measure (TEEB 2010; Milcu et al. 2013) and methods are lacking to capture some of the services falling in this category (Benayas et al.

2009; Hermann et al. 2011; Milcu et al. 2013). As with most of the non-use ES, measuring services in biophysical terms are challenging (MA 2005; Daily et al. 2009; Haines-Young and Potschin 2009, TEEB 2010).

1.4.1.2.4 Integrated valuation approach

There are various integrated approaches that can be used in the field of valuation of ES, among others the GUMBO, Multiscale Integrated Models of ES (MIMES), InVEST, Resource Investment Optimization System (RIOS) and Offset Portfolio Analyzer and Locator (OPAL) (Daily et al. 2009; Andrade et al. 2010; Tallis et al. 2011; Mandle 2014; Vogl et al. 2015). GUMBO is a software suite that models the dynamic and complex links between social, economic and biophysical systems of ES and their contribution to human well-being on a global scale (Andrade et al. 2010). MIMES uses a number of computational models to integrate the understanding of functions and ES and their interactions with human well-being in different spatial scales (Andrade et al. 2010). RIOS is a software-based modelling tool developed with the aim of improving returns from conservation investments, in different environmental, social and legal contexts. RIOS combines biophysical, social, and economic data to provide a standard approach to activities related to watershed management in different situations globally. With this approach, users are able to select suitable areas for protection and restoration of watersheds in order to maximize the ecological return on investment (Vogl et al. 2014). OPAL is a stand-alone software tool that enables users to estimate the effect of activities related to developments, ecosystems of terrestrial nature and the services they render, and then select mitigation measures to deal efficiently with impacts. It can also track how the environmental impact of development and mitigation activities affect people.

1.4.1.3 Valuation and mapping approach adopted by this study

The study applied the InVEST approach. InVEST is an approach that was developed by the Natural Capital Project in partnership with Stanford University, aiming at aligning economic forces with conservation by incorporating natural capital while making decisions such as those on land use (Daily et al. 2009). The InVEST is a system for quantifying values of ecosystem services across landscapes. It consists of a suite of different modelling, valuation and mapping tools (Tallis et al. 2011). Among these are carbon storage and sequestration, timber production and habitat quality models. InVEST models use data on LU/LC to determine economic, biophysical and social values of ES provided by the landscape, Figure 1.3 shows the InVEST toolbox.

The InVEST emanated from the need to take into consideration all aspects of the environment (ecological, social and economic) during valuation (MA 2005), in order to integrate natural assets successfully into decision-making (MA 2005, Daily et al. 2009), an idea first put forward by the MA (2005). InVEST is a software tool that consists of a modelling suite designed to quantify and value multiple services simultaneously. The main purpose of InVEST is to align economic forces with conservation (Daily et al. 2009), making it more relevant to the main aim of expressing the values of ES holistically.

Another advantage that makes InVEST more advanced than some of the valuation approaches (Andrade et al. 2010) is that it includes decision makers in an interactive and participatory process (Daily et al. 2009, Tallis et al 2011) during its first stages, which is crucial in improving the reliability of a valuation method (Haines-Young and Potschin 2009). The InVEST makes integrating natural capital into decision-making possible by informing managers and other decision makers about the impact of different management options of resource management choices involving the economy, human well-being and the environment in an integrated way (Daily et al. 2009). Outputs of InVEST are displayed according to stakeholder preference, spatially, graphically and/or in balance sheets. The values can be expressed in biophysical (e.g. tons of carbon), economic (e.g. dollars), or cultural (e.g. visitor-days) terms (Nelson et al. 2009; Daily et al. 2009).

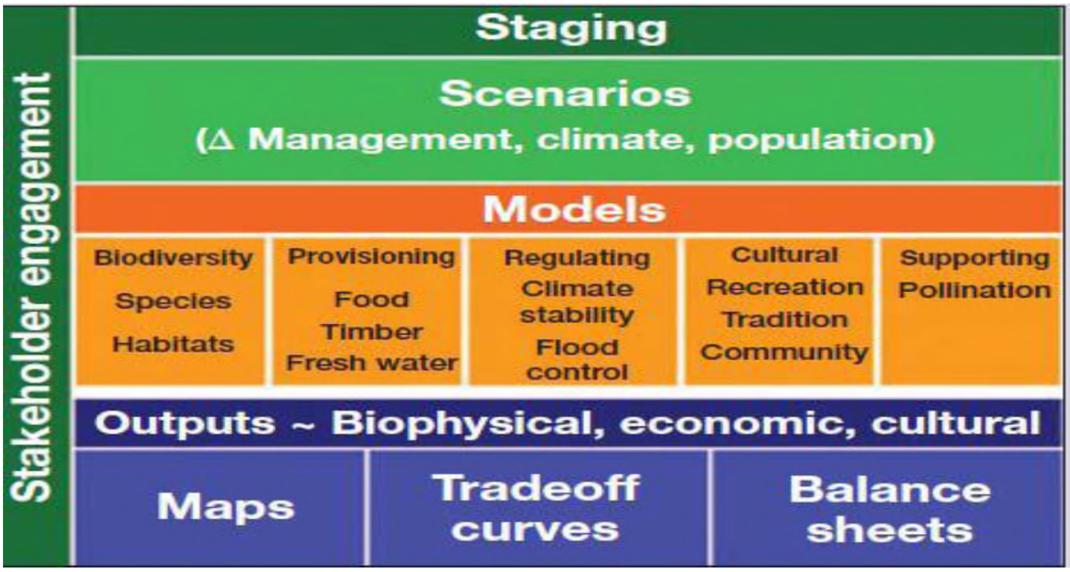

Figure 1.3 InVEST Toolbox (Source: Daily et al. 2009)

The first research question is covered by chapter 2, which looked at the status of valuation in SA, focusing on PAs, including BRs. Through various search engines, a desktop review of 28 studies that conducted valuation of ES in SA`s PAs was done. The review followed the approach of Le Maitre et al. (2007) of reading abstracts and selecting studies that conducted valuation of ES, although in this case the focus was on PAs, covering the following aspects: objectives of the study, geographic coverage focusing on major biomes (Mucina and Rutherford 2009); protected areas categories covered (IUCN 2004), ES covered, following the MA (2005) classification (MA 2005) and valuation approach/method applied.

The second and third research questions are addressed by chapter 4: Ecosystem services and its indicators: identification and mapping. Different ES indicators that occur in the study areas were investigated through stakeholder engagement. This was followed by a desktop review of studies that mapped ES and indicators used to map them in SA. The last stage covered in this chapter was mapping; 15 indicators and five ES were mapped using existing datasets and InVEST methodology. The maps were produced in standard GIS Environmental Systems Research Institute (ESRI) format. The fourth research question is covered by chapter 3 and is addressed by the first phase of the InVEST methodology, which involves a participatory decision-making process with stakeholders to identify and evaluate critical management decisions and to develop scenarios and projects indicating how provisioning of services might change in response to those decisions. The study followed a four-step process for creating scenarios, as presented in the work of Wollenberg et al. (2000). The steps are: (1) definition of the purpose of the scenarios; (2) information about a system's structure and major drivers of change; (3) generation of the scenarios and (4) implications of the scenarios.

Research questions 5 and 6 are covered by chapters 5-7, involving the modelling, quantification and valuation of ES, thus attempting to address the second phase of the InVEST approach. These are outlined as follows: Chapter 5 involves modelling and assessment of the condition of habitats combining threat data and LU/LC, to determine habitat quality and the extent of degradation. The InVEST model involved here is biodiversity: habitat quality and rarity model. Chapter 6 involves the assessment of carbon storage in the study areas, using the InVEST carbon storage and sequestration model. The InVEST carbon storage and sequestration model assesses and estimates carbon stocks in the landscape, using LU/LC data and carbon stored in the four pools, above ground, below ground, dead organic matter and soil. Chapter 7 involves modelling two provisioning ES, timber and firewood, in the study area following the InVEST timber modelling approach. The

InVEST timber production model estimates the production value of natural forests and forestry plantations. The timber model analyses the production of timber in natural and planted forests and outputs the net present values over some user-defined time interval.

1.4.2 STUDY AREAS

1.4.2.1 Study area selection

SA is divided into nine provinces, among which is Limpopo Province. Limpopo Province is located in the far northern part of the country, bordering Zimbabwe in the north, Mozambique in the east and Botswana in the west. Limpopo Province is divided into five district municipalities: Mopani, Capricorn, Sekhukhune, Waterberg and Vhembe.

The selection focus was biome-based, in this case the savannah, and within the same provincial borders. Other factors behind the rationale for the study area selection include that both have BRs and diverse LU, experience variable rainfall patterns and are situated within the savannah biome. The study areas are located within the Waterberg and Vhembe BRs. The selection of these two BRs was meant to allow for comparison to a certain extent, in view of their differences, although they also share similarities. Figure 1.4 shows the location of the study area.

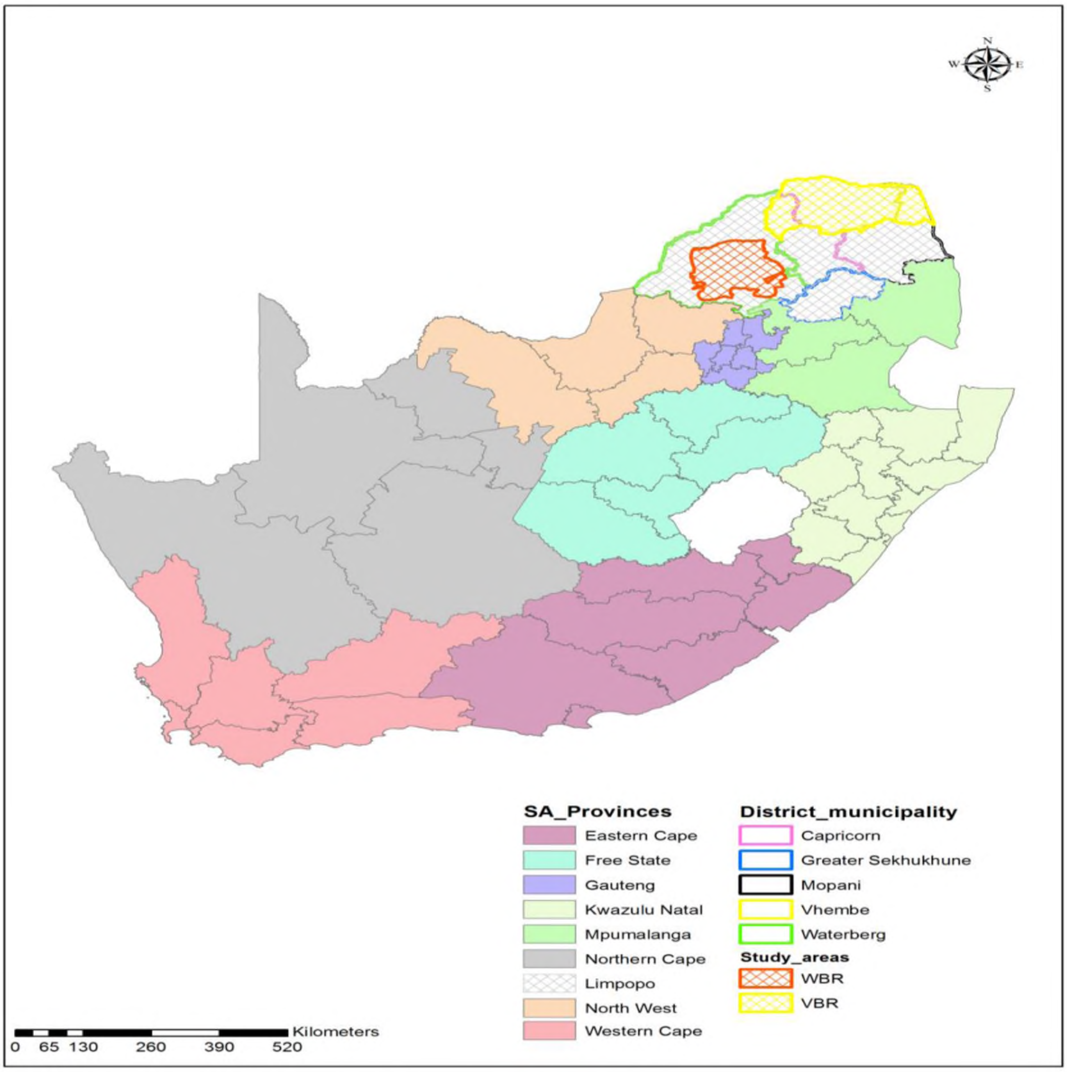

Figure 1.4 Study area locations: map of SA showing the provincial and biosphere reserve boundaries.

1.4.2.2 Vhembe Biosphere Reserve

1.4.2.2.1 Biophysical location

The Vhembe Biosphere Reserve (VBR) became SA's sixth BR in June 2009. The VBR is located in the northern tip of Limpopo Province. It is situated in Vhembe district municipality and covers five local municipality areas: Blouberg, Makhado, Thulamela, Musina and Mutale. The central point lies at 22, 794241° S and 30, 002458°E (Dombo et al. 2006). The VBR covers an area of 3 070 000 ha, consisting of three components following the UNESCO BR structure: the core (460 000 ha), buffer (357 500 ha) and transition zone (225 260 ha). It includes the northern part of the Kruger National Park (KNP), the Makuleke Wetlands Ramsar Site, the Soutpansberg and Blouberg biodiversity hotspots, as well as the

Mapungubwe Cultural Landscape and World Heritage Site and the Makgabeng Plateau (Dombo et al. 2006. A significant part of the VBR falls within two international important transfrontier conservation areas (TFCAs) with Botswana, Zimbabwe and Mozambique. TFCAs are large areas straddling two or more countries covering large-scale natural systems and encompassing one or more protected areas (de Villiers 1999). It is drained by five tributaries of the Limpopo River system (Dombo et al. 2006).

1.4.2.2.2 Climate

The Limpopo region has low rainfall, which generally falls in summer and varies between 200 mm in the hot dry areas to 1 500 mm in the high-rainfall areas. The greater part of the catchment receives less than 500 mm of rainfall per year, with the hot dry areas, located mostly in the main Limpopo River Valley itself, receiving about 200-400 mm per annum (FAO 2004).

1.4.2.2.3 Geology and soils

With regard to the geological composition of the basin, the Limpopo mobile belt and the Bushveld Igneous Complex separate the Kalahari and the Zimbabwe cratons. The cratons consist of igneous and metamorphic rocks, at the base of the continental crust (FAO 2004). The Kalahari craton is mostly covered with sedimentary rocks. The genesis of the Basement Complex falls within the Archaean period. Granite and gneiss are the dominant rock types of the Basement Complex on the highveld and escarpment of SA, with quartzite, granodiorites and various slightly to moderately metamorphosed sedimentary rock types occurring subordinately (FAO 2004). The southern part of the Limpopo River Basin within the highveld is characterised by the occurrence of Karoo sediments (Vryheid Formation), including sandstones, clay stones, shales and coal deposits (FAO 2004).

Soils in VBR are weak and shallow, on hard or weathering rocks. The Soutpansberg and Blouberg regions are dominated by rock with limited soil, shallow soil or weathering rock with clay soil and soil with a high base status in places. The dominant soil forms are Glenrosa, Plinthic catena, Primacutanic and/or Pedocutanic and Red-yellow apedal, following MacVicar et al.'s (1977) soil classification system.

1.4.2.2.4 Vegetation

The VBR covers three biomes: grassland, forest and the main part, dominated by savannah biome. Following Mucina and Rutherford's (2006) vegetation classification, the main vegetation types are represented as follows: in the Vhembe region, Musina Mopane Bushveld and Limpopo Ridge Bushveld dominate around Musina and the areas along the Limpopo River. Soutpansberg Mountain Bushveld and Soutpansberg Summit Sourveld are mainly confined to the Soutpansberg mountain region. VhaVenda Miombo also occurs in the Vhembe region. Mopane Basalt Shrubland and Makuleke Sandy Bushveld dominate the northern part of the KNP. Also occurring only in the northern part of the KNP are Cathedral Mopane Bushveld, Ironwood Dry Forest and Lowveld Riverine Forest (Mucina and Rutherford 2006). Figure 1.5 presents the VBR vegetation map.

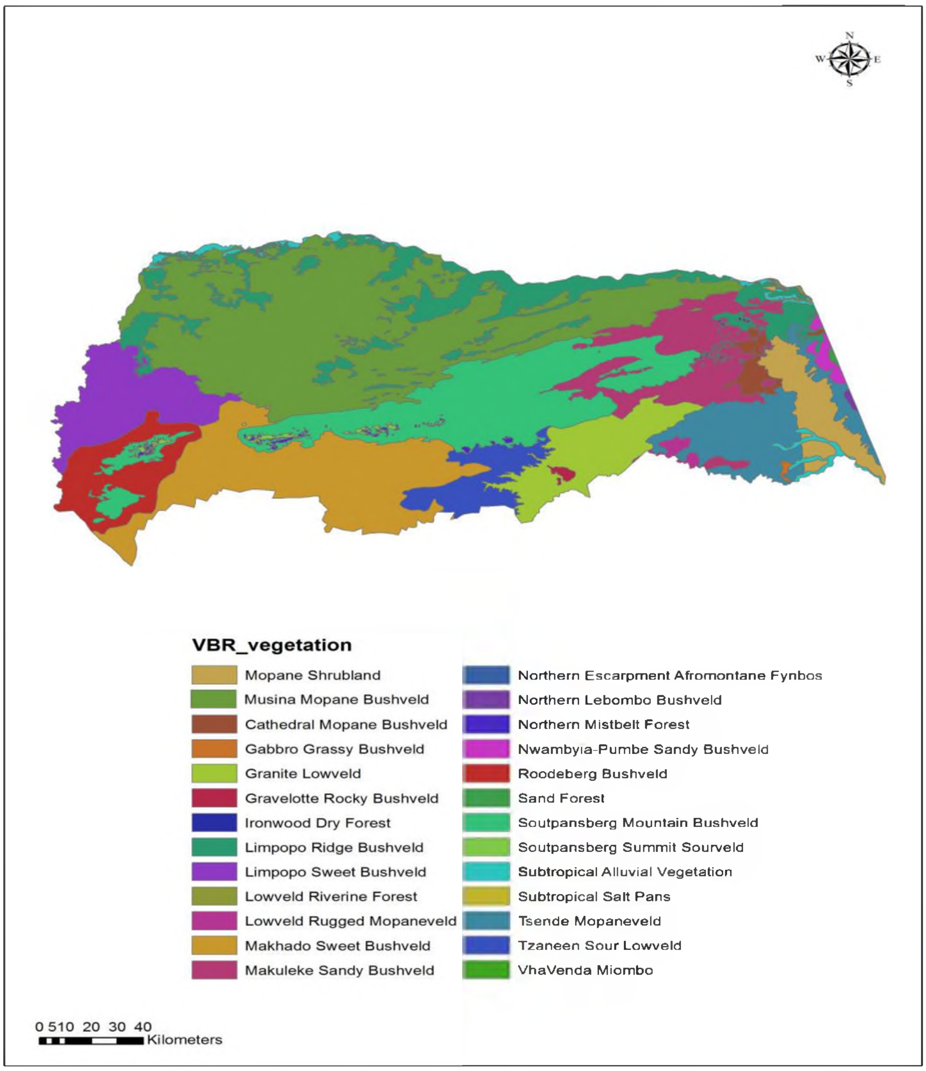

Figure 1.5 VBR vegetation map (Source: Mucina and Rutherford 2006).

1.4.2.3 Waterberg Biosphere Reserve

1.4.2.3.1 Biophysical location

The Waterberg Biosphere Reserve (WBR) was the first savannah BR in SA and was proclaimed in 2001. It is situated in the Waterberg district of Limpopo Province, located within latitudes 23°10-24°40'S and longitudes 27°30'-28°40'E (WBR 2012). It covers an area of 654 033 ha and includes Marakele National Park, Mokolo Dam Nature Reserve, Wonderkop Nature Reserve and Masebe Nature Reserve as core areas (WBR 2012). The WBR is very significant in the conservation of the important cycads plant species *Encephalartos eugene maraisii,* endemic in Waterberg Mountains, and the Cape vulture (*Gyps coprotheres*) colony, one of the largest breeding colonies in the world, situated in the Marakele National Park (MNPMP 2014). It is drained by four major tributaries of the Limpopo River, namely the Lephalala, Mokolo, Matlabas and the Mokgalakwena (De Klerk 2003; WBR 2012).

1.4.2.3.2 Climate

The climate is temperate, semi-arid in the south to arid in the extreme north. Rainfall is seasonal, with most rainfall occurring during the summer months. The winters are very dry (WBR, 2012). Annual rainfall varies from 500 to 750 mm. The mean annual temperature is 17.6°C (Mucina and Rutherford 2006), with the warmest month having an average of 25°C and the coldest month`s average being 10°C (WBR 2012).

1.4.2.3.3 Geology and soils

The main geological mass of the Waterberg consists of sedimentary rock, bound by escarpments on the north, east and south (WBR 2012). Its central portion forms the Palala Plateau. These sediments are entirely detrital and include sandstones, mudstones, shales, conglomerates and lenses of grits (WBR 2012). Conglomerates and occasionally breccias mark the lower levels of the Waterberg series. The formation consists of dominantly quartzite sandstones, but also conglomerates, flagstones and shale (WBR 2012).

Soils are leached and sandy, mostly of a diastrophic nature. Because of the hilly and mountainous nature of the terrain, a large portion of the soil is very shallow and rocky (WBR, 2012). The dominant soil forms are Mishap and Glenrosa (in rocky areas) and Clovelly and Avalon in flat areas, according to MacVicar et al.'s (1977) soil classification system.

1.4.2.3.4 Vegetation

The WBR is classified as a savannah biome. The vegetation classification of Mucina and Rutherford (2006) characterises the WBR by seven different vegetation types. Central Sandy Bushveld and Waterberg Mountain Bushveld dominate the areas around the Waterberg Mountains. Western Sandy Bushveld occurs mainly in the low-lying areas. Also occurring within the WBR are Limpopo Sweet Bushveld, Makhado Sweet Bushveld, Roodeberg Bushveld and Waterberg-Magalies Summit Sourveld. Figure 1.6 presents the WBR vegetation map.

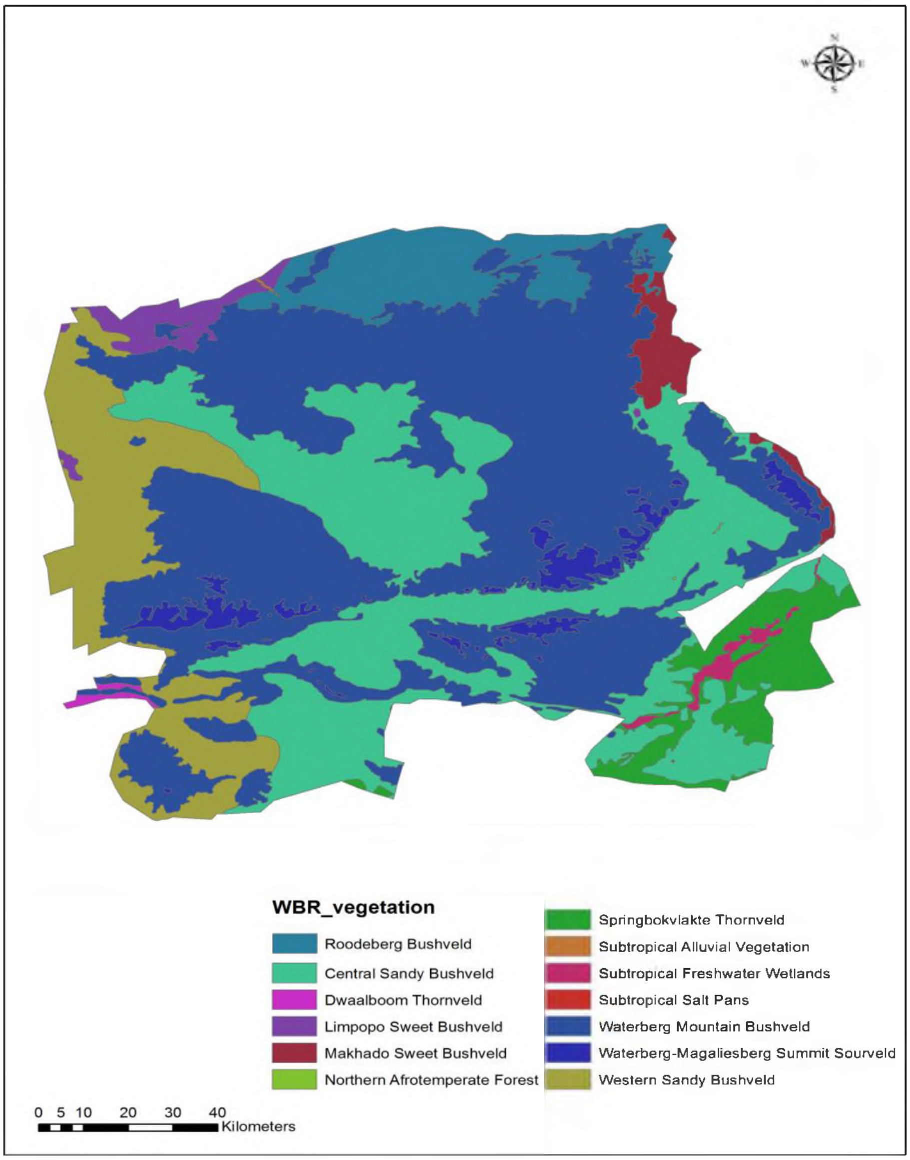

Figure 1.6 WBR vegetation map (Source: Mucina and Rutherford 2006).

1.5 STRUCTURE OF THE THESIS

In addition to this introductory chapter (Chapter 1), and synthesis (Chapter 8), the thesis is arranged into six chapters (Chapters 2-7), each addressing a key objective as outlined below (Table 1.1). The six core chapters have been formatted following the requirements of the target journal for publication, chapter 3 have already been submitted for publication and chapter 5 have been published.

Table 1.1 Chapters covered by the study.

Chapter	Title
1	Conceptual and contextual settings
2	Valuation of ecosystem services in protected areas: a review from SA
3	Land use change scenarios for two biosphere reserves in SA
4	Ecosystem services and their indicators: identification and mapping
5	Habitat condition assessment for ecosystem services
6	Above-ground carbon storage assessment in SA
7	Economic valuation of provision ecosystem services in a biosphere reserve context
8	Synthesis and conclusions

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1.7 APPENDICES

1.7.1 Appendix 1A: Valuation approaches and techniques used for different ES according to their values (source: adapted from de Groot et al. 2002; MA 2005; Farber et al. 2006; TEEB 2010).

ECOSYSTEM SERVICES	TYPES OF VALUES	VALUATION APPROACH	VALUATION TECHNIQUE
MA (2005) typology	USE VALUES - Utility that people derive from ecosystems directly or indirectly, including option value	Major categories of valuation approaches are divided into economic and non-economic (mainly ecological and socio-cultural)	Valuation techniques for different approaches
	NON-USE - linked to things that people do not consume or use directly; they are divided into bequest, altruist and existence values		1.Direct market - market price-based, factor income, replacement, avoided, mitigation and restoration cost methods 2.Stated preference - contingent valuation, choice modelling, group valuation 3.Revealed preference - travel cost, hedonic pricing
Provisioning	Direct use values	Economic category	Valuation techniques symbols

Includes all extractive/consumptive products that are obtained from ecosystems.	*Directly used by human beings (consumptive or non-consumptive)*	*Valuation approaches applicable to this category determine the value of ES in monetary terms - they are divided into direct and indirect market approaches. Indirect market approach is divided into revealed and stated preference valuation approaches*	*MP - Market price* *FI - Factor income* *AC - Avoided cost* *RC - Replacement cost* *TC - Travel cost* *HP - Hedonic pricing* *PF - Production function*
Food - food products derived from plants, animals and microbes (i.e. crops, wild foods, spices, meat)	Direct use	Direct market (market price-based)	FI
Fibre - wood, cotton, wool, silk	Direct use	Direct market (market price-based)	FI
Fuel- wood, dung and other sources of energy	Direct use	Direct market (market price-based)	FI
Biochemicals - natural medicines and pharmaceuticals	Direct use	Direct market (market price-based)	FI
Ornamental resources - animals and plant products (skin, shells, flowers)	Direct use	Direct market (market price-based)	FI
Fresh water supply - from various resources (dams, lakes, rivers)	Direct use	Direct market (cost-based)	AC, RC
Grazing material - fodder	Direct use	Direct market (market price-based)	MP
Regulating	Indirect use - ES indirectly used by human beings	Direct market and indirect market (revealed preference) valuation approaches	Direct market valuation techniques

	Option value		
Benefits obtained from the regulation of ecosystem processes			*1.Market price-based (FI)* *2.Cost-based valuation techniques - AC, RC*
Climate regulation - of temperature and precipitation and/or greenhouse emission or sequestration	Indirect use	Direct market (cost-based)	AC
Erosion regulation - soil retention and prevention of landslides by vegetative cover	Indirect use	Direct market (cost-based)	AC, RC
Disease regulation - control of human pathogens (e.g cholera) and disease vectors (e.g mosquitoes)	Indirect use	Direct market (cost-based, market-price)	RC, FI
Water regulation - timing and magnitude of aquifer recharge, runoff and flooding	Indirect use	Direct market (cost-based, market-price)	AC, FI
Water purification and waste treatment - the filtering out, detoxification and decomposition of organic waste in water bodies through soil processes	Indirect use	Direct market (cost-based)	RC

Disturbance/natural hazard regulation-reduction of the damage caused by hurricanes and large waves by the presence of coastal ecosystems such as mangroves and coral reefs	Indirect use	Direct market (cost-based)	AC, RC
Cultural services	Direct use, non-use, option values	Socio-cultural category –focus on non-material benefits people obtain from this category	Indirect market valuation techniques
Non-material benefits people obtain from the ecosystems.		*Revealed preference approach - based on observation of individual choices in existing markets* *Stated preference approach - use surveys to simulate market and demand for ES*	*Revealed preference (TC, HP)* *Stated preference (CV, CM, GV)*
Recreational - ecotourism, outdoor sports and recreational experiences	Direct use – non-consumptive	Revealed preference valuation approaches	TC, HP
Cultural diversity - including use of nature as motif in books, films, painting, folklore, national symbols, architecture, advertising,	Direct use – non-consumptive	Stated preference valuation approach	CV
Spiritual and historical - use of nature for religious or heritage value or natural merit.	Direct use - non-consumptive	Stated preference valuation approach	CV

Educational - use of natural systems for school excursions and scientific discovery	Direct use – non-consumptive	Direct market	MP
Aesthetic information	Direct use – non-consumptive	Revealed preference valuation approach	HP
Supporting services	Use values - indirectly	Ecological/biophysical category	Direct market valuation techniques
Those services that are necessary for the production of all other ecosystem services		*Valuation approaches relevant for this category examine the ecological importance of attributes, qualities and quantities characterising nature`s condition and functioning*	*1.Cost-based (AC, RC)* *2. Production-based (PF)*
Nutrient cycling	Indirect use	Direct market (cost-based)	RC
Pollination	Indirect use	Direct market (cost-based)	RC, AC
Primary production	Indirect use	Direct market (production function-based)	PF
Photosynthesis	Indirect use	Direct market (production function-based)	PF
Soil formation	Indirect use	Direct market (cost-based)	AC

CHAPTER 2

VALUATION OF ECOSYSTEM SERVICES IN PROTECTED AREAS: A REVIEW FROM SOUTH AFRICA

This chapter intended for submission to the Journal: *Ecosystem Services* as Ntshane B.C. and Gambiza J. Valuation of ecosystem services in protected areas: A review from South Africa.

Abstract

Despite the fact that protected areas (PAs) provide a variety of ecosystem services (ES), their value is often not reflected in decision-making. Challenges exist in advocating the case of these systems amidst the drive for economic development, where biodiversity conservation is often compromised in favour of other land uses that are economically robust, such as mining. The Convention on Biological Diversity, of which approximately 200 countries, including South Africa (SA), are signatories, requires that natural assets be incorporated into national accounting. It is against this backdrop that valuation of ES provided by PAs becomes crucial. We reviewed 25 studies that conducted valuation of ES generated by PAs in SA, with the aim of understanding the status on valuation and to identify the research gaps in this regard. In order to achieve the main aim, the study attempted to answer the following questions: (1) What were the objectives of the study? (2) Which geographic areas were covered? (3) Which IUCN PAs categories were covered? (4) Which ES were covered? and (5) Which valuation approach/method was applied? The results of the study indicate that valuation focussed on 6% of around 500 PAs that exist in SA, covering three of the IUCN PA categories across seven vegetation biomes, mainly to determine the economic value. Of these studies, 76% focused on cultural ES, 28% on provisioning and 4% on supporting ES, and 4% on regulating ES. The review highlighted research gaps in terms of geographic area coverage, as well as supporting and regulating services. This study thus proposes an integrated valuation of all ES provided by PAs, in order to provide evidence to mobilise support for their existence and to mainstream them into national accounting.

Key words: ecosystem services, valuation, protected areas, economic value, Convention on Biological Diversity.

2.1 INTRODUCTION

Conservation communities are striving to balance the need for mainstreaming natural assets for economic development and the conservation of biodiversity (Bajracharya and Dahal 2008; TEEB 2010; Le Maitre et al. 2007). Until recently, many protected areas (PAs) were mainly established for biodiversity conservation, with more emphasis on the hands-off approach (Bajracharya and Dahal 2008; Pullin et al. 2011). However, the establishment of the Convention on Biological Diversity (CBD 2010) prompted the development of approaches that promote sustainable utilization of natural resources. These developments shifted perceptions that PAs represent institutions that promote people`s displacement, inaccessibility and non-utilization of the natural resources (Colchester 2001; McLaughlin 2011) to a more inclusive triple bottom line approach that reflects social, economic and ecological dimensions (CBD 2010) to address tangible and intangible benefits for human well-being. Despite the fact that protected areas (PAs) provide a variety of ecosystem services (ES), their value is often not reflected in decision-making. Challenges exist in advocating the case of these systems amidst the drive for economic development, where biodiversity conservation is often compromised in favour of other land uses. Furthermore, the CBD, of which approximately 200 countries, including South Africa (SA), are signatories, requires that natural assets be incorporated into national accounting.

2.1.1 What are protected areas?

PAs are the backbone of biodiversity conservation (Stolton et al. 2010; IUCN 2004) and are defined as "areas of land and/or sea especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means (IUCN 2004). The International Union for the Conservation of Nature (IUCN) further adopted a six-category PA system (IUCN 2004), which includes strict nature reserves (IUCN Category Ia), wilderness areas (IUCN Category Ib), national parks (IUCN Category II), natural monuments or features (IUCN Category III), habitat/species management areas (IUCN Category IV), protected landscapes/seascapes (IUCN Category V) and protected areas with sustainable use of natural resources (IUCN Category VI), (IUCN 2004).

Given all the challenges facing natural assets, the IUCN PAs alone are not enough to conserve biodiversity (NSBA 2004). Other strategies also meant to achieve biodiversity conservation aims are the conservation stewardship programs and biosphere reserves (BRs), (NSBA 2004; UNESCO 2010). BRs are terrestrial and coastal ecosystems aimed at reconciling conservation efforts to achieve biological diversity with sustainable utilization (UNESCO 2010) For the purpose of this analysis, PAs will include all the IUCN categories and UNESCO`s BRs. The importance of PAs is confirmed by the ongoing commitment to putting land aside for conservation purposes (NPAES 2008; Pullin et al. 2011) emanating from the CBD`s Aichi target 11 (CBD 2010). In SA, PAs, totalling around 500 (DEAT 2003) represent 6.5% of the terrestrial surface area across 10 major biomes and 0.4% of the marine areas (NPAES 2008) In line with the CBD`s Aichi target, PAs in SA therefore still need to be expanded to an additional 8.8% of the terrestrial surface area to include most of the threatened and rare vegetation types, and approximately 40% of the marine area by 2020 (NPAES 2008) to ensure the sustainability of the country`s biodiversity and ecological processes.

2.1.2 Benefits provided by protected areas

PAs provide benefits, called ES, which are important for human well-being (MA 2005; Stolton et al. 2010). Since their inception, many definitions and methods of classification have been proposed (de Groot et al. 2002; MA 2005; TEEB 2010). The MA (2005) defines ES as benefits that people derive from ecosystems, and arrange them into four primary categories: provisioning, regulation, supporting and cultural categories.

In view of their intact nature, mainly underpinned by their primary function of biodiversity conservation (IUCN 2004; Stolton et al. 2010), most PAs are capable of providing ES. The term PA implies that most of the ES produced are protected from several threats, because of various laws and regulations that govern them (NEMPAA 2003; CBD 2010), thus making them suitable and sustainable in supplying a variety of ES (Stolton et al. 2010). On top of their well-known functions of protecting biodiversity and providing ES that contribute to human well-being (MA 2005), PAs are known for contributing positively to countries' economies through ecotourism, among others (Bajracharya and Dahal 2008; Stolton et al. 2010).

2.1.3 Threats to protected areas

The importance of PAs in protecting biodiversity and providing ES cannot be emphasized enough, amidst severe degradation caused by among others climate change, alien species invasion, agricultural activities, habitat destruction and unsustainable resource extraction (MA 2005). Some of these induced pressures could have been exacerbated by the fact that most PAs historically imposed restrictions on both access and utilization of resources (Pullin et al. 2011) coupled with forced removals to make way for PAs' establishment (Colchester 2001; McLaughlin et al. 2011). Since natural resources are the backbone of many countries` economies (Bajracharya and Dahal 2008; Stolton et al. 2010), growing pressures on resource utilization will not only have an impact on biodiversity resilience (MA 2005) but will also reduce PAs` capacity to render social and economic contributions (Bajracharya and Dahal 2008; Stolton et al. 2010).

In SA, some historical pressures related to PAs' establishment are being addressed through various stakeholder engagement programs and benefit-sharing arrangements (Pelser et al. 2011), informed by regulations that advocate the inclusion of communities in the management of PAs and sharing of benefits derived from these PAs (CBD 2010; NEM:PAA, 2003). However, the existence of these regulations is not enough to guarantee the PA system the attention it deserves; challenges still exist in respect of attempts to advocate the importance of these systems (Strydom and King 2009; Lopoukhine et al. 2012) for economic growth (Bajracharya and Dahal 2008; Stolton et al. 2010). Concerns are brewing in areas where conservation is compromised in favour of economic robust land uses, such as mining (Turner 2012). Although some of these activities are likely to give the necessary boost to the economy, mining-related activities are regarded as unsustainable in view of their limited life span (Tilton 2009) when compared to PAs, which can be sustained indefinitely if threats could be held at bay. For example, SA`s popular Kruger National Park was established in 1902 (SANParks 2010) and is still highly sustainable.

The challenges faced by PAs, on the other hand, could be aggravated by the fact that there is little evidence of the contribution of PAs to either the country`s economy or human well-being (Pullin et al. 2011; Lopoukhine et al. 2012). Evidently, because of lack of information that reflects the value of ecosystems and the ES they provide (MA 2005; Daily et al. 2009) natural systems are often ignored during decision-making (Daily et al. 2009) and hence suffer immense degradation (MA 2005; Daily et al. 2009; TEEB 2010).

2.1.4 Why do we need to value ecosystem services provided by protected areas?

It is well known that ES provided by PAs are often difficult to quantify (Stolton et al. 2010) and many of the generated ES are not involved in market transactions (Daily et al. 2009; TEEB 2010), thus making it difficult to include them in decision-making (MA 2005; Daily et al. 2009). In the absence of information and associated evidence to support their contributions to the national economy (Lopoukhine et al. 2012) natural assets, including PAs, are often compromised, making way for other land uses that are known to be economically robust (Strydom and King 2009; TEEB 2010; Turner 2012). Valuation is useful in providing strong arguments against mining (TEEB 2010).

PAs as strategies meant to conserve biodiversity are managed under the prescripts of the CBD (CBD 2010). The CBD prescribed 20 deliverables called Aichi targets. All nations are required to incorporate these targets into their national plans and report progress with their delivery every two years through CBD`s Conference of the Parties meetings (CBD 2010). The CBD`s Aichi targets 1 and 2 require biodiversity to be integrated into development and planning processes and incorporated into national accounting and decision-making (CBD 2010) to encourage their appreciation, recognize their worth and minimize their destruction (MA 2005; Daily et al. 2009). Valuation is crucial for illustrating the importance of biodiversity (Stolton et al. 2010), thus making it possible for PAs to be integrated into decision-making (Daily et al. 2009; TEEB 2010; Stolton et al. 2010), and can also assist in justifying PAs' policies (TEEB 2010). Valuation not only affords natural assets an opportunity to be aligned with the CBD`s Aichi targets; it is also an important mechanism that assists them to reflect their social, ecological and economic value, required for decision-making (MA 2005; Daily et al. 2009). The term valuation is referred to as a process of expressing value related to a specific action or object, in order to achieve a certain goal (Farber et al. 2002). Valuation of ES is not a recent phenomenon, but has been conducted for more than six decades (Hotelling 1949).

2.1.5 Different ways to value ecosystem services provided by protected areas

According to Farber et al. (2002) valuation is the process of expressing a value for a particular action or object. Many approaches and techniques can be applied to estimate both use and non-use values (de Groot et al. 2002; Farber et al. 2002; TEEB 2010). These are divided into economic, non-economic and integrated valuation approaches (de Groot et al. 2002; Farber et al. 2002; Daily et al. 2009; TEEB, 2010). Non-economic valuation approaches include most of the socio-cultural and ecological valuation approaches (de Groot et al. 2002; Farber et al. 2002; TEEB 2010). Ecological valuation approaches are determined both by the integrity of the regulation and habitat functions of the ecosystem and by ecosystem parameters such as complexity, diversity and rarity (de Groot et al. 2002; Farber et al. 2002; TEEB 2010). Socio-cultural value mainly relates to information functions (de Groot et al. 2002).

Economic valuation approaches attempt to determine the value of goods and services in monetary terms (de Groot et al. 2002; Farber et al. 2002; Daily et al. 2009; TEEB 2010) and are divided into the following valuation approaches: direct market, indirect market, contingent and group valuation (de Groot et al. 2002; Farber et al. 2002; TEEB 2010). Direct market approaches are used to determine the values of those ES that can be involved in market transactions, such as timber and crops (de Groot et al. 2002; Farber et al. 2002; TEEB 2010). Indirect market valuation approaches are used when there are no explicit markets (de Groot et al. 2002; TEEB 2010). These include the (1) avoided cost, e.g. flood control service by wetlands (avoids property damage), (2) replacement cost, e.g. replacing natural waste treatment with human-made systems, (3) factor income, e.g. enhancing water quality to increase fish cash, thus increasing the income of fishermen, (4) hedonic pricing based on the demand for an environmental attribute related to the marketed ES (de Groot et al. 2002; Farber et al. 2002; TEEB 2010), and (5) the travel cost (TC) method, which was originally proposed in the 1940s (Hotelling 1949) and is mainly used to determine the value associated with benefits that require traveling, e.g recreation (de Groot et al. 2002; Farber et al. 2002; TEEB 2010).

Contingent valuation approaches are used to estimate value by eliciting individuals' preferences/choices by means of a survey/questionnaire, e.g. asking respondents how much they are willing to pay for the provisioning of an ES (de Groot et al. 2002; Farber et al. 2002; TEEB 2010). Contingent valuation came on the scene during the 1960s (Knetsch and Davis 1966). The last valuation approach is group valuation, which combines stated preference techniques with elements of deliberative political and social processes (de Groot et al. 2002; Farber et al. 2002; TEEB 2010).

The integrated valuation approaches are very recent (Daily et al. 2009; Andrade et al. 2010) and take into consideration all aspects of ecosystems: social, economic and ecological (Daily et al. 2009). Among the well-known integrated valuation approaches are: Integrated

Valuation of Ecosystem Services and Trade-offs (InVEST), Multiscale Integrated Models of ES (MIMES) and Global Unified Metamodel of the Biosphere (GUMBO) (Daily et al. 2009; Andrade et al. 2010) What these approaches have in common is the ability to value multiple services simultaneously and at different scales, rightfully placing them among crucial tools that can be used in processes to incorporate natural assets in decision-making (MA 2005; Daily et al. 2009).

2.1.6 Overview of valuation of ecosystem services in protected areas

Numerous studies have been undertaken in various countries regarding valuation of ES generated by PAs since a few decades ago (Hadker et al. 1997; Hotelling 1949; Ulph and Reynolds 1981). In Africa, valuation of ES was introduced more than two decades ago (Moran 1994; Turpie et al. 2010). In SA, valuation of ES has been recorded since about two decades ago (Razafindralambo 1998).

Despite progress made in understanding the value of ES provided by PAs (Bajracharya and Dahal 2008; Stolton et al. 2010), almost no study reports an analysis of the status of valuation of ES generated by these systems in SA. On the related subject of valuation, only one study gave an idea of the status of valuation of ES in SA, by reviewing 40 studies that had assessed values of ES found in different habitats (DEA 2012) while another reviewed 17 studies that looked at ES generally, not specifically valuation (Le Maitre et al. 2007). Despite the fact that both reviews included most of the major habitats, fewer than 50 studies that assessed ES were recorded. Since ES generated by PAs were not given special focus, but formed part of these general analyses, this highlights a major research gap related to understanding benefits provided by PAs. Understanding of ES generated by PAs in SA is crucial in mainstreaming biodiversity and ES into national accounting and as a mechanism for achieving the ministerial deliverable agreement sub-output 4.4 of Outcome 10: Environment Delivery Agreement (DEA 2012).

We addressed this research gap by reviewing studies that conducted valuation of ES generated by SA`s PAs and BRs. Our study attempted to answer the following questions: (1) What were the objectives of valuation? (2) Which geographic areas were covered? (3) Which IUCN PAs categories were covered? (4) Which ES were covered? (5) Which valuation approach/method was applied? This review will serve as a basis for valuation of ES in SA.

2.2 MATERIALS AND METHODS

We reviewed literature on the valuation of ES in SA. The review covered studies that were conducted from 1990s until 2014. Data was collected during the years 2012-2014. The review covered the use of carefully designed search strings (key words); a specific search followed these key words: valuation of ES in PAs/conservation areas (CAs), valuation of PAs/CAs, economic valuation of ES; economic valuation of PAs/CAs, ecological valuation of PAs/CAs. The search strategy included searching of multiple databases, such as Science Direct, Scopus, Web of Knowledge, Google, Google Scholar and Sabinet.

To avoid publication bias, the review included some grey literature as well. The criteria to identify differences and similarities of ES in terms of how they were described, classified and valued were adopted from Haines-Young and Potschin (2009). The scope of the search was Africa, then Southern Africa and further narrowed down to SA. Because of a vast body of literature on ES valuation, this study mainly focused on PAs. Search results yielded 46 studies that conducted valuation of ES in SA, covering different study areas that included marine environments and some of the major biomes (Cooper and Jayiya 2001; Le Maitre et al. 2009; De Lange et al. 2011). Results were screened using predetermined inclusion criteria by screening titles and abstracts and where necessary full text. Of the 46 studies found through the search, 25 conducted valuation of ES generated by PAs in SA.

The last step followed in this review was the analysis and synthesis of the results. Relevant studies were arranged according to five aspects: (1) objectives for valuation, (2) geographic area covered, focused on major biomes, following Mucina and Rutherford's classification (Mucina and Rutherford 2006) and whether a PA was situated in a marine or terrestrial area, (3) PA categories covered, focusing on the IUCN list of PA categories (IUCN 2004), (4) ES covered, following the MA`s classification of ES, (MA 2005) and division of ES into provisioning (including consumptive and extractive products from plants and animals for food, fibre, fuel, biochemicals, ornamental resources, and grazing material; regulating (including climate regulation, disease regulation, water and natural disaster regulations); cultural (consisting of non-material benefits people obtain from ecosystems, such as recreational and educational activities, cultural heritage and diversity, as well as spiritual and historical aspects), as well as the supporting category, which consisted of services that are necessary for the production of other ES (such as nutrient cycling, primary production, pollination and soil formation), (5) valuation method/approach applied (including different approaches such as ecological, economic and social (socio-cultural) and different techniques falling under them) (de Groot et al. 2002; Farber et al. 2002; TEEB 2010), and (6) the type of source document, e.g peer-reviewed article, discussion document, report, dissertation/thesis.

Although the main focus of the entire study of which this paper forms part was BRs, there were only six BRs in SA at the time the study was conducted, which were not enough to provide for a comprehensive valuation analysis. A decision was then taken rather to undertake an exclusive review of PAs, as they represent the highly protected zonation component (core areas) within a BR structure and are often compromised when important land-use decisions are made and more economically robust decisions are favoured (Turner 2012). There is also a perception that for PAs to get the attention they deserve, they have to undergo a valuation process, in order to reflect their social, ecological and economic values (Stolton et al. 2010), thus providing the necessary evidence to support land-use decisions affecting them financially and politically, while generally raising awareness of these systems' role in conservation of the natural and cultural heritage. This review will thus provide baseline information for assessing the status of valuation of ES in PAs in SA.

2.3 RESULTS

Of the 46 studies found through the search, 25 conducted valuation of ES generated by PAs in SA. A summary of the studies is presented in Table 2.1, with more details covered in the sections below.

2.3.1 Objectives of valuation

The main objective of the 25 studies was the determination of the values of selected ES. Although 14 of the studies had the word 'economic' in their titles/objectives, it was found that seven of them integrated more than one objective; in total there were 31 objectives. The main focus of 21 of these objectives was the determination of economic values; of these eight determined socio-economic values. Five determined the values of selected ES generally without specifying whether these were economic or otherwise, two determined visitors` willingness to pay for an ES, two estimated biodiversity values, two assessed costs and benefits, one determined the non-consumptive value of ES and one assessed whether clearing of alien species would add value to ES. More details regarding studies' objectives are presented in Table 2.1.

2.3.2 Geographic area covered

The studies involved seven of the nine major vegetation biomes that occur in SA, namely savanna, forest, fynbos, Indian Ocean Coastal Belt, grassland; Succulent-Karoo and Nama-Karoo. The studies were conducted in both the terrestrial and marine environment. The terrestrial environment involved 13 PAs, Kruger, Namaqua, Karoo, Pilanesberg, Tankwa, Agulhas (national parks), and the following nature reserves: Hluhluwe-Umfolozi, Umgeni, Hester Malan Flower Reserve, Goedgap, Anysberg and Oorlogskloof nature reserve), as well as a transfrontier conservation area (Kgalagadi). In the marine environment, five national parks (Garden route, Wilderness, West-Coast, Table Mountain, Kogelberg and Tsitsikamma National Park) were involved.

2.3.3 Protected areas categories covered

Twenty-one of the valuation studies involved 13 PAs of national importance, falling under IUCN Category II and represented by the following national parks: Kruger, Karoo, Pilanesberg, Tankwa, Tsitsikamma, Namaqua, Agulhas, Wilderness, Garden Route, Karoo, West Coast, Table Mountain and a transfrontier conservation area (Kgalagadi). There were 10 PAs of regional importance, represented as follows: eight fell under IUCN Category Ia (strict nature reserves) represented by DeHoop, Umgeni, Anysberg, Hluhluwe-Umfolozi, Hester Malan Flower Reserve, Goedgap and Oorlogskloof nature reserve, one fell under IUCN Category Ib (wilderness areas), represented by Cederberg Wilderness Area, and one was a BR (Kogelberg).

2.3.4 Ecosystem services covered

In terms of the ES covered, all four categories of ES following the chosen classification were considered as follows: (1) under provisioning, three studies looked at fish and two focused on honey, three studies focused on water, two focused on fuelwood, one study looked at timber, one study was on grazing, and two studies focused on medicinal plants); (2) under regulating one study focused on both carbon sequestration and restoration; (3) under cultural, the most popular ES was recreational/tourism with 19 studies, followed by education and existence values with four studies each, and the last one was aesthetic with one study; and (4) under supporting, one study was on pollination and one on biodiversity. More details regarding ES covered are presented in Table 2.1.

2.3.5 Valuation methods applied

Of the 25 studies that were reviewed, 23 applied economically based methods, one used the social approach and one expressed the values in biophysical/ecological terms (refer to Table 2.1). The following techniques were applied: six studies used contingent valuation and another six willingness to pay, five used TC, seven used economic multipliers, five used social surveys, three used choice experiment and two used total economic value (TEV), two market prices, two literature reviews, one the ecosystem service approach, one cost benefit and another one cost recovery.

2.3.6 Reference source type

Valuation of ES studies that focused on PAs fell into five categories of sources: 14 studies had been published in peer-reviewed journals, five were report documents, four were Master`s degree dissertations, one was a working document and one was a discussion document (Table 2.1).

Table 2.1 Overview of valuation of ES generated from protected areas in SA

Reference	Source type	Study area	Study objective	ES involved	Valuation method	Value estimated
1. Blignaut and Moolman 2006	Working paper	-Kruger National Park (KNP) - Savanna biome	-To quantify the potential of restored natural capital to alleviate poverty and conserve nature	- Recreational - Timber - Fuel wood - Medicinal plants - Honey	- Willingness to pay - TEV	Yes
2. Dikgang and Muchapondwa 2012	Journal article	- Kgalagadi Transfrontier Park (KTP) -Savanna biome	-To investigate the values communities assign to biodiversity conservation in the Kgalagadi area	-Biodiversity	-Contingent -Choice experiment -Willingness to pay	Yes
3. Dikgang and Muchapondwa 2013	Discussion paper	-KTP - Savanna biome	-To value ES in the KTP	-Provisioning services (hunting, grazing, fuel wood, medicinal plants)	-Choice experiment	Yes
4. Dikgang and Muchapondwa 2014	Journal article	-KTP -Savanna biome	-To value selected attributes of nature-based tourism, and to assess their potential to contribute to Khomani SAN community	-Recreational	-Choice experiment method -Willingness to pay	Yes

5. DWAF 2010	Report document	-Olifants, Inkomati and Usutu to Mhlatuze Water Management Areas (Ismangaliso Wetland Park, KNP, Hluhluwe-Umfolozi Park) -Savanna/Indian Ocean Coastal Belt	-To determine the value of the aquatic resources	-Recreational -Fish -Educational -Water provision	-Social surveys -Literature review	Yes
6. Engelbrecht and van der Walt 1993	Journal article	-KNP	-To compare the economic benefits of the park with agriculture as an alternative land use	-Recreational -Education	-Benefit-cost analysis	-Yes
7. Ferreira 2008	Master`s degree dissertation	-Karoo National Park -Succulent-Karoo biome	-To determine the socio-economic impact of the park	-Recreational	-Surveys and questionnaires	Yes
8. Fourie et al. 2013	Journal article	-Agulhas plain – (Agulhas National Park) -Fynbos biome	-To assess whether alien clearing and natural capital restoration would add value to the Agulhas Plain	-Water provision -Fuel wood -Honey -Wild flowers -Pollination	-Cost benefit analysis	Yes
9. James et al. 2007	Journal article	-Namaqua National Park (NNP) -Succulent-Karoo	-To determine the economic value of flower viewing	-Recreational	-Travel cost	Yes

10. Le Maitre et al. 2009	Report document	-Succulent-Karoo biome -PAs involved: Anysberg, Tankwa, Goedgap, Hester Malan Flower Reserve, Oorlogskloof, NNP	-To develop a spatially explicit overview of the ecosystem services of the Succulent-Karoo Ecosystem Programme domain -To identify the relationships between different kinds of beneficiaries and the ES they depend on.	-Water -Grazing -Recreational -Natural products -Restoration -Carbon sequestration	-Social assessment -Proportional weighting approach -Ecosystem service-based approach -Household income approach -Market price method	Yes
11. Motlhake 2006	Master`s degree dissertation	-Pilanesberg National Park (PNP) -Savanna biome	-To determine the socio-economic impact of nature-based tourism on surrounding communities	-Recreational	-Semi-structured interviews	Yes
12. Mouton 2009	Master`s degree dissertation	-Wilderness National Park (WNP) -Marine -Fynbos and forest biome	-To determine the socio-economic benefits of the park -To determine the length of residency as an influential factor in the social impact of tourism	-Recreational	-Economic multiplier analysis	Yes
13. Nikodinoska et al. 2014	Journal article	-PNP -Savanna biome	-To determine visitors' willingness to pay to control the invasion of *O.*	-Recreational	-Contingent -Willingness to pay	Yes

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14. Oberholzer et al. 2010	Journal article	-Tsitsikamma National Park -Marine -Fynbos and forest biome	-To determine the economic value of the park -To assess communities' perceptions of the park and how they benefit from it	-Recreational	-Economic multiplier analysis	Yes
15. Razafindralambo 1998	Master`s degree dissertation	-Umgeni Nature Reserve -Grassland/forest biome	- To determine visitors' willingness to pay for environmental change -To assess the value of the reserve through implicit prices of travelling costs to the site	-Recreational	-Travel cost -Contingent	Yes
16. Saayman and Saayman 2006	Journal article	-KNP -Savanna biome	-To determine the economic contribution of visitor spending	-Recreational	-Economic multiplier	Yes
17. Saayman et al. 2009	Journal article	-Karoo National Park -Nama-Karoo biome	-To determine the socio-economic impact on the local economy -To determine the impact of tourism business development in the	-Recreational -Education -Existence value	-Input-output model -Economic multiplier -Sample matrix inversion	Yes

			Karoo district,			
18. Saayman et al. 2009	Journal article	-WNP -Fynbos/forest biome	-To determine the socio-economic impact of the park	-Existence value	-Economic multiplier	Yes
19. Saayman 2014	Journal article	-Table Mountain National Park (TMNP) -Fynbos biome -Marine	-To determine the non-consumptive value of five marine species -To determine the socio-demographic and behavioral variables that influence willingness to pay to see these species.	-Non-consumptive value	-Willingness to pay -Regression analysis	Yes
20. Sims-Castley et al. 2005	Journal article	-Indalo Private Protected Areas Association (Eastern Cape) -Grassland, Fynbos Savanna, Thicket Forest,Nama-Karoo	-To determine the socio-economic significance of game reserves	-Recreational	-Economic multipliers	-Yes
21. Standish et al. 2004	Report document	-TMNP -Fynbos biome -Marine	-To assess the economic impact of the park	-Recreational -Aesthetic -Educational	-Contingent -Willingness to pay -Travel cost	Yes
22. Turpie and Joubert 2001	Journal article	-KNP Rivers -Savanna biome	-To estimate the economic impact of	-Recreational	-Travel cost -Contingent	Yes

			water quality on tourism		-Conjoint	
23. Turpie 2003	Journal article	-West Coast National Park, De Hoop Nature Reserve and the Cederberg Wilderness Area) -Marine - Fynbos biome	-To estimate biodiversity existence value	-Existence value	-Contingent	Yes
24. Turpie et al. 2006	Report document	-Garden Route MPAs -Fynbos, forest	-To estimate the costs and benefits associated with the MPAs and how these costs and benefits might change under different scenarios	-Recreational -Fish -Opportunity cost -Option and existence	-TEV -Travel cost -Contingent	Yes
25. Turpie et al. 2009	Report document	-Kogelberg Coast BR -MPAs	-To determine the value of the Kogelberg Coast BR	-Recreational -Fish	-Literature review	Yes

2.4 DISCUSSION

2.4.1 Objectives for valuation of ecosystem services

The common objective in the 25 studies was determination of the economic value of ES. This is not surprising, as mainly those ES that are tradable in markets are seen as a reflection of natural systems' value to human well-being (MA 2005; Daily et al. 2009). The fact that only two studies focused on the determination of non-economic values is a major research gap, since integrating ES successfully into decision-making requires all values to be taken into account, including those that are not reflected in economic terms (MA 2005; Daily et al. 2009; TEEB 2010).

2.4.2 Geographic area covered

Although most of the major biomes were considered, two biomes, namely Albany thicket and desert, were omitted, despite the fact that two of the well-known national parks (Addo and Richtersveld) are situated in these biomes. The omission of desert in valuation was also found elsewhere (DEA 2012; de Groot et al. 2012). The fact that these biomes received no attention at all is a serious issue of concern, given their association with some of the ES (DEA 2012; SANParks 2010). Although biomes such as grassland and forest were included in valuation, they were not given adequate consideration, since valuation only focused on a small portion that formed part of other biomes. Fewer studies on grasslands and forests were also a finding in the study conducted by DEA (2012) and this could be attributed to the fact that only 1% of both biomes are conserved in national PAs (SANParks 2010). In sharp contrast, forest was among the most frequently studied biomes (Costanza et al. 2014). Aggravating the grassland situation is the fact that only 2% is under conservation overall in SA, making it the least conserved biome (NPAES 2008).

The situation in the forest biome is slightly different; although it currently represents the best conserved biome in SA at 13%, (NPAES 2008), only 1% is represented in national PAs (SANParks 2010). Fynbos and savanna biomes, however, received more attention than the other biomes, followed by the Succulent-Karoo and Nama-Karoo biomes respectively. More studies on valuation, approximately 40%, were recorded on the savanna biome. This could be attributed to the fact that this biome is well protected in two of the larger and well-known national parks in SA (Kruger and the Kgalagadi) (NPAES 2008; SANParks 2010), on which most of the studies concentrated. A high concentration of valuation studies on the fynbos biome was also a finding elsewhere (Le Maitre et al. 2007; DEA 2012). These findings are not surprising, since fynbos ranks third in terms of biome representation under conservation in SA (NPAES 2008; SANParks 2010). Although marine areas also received reasonable attention, overall more studies conducting valuation of ES were done on the terrestrial component. This was also found to be the case in the analysis done by DEA (2012), which covered most of the habitat types in SA. This finding is to be expected, since the establishment of marine PAs in SA still lags far behind the set targets (NPAES 2008).

2.4.3 Protected areas categories covered

There are approximately 500 PAs in SA, which include private (private nature reserves and game ranches) and state land (national parks, provincial nature reserves, world heritage sites), etc. (DEAT 2003), but only 26 (approximately 6%) have been involved in valuation. Although this is a good attempt, there is a need for more valuation studies to focus on biodiversity and ES conserved in PAs, to ensure that they are reflected in national accounting in line with the CBD`s objectives and to assist in their integration in decision-making (MA 2005; Daily et al. 2009; CBD, 2010). More focus on national parks was expected, as they are of national importance. However, the focus of the 21 studies was mainly on 12 of the existing 21 national PAs (SANParks, 2010). It is therefore highly recommended for the remaining nine PAs to be exposed to valuation studies as well, as valuation for biodiversity could be used to provide arguments against conflicting land use, such as mining (TEEB 2010).

2.4.4 Ecosystem services covered

Although a number of ES underwent valuation, special preference was shown for use-values, while little attention was paid to non-use values; this was also a finding elsewhere (Daily et al. 2009; TEEB 2010). Despite the shortcomings mentioned above, the review revealed that almost all ES categories (MA 2005) represented in SA`s PAs underwent a valuation process.

For cultural ES to have topped the ranking in the valuation studies are good news, since strong emphasis has only been placed on this category recently (MA 2005). More valuation studies on recreation and tourism than any other ES under the cultural ES category correlates with other findings (de Groot et al. 2012; Milcu et al. 2013). Provisioning ES came second, with at least seven studies undertaking valuation of these ES, involving commodities such as water, grazing, honey, fuel wood, timber, medicinal plants and fish. This finding is in close correlation with the results of de Groot et al. (2012), where the provisioning category had the second most studied ES. Although provisioning came second in terms of valuation studies under review, more studies were expected, as this category encompasses valuable direct, tangible benefits to people (MA 2005). Fewer valuation studies conducted on water was also a finding elsewhere (DEA 2012). This, however, was in contrast with the results of de Groot et al. and Brander et al. (2013), who identified water as the most frequently studied service. Water is a valuable and scarce resource in SA (DEA 2012), thus more studies on it were expected, since more solutions and strategies, such as payment for ES (Bajracharya and Dahal 2008), could assist water conservation in SA.

Two studies focused on valuation of supporting services, involving pollination and biodiversity. Less attention paid to this context is in close correlation with other workers' findings (DEA 2012; de Groot et al. 2012). This is not entirely surprising, as it reflects the difficulties associated with capturing the value of these types of services (MA 2005; TEEB 2010), since they are not commonly traded in formal markets (MA 2005; Daily et al. 2009).

The regulating category of ES was studied less; only one study was found through the search. ES involved in valuation in this category were carbon sequestration and restoration. Other regulating ES, such as air quality and carbon storage, received no attention. Fewer valuation studies on regulating services were also found by Costanza et al. (2006) in a study involving New Jersey`s natural capital. However, this category of ES was the second most studied in another study (de Groot et al. 2012). Despite the recent assignment of economic value to this type of ES, the occurrence of fewer studies on these ES could be attributed to the fact that they remain invisible in society`s daily accounts (TEEB 2010). Fewer studies on regulating ES indicate a serious shortcoming, since the issue of carbon storage and sequestration is prominent in SA, given its association with climate change (MA 2005; DEA 2010). It is also concerning that PAs are not taking the lead in the valuation of regulating ES, since these are vital for climate change adaptation to sustain ecological processes (NPAES 2008; Stolton et al. 2010).

Another value that received some attention was existence value. At least four studies that were reviewed conducted valuation of the existence value of PAs and/or biodiversity (Turpie 2003; Saayman et al. 2009a; 2009b; Dikgang and Muchapondwa 2012). Attention paid to this matter indicates that societies are conscious of the value attached to PAs in terms of their continued existence for the benefit of present and future generations (Bajracharya and Dahal 2008; Stolton et al. 2010).

2.4.5 Methods of valuation used

Generally, over-emphasis on the use of the individual TEV methodologies was noticed. Although TEV methods have the ability to assess some non-use benefits, they concentrate mainly on the economic values of single services. This kind of assessment was also done elsewhere (TEEB 2010). Furthermore, economic valuation was found to be the most commonly used approach elsewhere (de Groot et al. 2012). In view of the need to include ES in decision-making, including ES provided by PAs, an integrated approach is recommended as one of the best strategies (Daily et al. 2009) to achieve this need. Although a wide range of techniques was applied by studies in this review, there is a major shortcoming in the use of approaches that are incapable of valuing ES holistically, especially in biophysical and socio-cultural terms (Daily et al. 2009; TEEB 2010). The inclusion of both direct use and indirect use values is crucial in illustrating the relationship between human well-being and ES (TEEB 2010).

2.4.6 Reference source type

Notwithstanding the effort put into the studies under review and regardless of their different purposes, more work still needs to be done. In terms of the published articles, the 14 studies reviewed did not cover all the services and the important habitats of PAs in SA, and this is a serious shortcoming. The number of published articles indicates that ES is still a new concept and not yet fully developed in SA. Given the importance of incorporating natural assets into national accounting (CBD 2010), and the challenges associated with land use decision-making for economic growth (Lopoukhine et al. 2012), more studies are needed on the values provided by PAs to inform land use decision-making.

2.5 CONCLUSIONS

SA has shown progress in attempting to value ES, but more work still needs to be done. Some of the research gaps highlighted by this study include (1) inadequate geographic coverage, since two of the major biomes have been omitted, (2) inadequate information on regulating services, (3) no information on supporting services, (4) overlooking spiritual and amenity services in the cultural category, and (5) inadequate representation of different goods and services under the provisioning category. In terms of valuation methods, it has been noted that despite better representation of various methodologies by the studies, less emphasis was put on the integrated category, which is crucial in realizing the MA`s (2005) vision of integrating ES in decision-making.

Furthermore, the review identified lack of valuable estimates of the overall value of ES generated in PAs. Until the total value of PAs can be reflected in an integrated way, thus reflecting their importance and contribution to the country`s economy, challenges will continue to exist in justifying their existence in the current economic growth-orientated period. The shortcomings highlighted above reflect gaps in alignment with the CBD`s Aichi targets and its sustainable development principles, which are mandatory for all signatory countries, thus calling for more research to bridge this gap. Since PAs are national assets and valuation of ES requires considerable investment in time and money, this calls for national allocation of funds and sponsorships to support valuation of ES in PAs.

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CHAPTER 3

LAND USE CHANGE SCENARIOS FOR TWO BIOSPHERE RESERVES IN SOUTH AFRICA

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ABSTRACT

Conflicting visions on conservation and development goals are a common challenge facing land use planners in and around protected areas. The biosphere reserve concept is designed to include local stakeholders' interests in decision-making to achieve sustainable development goals. This study applied a participatory scenario planning process in Vhembe Biosphere Reserve (VBR) and Waterberg Biosphere Reserve (WBR) in South Africa, to assess the effects of changes in land use on biodiversity conservation and ecosystem services (ES). We looked at three different development scenarios, namely ecological, social and economic. Drivers of land use change were diverse and affected biodiversity and ES in a number of ways. There were always trade-offs in the choice of land use. Under the ecological development scenario, land use change impacted on biodiversity and ES positively as a result of the expansion of conservation areas (CAs) by 40% in WBR and 30% in VBR whereas agricultural ES decreased by 2% in WBR and <1% in VBR. Under the economic development scenario at least 20% of the land could be lost to mining in both biosphere reserves leading to loss of biodiversity and ES. In the social development scenario, biodiversity and ES in 20% of the conservation area and 3% of agricultural land could be affected negatively in WBR as a consequence of the land restitution program. In sharp contrast, negative impacts to biodiversity and ES in 25% of the CAs and ES in 30% of agricultural land could result from the land restitution program in VBR. Yields of ES in the ecological development scenario were likely to be much higher than in both the social and economic development scenarios. The main driving force in all three scenarios was economic growth.

Key words: biosphere reserve; ecosystem services; land reform; land use; protected area; scenario planning; sustainable development.

3.1 INTRODUCTION

Biodiversity loss is a major ecological crisis globally and has accelerated massively in response to human actions (Rockström et al. 2009). The causes of biodiversity loss include transformation of land use to agriculture and invasion of alien vegetation leading to habitat loss and degradation (Hooke et al. 2012; Dar et al. 2015). Habitat loss is regarded as the greatest threat to biodiversity and may lead to species extinction (MA 2005). Habitat degradation causes a decline in ES (MA 2005). ES are benefits that people derive from ecosystems. The Millenium Ecosystem Assessment (MA), (2005) organizes ES into four categories: provisioning (e.g., food, water, raw materials, medicinal plants), regulating (climate regulating, natural disaster regulating, disease regulating), cultural (recreation, spiritual value, cultural heritage, aesthetic quality) and supporting (primary production, soil formation). Besides the MA`s (2005) ES typology, a number of ES classification systems has been developed and the research on ES is ongoing (Haines-Young and Potschin 2013; TEEB 2010).

Establishment of conservation areas (CAs) is one of the strategies for combating the loss of biodiversity and ES. To achieve this, the International Union for the Conservation of Nature (IUCN) established a system of protected areas (PAs) (Dudley 2008). In view of the magnitude of biodiversity loss and the rate at which it is progressing, PAs alone are inadequate for the conservation of biodiversity (Kuntonen van`t Riet 2007). Some of the factors that hamper PAs' effectiveness are conflicting economic development and conservation visions that result in degradation of land and the rapid transformation of land use around PAs (Naughton-Treves et al. 2005; Palomo et al. 2011). There is therefore a need to look at complementary strategies such as biosphere reserves (BRs) for conserving biodiversity.

BRs are social-ecological systems established to reconcile conservation, economic and social development goals while improving the relationship between man and the environment (UNESCO 2010). The concept of BRs was formally established in UNESCO's Man and Biosphere program (MAB) in 1973. Each BR consists of three zones, namely the core, buffer and transition zones. The core consists of protected sites to conserve biological diversity, represented mainly by formally registered PAs. The buffer zone surrounds the core area and is used for activities compatible with sound ecological practices. Finally, the transition zone contains a variety of developmental activities, which includes agriculture, settlements and other uses (UNESCO 2010).

Despite their potential benefits, BRs are facing major challenges. There is a discrepancy between the goals of a BR and the legislation on conservation and sustainable development which hampers the successful implementation of the BR concept (UNESCO 2010). Although the MAB program sought to reconcile conservation with development, with the aim of achieving sustainable development, the achievement of this aim is often crippled by the perception that humans are harmful to the environment (Bosak 2008). This kind of incoherence often leads to top down approaches which ignore local knowledge (Bosak 2008). Harmonization of the relationship between humans and nature may help to promote the BR`s aim of sustainable development. However, striking a balance to achieve development and conservation land use goals in socio-ecological systems has proven to be a challenge (Palomo et al. 2011) and it is uncertain how changes in land use will affect biodiversity conservation and the provisioning of ES. Scenario planning has been applied to address some of these challenges (Palomo et al. 2011; Schwenker and Wulf 2013).

Scenario planning was developed during the twentieth century (Borjeson et al. 2006; Kishita et al. 2016). Scenarios are used to describe a plausible or anticipated future state or trajectory (Rawluk and Godber 211; Schwenker and Wulf 2013; Beach and Clark 2015; Kishita et al. 2016). Scenarios are multi-purpose and powerful approaches for decision-making (Borjeson et al. 2006; Beach and Clark 2015). They are used to address complexity and uncertainty (Priess and Hauck 2014) and to analyse drivers of change (Wollenberg et al. 2000). They can be used to facilitate stakeholders' understanding, communication and networking of ideas regarding different issues and to provide guidance in the policy arena (Wulf et al. 2010; Oteros-Rozas et al. 2015).

There are many methods and approaches to scenario planning (Wollenberg et al. 2000; Priess and Hauck 2014; Kishita et al. 2016). Scenarios may be grouped according to purpose or methodological approach (Dettinger et al. 2012; Oteros-Rozas et al. 2015). Scenario planning methods could be expert-led, exploratory, anticipatory or participatory and involve different forms of stakeholders` inputs (Rawluk and Godber 2011; Palomo et al. 2011; Dettinger et al. 2012; Oteros-Rozas et al. 2015; Kishita et al. 2016). Scenario analysis may also be qualitative or quantitative.

Scenario planning has been applied widely in social-ecological systems for land use planning and to explore potential future developments and the impacts of climate and land use changes on biodiversity and ES (Palomo et al. 2011; Beach and Clark 2015; Carpenter et al. 2015, Catano et al. 2015; Oteros-Rozas et al. 2015). Scenarios are applicable at different geographical scales, and have been very useful for global initiatives such as the millennium ecosystem assessment and the intergovernmental platform on biodiversity and ES. Our study applied a participatory planning approach as described in Wollenberg et al. (2000) to develop three future scenarios. Our objective was to evaluate the effects of land use changes in response to different drivers of change and management strategies on biodiversity conservation and ES.

3.2 MATERIALS AND METHODS

3.2.1 STUDY AREAS

Waterberg Biosphere Reserve (WBR) is the first savannah BR in SA and was proclaimed in 2001. It is situated in the Waterberg district of Limpopo Province. It covers an area of 654 033 ha and includes a national park and six declared nature reserves (WBR 2012). The extent of the core zone is 121 249 ha, consisting of government-owned land. The buffer zone consists of 146 157 ha of privately owned land. Agricultural land use has changed over the last 30 years from crop and cattle farming to game farming (De Klerk 2003; WBR 2012). Mining occurs within the WBR, but on a small scale, mainly on the periphery of the transition zone of the BR (De Klerk 2003; WBR 2012).

Vhembe Biosphere Reserve (VBR) became SA's sixth BR in June 2009. It includes two national parks, several nature reserves, the Soutpansberg and Blouberg biodiversity hotspots, as well as the Makgabeng Plateau (Dombo et al. 20006). It covers an area of 3 070 000 ha, including its 460 000 ha core area, a 357 500 ha buffer zone and a 225 260 ha transition zone. Current land uses include crop and cattle farming (Dombo et al. 2006). Game farming and the hunting industry have expanded rapidly over the past two decades (Dombo et al. 2006). Mining also takes place at several sites around the VBR area (Dombo et al. 2006). Fig. 3.1 shows the location of the study areas.

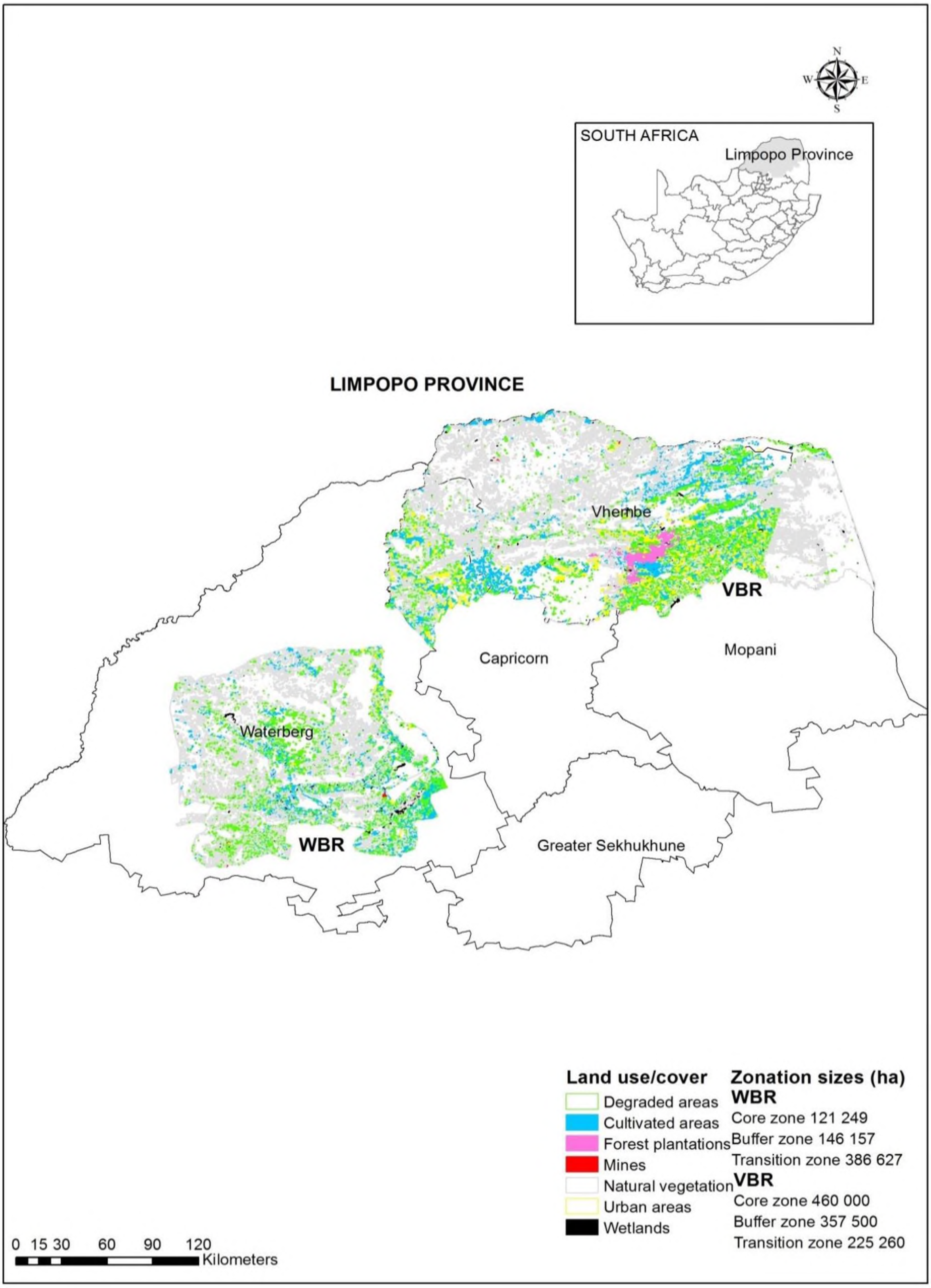

Figure 3.1 Map of Limpopo Province of South Africa, showing the five district municipalities (Waterberg, Vhembe, Greater Sekhukhune, Capricorn and Mopani) and the location of the Waterberg Biosphere Reserve (WBR) and Vhembe Biosphere Reserve (VBR) study areas, as well as sizes of each biosphere`s three zones (core, buffer and transition).

3.2.2 SCENARIO PLANNING PROCESS

This study applied a four-stage scenario-based approach as described in Wollenberg et al. (2000). The four stages applied for scenario analysis were: (1) definition of the purpose of the scenarios; (2) information about a system's structure and major drivers of change; (3) generation of the scenarios and (4) implications of the scenarios.

3.2.2.1 Definition of the purpose of the scenarios

The purpose of the scenarios was to identify and assess land use decision options and their assumed impacts on biodiversity and ES in response to different drivers of change and uncertainties which include among others government policies, climate change and economic development needs in line with the BRs' visions.

3.2.2.2 The system's structure and major drivers of change

Both BRs had established stakeholders' engagement platforms through park forums and BRs stakeholders meetings. We decided to refer to both platforms as issues that were often discussed on both sides were similar especially those regarding land use. The BRs' stakeholders' lists were compiled from landowners' registers, nature conservancies as well as the membership of national park forums (NPF) falling within the borders of the BRs and kept by the secretariat in the BR committee. The VBR had over 100 registered stakeholders and the WBR had 80 stakeholders. The percentages of representation were calculated based on 80 stakeholders for the WBR and 100 stakeholders for the VBR. The first stakeholder engagement process considered for the purpose of this analysis was held in 2010 in WBR and 2011 in VBR. During these meetings, stakeholders raised and deliberated different land use issues, drivers of change as well future plans in line with the desired BRs' visions. Fourteen stakeholders attended the meeting held in 2010 and 10 attended the meeting held in 2011.

The second process involved face-to-face interviews of stakeholders. Sixteen stakeholders were interviewed. Of the stakeholders who were interviewed, 10 were from the WBR, representing 13% of the BR`s stakeholders and six stakeholders, representing 6% were from the VBR's stakeholders (Table 1). Face-to-face interviews were followed by a questionnaire survey sent by email to key stakeholders. Eight stakeholders responded to the questionnaires.

Of these respondents, five were from the WBR (representing 6% of the stakeholders) and three stakeholders (representing 3%) were from the VBR. A follow-up telephonic interview was conducted, in an attempt to reach stakeholders who had not responded to the questionnaires nor taken part in the one-on-one interviews. Seventeen of them responded. Nine (11,25% of stakeholders) represented the WBR and eight (representing 8% of stakeholders) were from the VBR. In the end a total of 47 stakeholders participated in the interviews and surveys in both BRs (Table 3.1).

Table 3.1 Main stakeholders who participated in the study

Stakeholder group	Meeting participation		Face-to face interview		Questionnaire survey		Telephonic interview	
	VBR	WBR	VBR	WBR	VBR	WBR	VBR	WBR
National park forums	2	4		2		1	2	
Department of Environmental Affairs	1	1					4	
Nature conservancies		2	1	1	1		1	3
Agricultural Union		1						2
Biosphere reserve private landowners	5	8	4	1	1	2	4	
Local municipalities		3		2				2
Independent ecologists		1		1		2		
Biosphere reserves		2		1			1	
National parks	2	6	1	2	1		1	
Mining companies x3 (focus area: iron ore in WBR and coal in VBR)							1	2
Total	10	28	6	10	3	5	14	9

Data collected through all stakeholders' engagement processes were organized into drivers of change and uncertainties as in Rawluk and Godber (2011). For the purpose of this analysis, uncertainties included land use and policy environment as it was not certain how they will develop in future in response to different drivers of change. Stakeholders identified 12 drivers of change and six different kinds of land uses. Government policies that were identified as having a potential of contributing to land use tenure include the National Protected Areas Strategy, land reform program and economic development policies. Stakeholders were not familiar with the concept of ES, unpacking of this concept enhanced their understanding. At the end, four provisioning services, three regulating services and one cultural service were identified. We also requested stakeholders' inputs on trends on land use (Table 3.2).

Table 3.2 Stakeholders' views on trends in land use changes and their associated drivers. Both land use changes and drivers are listed in decreasing order of importance.

Past	Current	Future	Drivers of change
Cattle farming	Conservation	Conservation	Economic growth
Crop farming	Game farming	Ecotourism	Government policies
Game farming	Crop farming	Game farming	Climate change
Conservation	Cattle farming	Crop farming	Institutional arrangements
Tourism	Tourism	Mining	Technology
Mining	Mining	Cattle farming	Population growth

Information received from stakeholders regarding ES are presented on Table 3.3.

Past trends were back casted for a period of 30 years from 2010. The current period was taken as 2009-2010.

Table 3.3 Stakeholders' views on trends in the supply of ecosystem services and their major drivers. For a given ecosystem services, drivers are listed in decreasing order of importance.

Ecosystem service	Past	Current	Future	Driver of change
Agricultural crops (food provisioning)	Dominant	Decreased	Decreased	Climate change Land restitution Institutional arrangement
Ecotourism (cultural services)	Not popular	Increased	Dominant	Economic growth Climate change Land use change
Wild plant products	Abundant	Decreased	Decreased	Land use change Unsustainable utilization Population growth Climate change
Livestock products	Abundant	Decreased	Declined	Land use change Climate change
Water provisioning	Abundant	Scarce	Scarce	Population growth Climate change Pollution Unsustainable utilization
Air regulation	Well- functioning	Reduced	Declined	Industrialization (pollution) Climate change Deforestation
Regulation by wetlands	Well-functioning	Reduced	Declined	Agriculture Urbanization Climate change Industrialization
Regulation by forests	Well-functioning	Reduced	Declined	Agriculture Urbanization Climate change Industrialization Economic development

3.2.2.3 Generation of the scenarios

According to Wollenberg et al. (2000), scenarios can be based on the comparison of desirable and undesirable situations. Uncertainty data were further coded into three contrasting themes of a BR`s sustainable development, namely ecological, economic and social. Based on these themes, we generated three scenarios: ecological development, economic development and social development within a time frame of 30 years from 2010 (Fig. 3.2).

The ecological development scenario was driven by the SA government`s Protected Areas Expansion Strategy (NPAES) of 2008, and focused mainly on conservation area expansion. This strategy aimed at addressing the shortfall to conserve biodiversity and ecological processes effectively through the current PAs (NPAES 2008). The NPAES (2008) seeks to increase PAs by 8.8% (10.8 million ha), adding to the current conserved areas of 7.9 millon ha to reach the targeted 12% by 2030. The expansion target set for Limpopo Province is 5.5%, representing 687 000 ha, to be achieved in 2030.

The economic development scenario involved mainly mining developments, driven by economic needs. This scenario was mainly driven by government`s job creation and economic growth objectives. South Africa's Economic Policy and Growth Strategy (Manuel 2007), recognized mining as one of the sectors with potential to boost the economy. The Minerals and Mining Policy White Paper for South Africa (1998) also identified mineral beneficiation as one of the priority growth nodes for job creation to achieve a target of 5 million jobs by 2020.

The social development scenario was mainly driven by the SA Government`s land reform program. This program is embedded in the SA`s Land Affairs White Paper of 1997`s land policy aiming at redistributing at least 30% of agricultural land to poor and previously disadvantaged people by 2014. The program consists of three sub-programs: (1) land tenure, strengthens the security of tenure of farm dwellers living on commercial farms, (2) land redistribution, which focuses on giving previously disadvantaged people the opportunity to own land through settlement and acquisition grants and (3) land restitution, which aims to return land or compensate victims unfairly dispossessed of their land after SA's 1913 Land Act.

3.2.2.4 Implications of the scenarios and use by decision-makers

The final step outlined by Wollenberg et al. (2000) involves analyzing the implications of the scenarios to decision-making. In WBR, the generated preliminary scenarios were presented orally and in maps in a meeting held in 2012, attended by 14 stakeholders (Table 3.1). Maps were produced using GIS ArcMap program (ESRI 2013). Lack of opportunity to hold a meeting in VBR led to telephonic discussion of the scenarios in 2013 with six stakeholders (Table 3.1). Based on the information that was received from both BRs, generally, the economic development scenario was influencing land owners to enter into stewardship programme as a way to counteract on mining. Tourism opportunities presented by the ecological development scenario motivated decision making into partnership with large CAs for various tourism activities in both BRs. The social development scenario was crucial in assisting stakeholders to rethink their approaches to land restitution and find ways to make it work in both BRs.

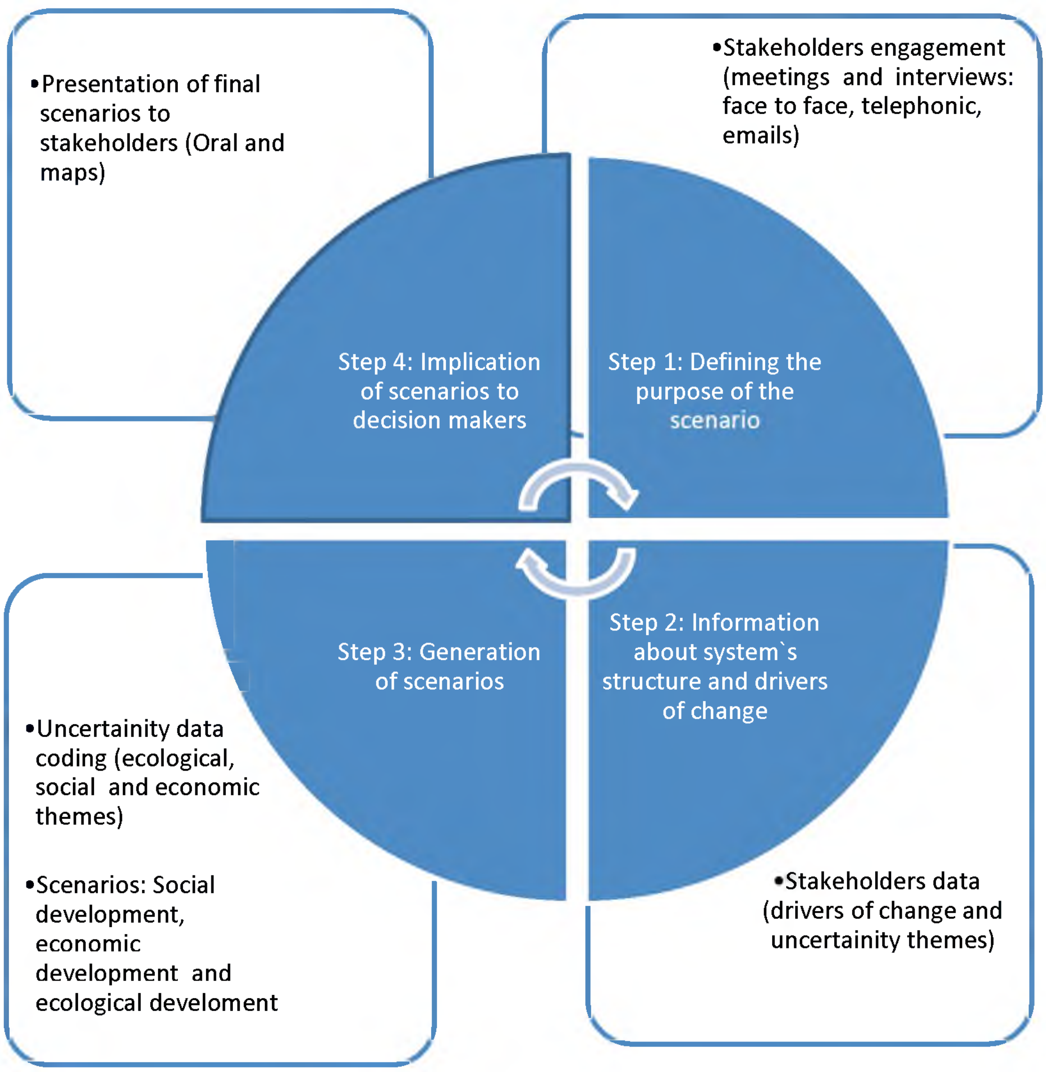

Figure. 3.2 Scenario planning development framework outlining activities undertaken in each stage of the scenario development process.

3.3 RESULTS

3.3.1 Ecological development scenario

The outcome of this scenario showed that 90% of the 38 stakeholders who were interviewed indicated that CAs have the potential to expand in future, because of the current shift of land use in favor of ecotourism, with 10% seeing it as a solution to prevent mining development, since it is prohibited within PAs, according to the National Environmental Management Act (NEM:PAA 2003). For this reason, most of the private landowners practicing conservation are in the process of entering a stewardship program or contractual agreements as a way of saving their lands from the mining invasion, thus increasing the core area's size.

As a result of the planned CAs expansion, the core zone of the WBR will grow by 40% from its current size of 104 179 ha. Contributing to the growth is the inclusion of the CAs currently in the buffer zone, which are in the process of acquiring PA status. The core, Marakele National Park (MRNP), will contribute to this growth by 100 000 ha following its expansion strategy. In VBR, the expansion plan includes the integration of 33 000 ha of fragmented land of Mapungubwe National Park, the inclusion of a private nature reserve of 36 000 ha and the privately owned land centrally located in the core area, as well as the biodiversity hotspot of the Soutpansberg Mountains (Fig. 3.3). The planned expansion will add over 150 000 ha (30%) to the existing core area, thus contributing positively to the conservation of biodiversity and ES. In WBR, approximately 2 000 ha (2%) of agricultural land could be lost due to conservation area expansion, while in VBR, less than 500 ha (<1%) of agricultural area could be lost as a result of this development. Fig. 3.3 also presents the state of agriculture and CAs under the ecological development scenario.

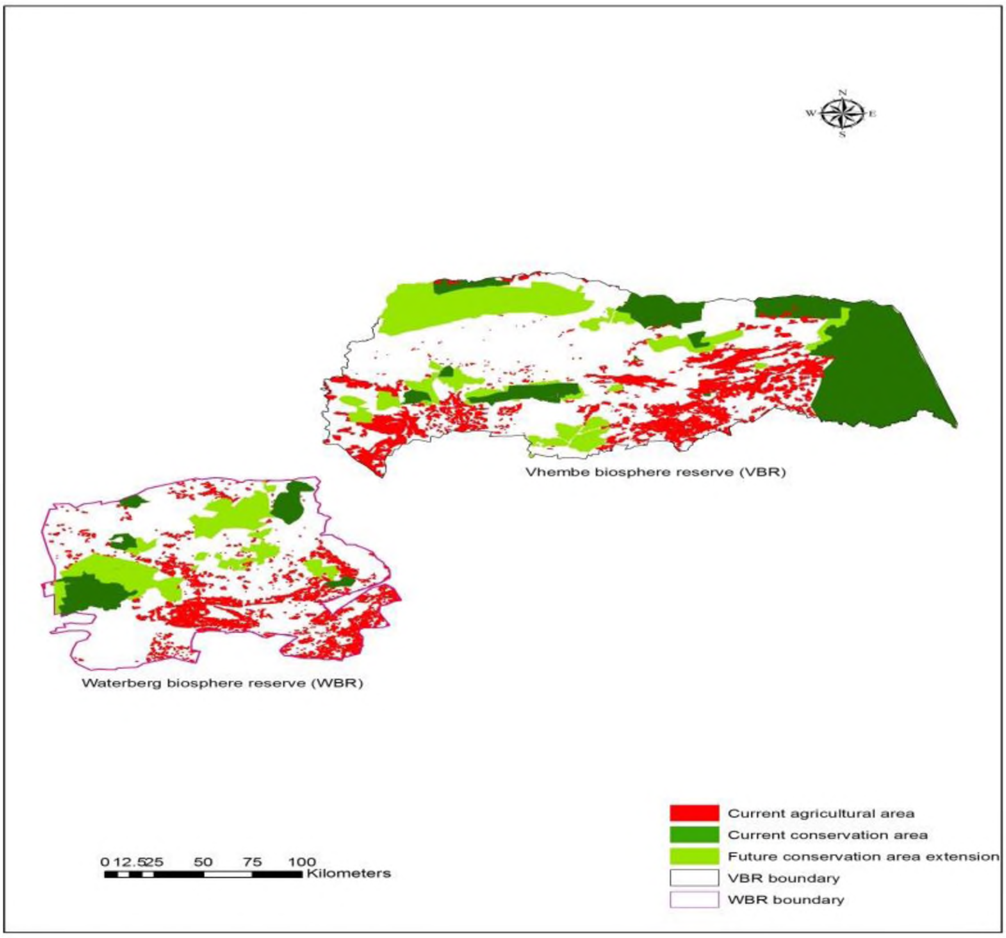

Figure 3.3 An illustration of the ecological development scenario, showing interactions between conservation (current and future conservation area extension) and agriculture (current) in the VBR and WBR study areas.

3.3.2 Economic development scenario

According to 80% of the 38 stakeholders interviewed, mining development is seen as the potential future land use after conservation. This conclusion took into consideration the recorded mining prospecting rights granted by the relevant authority in the study areas. In VBR, the core, buffer and transition zones are expected to be affected by coal mining; over 600 000 ha (20%) could be lost in this regard. In WBR, the core area (MRNP) and surrounding areas are under threat of mining development, amounting to 25 528 ha, of which 11 784 ha will be inside the park. Reduction in core areas might impact negatively on the conservation of biodiversity and ES. Meanwhile, more prospecting applications affecting more than 40 properties, over 100 000 ha, were received in this BR during 2010 to 2012, bringing the total area under threat of mining developments to about 140 000 ha (20%). Fig. 3.4 shows changes in land use under the economic development scenario.

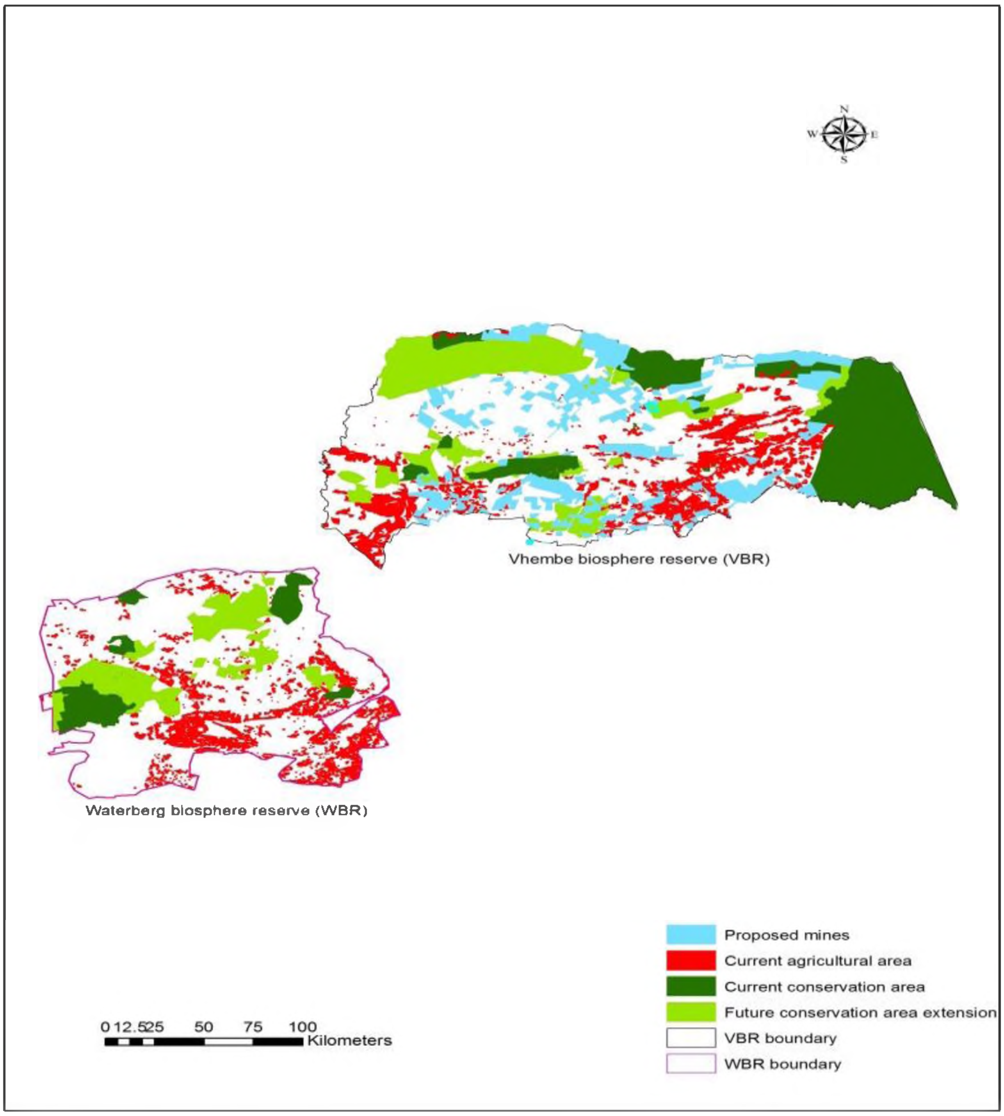

Figure 3.4 An illustration of the economic development scenario, showing interactions between proposed mining developments, conservation (current and future conservation area extension) and agriculture (current) in the VBR and WBR study areas.

3.3.3 Social development scenario

The outcome of this scenario indicated that 20% of the 38 stakeholders interviewed identified land restitution as the major driver of land use change in future, compared to the other two processes of land reform. At least 60% of the stakeholders identified it as a threat to agricultural ES and 30% saw it as an economic driver through ecotourism, while 10% saw it as threatening biodiversity conservation. In WBR, claims for at least 102 168 ha of land under restitution have been gazetted and claims for 39 625 ha are expected to be gazetted in future and settled within the next 30 years. This will bring about an increase from the current settled claims of approximately 17 544 ha, from the five major claims lodged with the land claims commissioner. The total loss of CAs (core and buffer) to land claims in this context is at least 45 146 ha (20%) and at least 6 045 ha (3%) of agricultural land is involved with assumed negative impacts on biodiversity and ES.

In VBR, about 114 976 ha are expected to be claimed and the claims are expected to be resolved within the next 30 years, adding to the current settled (12 671 ha) and gazetted (817 776 ha) sections totaling an area of 830 447 ha. About 113 814 ha (25%) of the 830 447 ha will have a negative impact on biodiversity conservation, while 62 267 ha (30%) will affect agricultural ES negatively with highly productive areas being lost. Land restitution might negatively affect biodiversity conservation and the provisioning of agricultural ES. The mining sector will also be affected negatively by at least 2 828 ha being lost as a result of land restitution. Figure 3.5 shows land use change under the social development scenario.

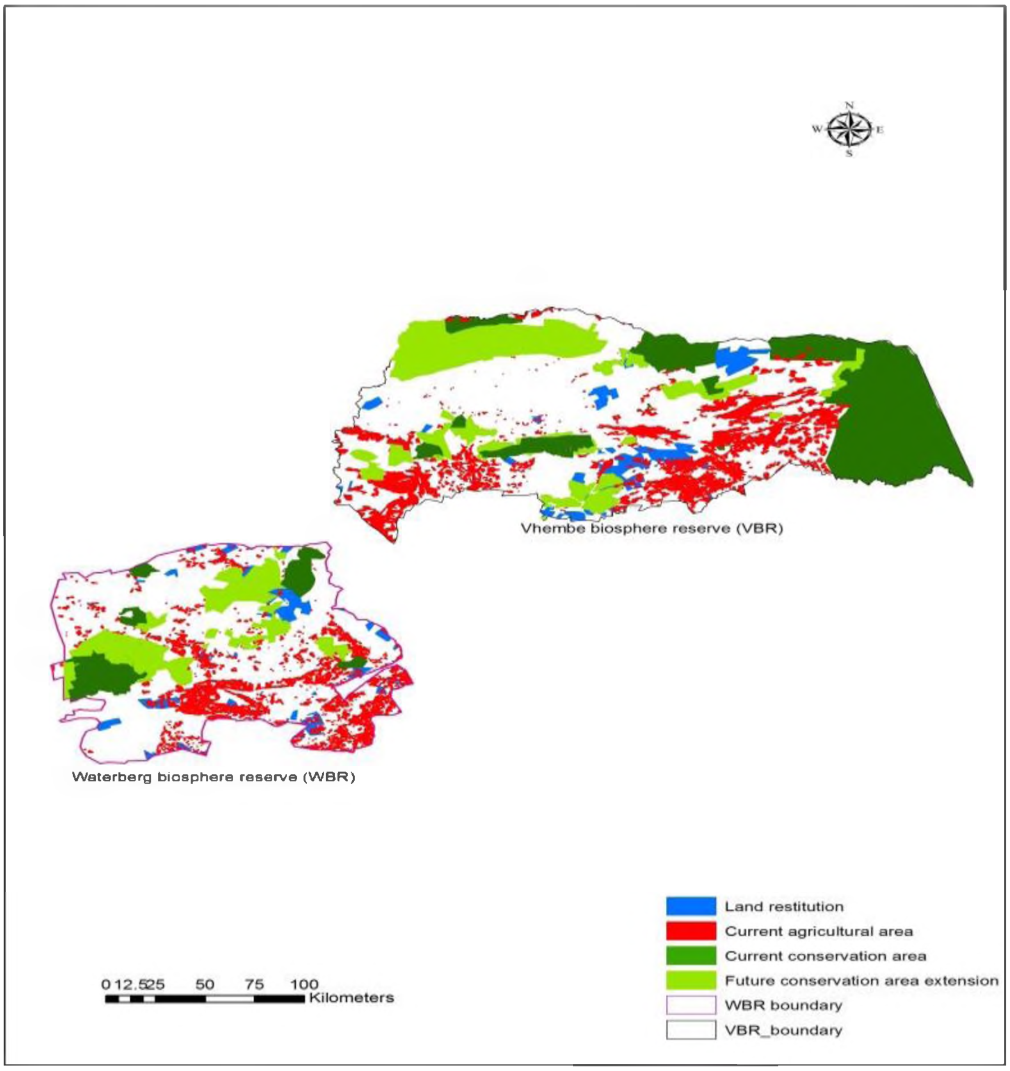

Figure 3.5 An illustration of the social development scenario, showing interactions between land restitution, conservation (current and future conservation area extension) and agriculture (current) in the VBR and WBR study areas.

3.4 DISCUSSION

3.4.1 Ecological development scenario

The core and buffer zones of both BRs will grow as a result of conservation area expansion. The consequence of the growth of core and buffer zones is the expansion of PA systems thus contributing to biodiversity conservation. Animal species with large home ranges such as elephants will thrive well under this scenario. Conservation area expansion will also contribute to the diversity in plant species, resulting in diversity of animal species. Consequent to the expansion, the production of ES is likely to be higher, with substantial opportunities for recreational activities, biodiversity conservation, an increased carbon pool, and improved water quality (Nelson et. al. 2009; Power 2010). Nature-based tourism is an important source of income around the world (Köberl et al. 2016) and contributes approximately 10% to SA`s GDP (WTCC 2013). The region is therefore likely to experience economic growth and employment opportunities in response to increased tourism. As more PAs are added, more sustainable use of ES is expected. Since PAs are controlled legally, it is assumed that legal protection of habitats will mitigate the impact of threats to biodiversity and ES (Tallis et al. 2011).

As a trade-off, the consequences of increased tourism among others is reduced water quality and quantity, thus impacting negatively on water dependent biodiversity and ES (Ying 2015; Sonya 2015; Sanyanunthana and Benabdelhafid 2016) as more natural areas create opportunities for bringing more tourists into the area, resulting in a high demand for water resources and energy. Tourism has also been found to adversely affect biodiversity through wildlife mortality (Pickering et al. 2003), mainly due to road kills as a result of speeding and driving at night (*Ntshane, B.C. Personal observ.*). Increased tourism has also been associated with a decline in composition and abundance of native species (Tolvanen and Kangas 2016). Tourism has been found to contribute negatively to biodiversity through the spread of alien species (Tolvanen and Kangas 2016) as the development of tourism roads creates corridors for the dispersal of alien vegetation. For example, Dar et al. (2015) found that most alien species were thriving well along the roadsides.

Information presented by stakeholders suggested that at least 3% of agricultural areas could be lost as a result of conservation area expansion (Fig. 3.3). Agriculture alone accounts for 70-85% of global water use (Foley et al. 2005; Power 2010). Replacement of agricultural areas by conservation would mean an improvement in water quality and quantity with positive impact on biodiversity conservation as reported by Nelson et al. (2009). Agricultural practices also affect biodiversity through emissions of pollutants into water resources and reduced water quantity through irrigation, withdrawals and diversion (Foley et al. 2005). As a trade-off, a change in land use from agriculture to nature conservation will reduce the production of agricultural ES such as food crops, fibre, forage, fuel and soil carbon among others (Power 2010).

3.4.2 Economic development scenario

The results presented by this scenario assume that more mining development will take place in future, especially in the buffer and transition zones of the BRs. Generally, the implications of this scenario include densification and expansion of mining in the BR (Fig. 3.4). The main problem associated with mining is the likelihood of biodiversity loss in the core areas. The most obvious contributor to biodiversity loss in this context is the clearing of vegetation (Alvarez-Berríos and Aide 2015) resulting in habitat loss ultimately leading to species extinction (Scholes and Biggs 2004). Another consequence of the clearing of vegetation could be a decrease in the provisioning of ES such as raw materials, medicinal plants, the carbon pool and regulation services for natural disasters such as floods and hurricanes (MA 2005). Mining has also been associated with pollution that has negative impacts on biodiversity and water provisioning service (Besser et al. 2009). Another consequence of mining development in the study areas is loss of agricultural land (Fig. 3.3). The loss of agricultural areas could be associated with competition for resources such as water and land (Ashton et al. 2001) and pollution of crops (Scholes and Biggs 2004). The consequence of loss in agricultural land is a reduction in agricultural ES (Power 2010). On a positive note, reduced agricultural areas due to mining could improve water regulation services; reduce habitat loss, sedimentation, biodiversity loss and greenhouse gas emissions among others (Power 2010).

IUCN (2011) found that mining is currently affecting at least 25% of PAs in Africa. This, together with more prospecting rights granted by the authorities of the Department of Mining and Energy (DME), is increasing fears that mining could overtake conservation within the BRs with increasing negative impacts on biodiversity and ES. Another concern is “gaps in legislation” related to mining in many countries (Kuntonen-van’t Riet 2007). None of the PAs in the study area is regulated by legislation containing clauses to allow mining operations. Although registered PAs are also protected by legislation, developing countries often seek to exploit mineral resources as a way of providing much-needed revenue (Alvarez-Berríos and Aide 2015; IUCN 2011). The intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development also recognizes the effect of mining on the environment (IGF 2010), hence the biodiversity offset program is meant to compensate for the impact of biodiversity loss (ICMM 2005). This program has failed to date (Kuntonen van`t Riet 2007), indicating that it might be time for the DME to employ other sustainable mining development strategies. On a positive note, drawing from the contributions made by mining in SA during

2010, which is 9% of total GDP (R230 billion) and 514 760 jobs, therefore, more mining development means economic growth in the region and more employment opportunities.

Mining in SA was managed by DME and conservation by the Department of Environmental Affairs (DEA). Concern about conflict between these two departments through their legislation was raised in a report by Kuntonen-van`t Riet (2007). This report indicates that since the DME currently "authorize[s] mining from an environmental perspective", conflict of interest is inevitable, since the DME is supposed to promote mining. To date the process of mining has involved application for a prospecting license from the DME; some applications have been granted without an ecological impact assessment and even granted in no-mining areas, i.e. PAs (*Ntshane, B.C. Personal observ*). This makes the application of NEMA (2008) regulations difficult and conflict between the two departments has emerged. According to NEMA (2008) prescripts, the DEA must authorize mining activities. Despite the recently gazetted Biodiversity Policy and Strategy on Buffer Zones for National Parks (2012) of the National Environmental Management: Protected Areas Act (NEM:PAA 2003), which aims to protect PAs by regulating mining developments in areas located 10 km from PAs, and NEMA (2008) prohibiting mining in PAs, mining prospecting rights are still granted within the buffer and core zones of these BRs. There are currently more than 20 prospecting license applications affecting the core and buffer zones in these BRs.

3.4.3 Social development scenario

The outcome of this scenario indicated that more than 20% of agricultural areas could be negatively affected by restitution (Fig. 3.5). Negative impacts on agricultural areas affect the provisioning of ES such as food crops, forage, fibre, fuel and genetic resources as well as the delivery of regulating services such as ground cover, soil carbon and water regulation (Power 2010). In SA, production of land under the redistribution program declined by 44% (de Villiers 2008) and the program has fallen short in reaching the set targets in terms of the hectares of land planned for redistribution (Greenberg 2010). On the other hand, some studies suggest that most of the restituted land under agricultural areas did not yield the expected results (Moabelo 2007). A decline in agricultural production associated with land restitution has also been reported (Holt-Jensen and Raagmaa 2010; Mafa et al. 2015). The decline in the productivity of land under land reform programs is associated with inadequate post-settlement financial support and skills enhancement (Manenzhe 2007; Moabelo 2007). Perhaps exploring opportunities for achieving this program's set targets through the expansion of CAs (NPAES 2008) could fast-track the achievement of the set target.

In the economic and ecological development scenarios, land restitution was found to have minimal impact in terms of land use. Literature suggests that co-management in PAs subject to land restitution, as promoted by this MOA, coupled with the alignment with NEM: PAA (2003) is proving to be a good management strategy (de Koning 2010; Weidemann 2011). This strategy, though, poses challenges: there are often conflicts between the management authority and the claimants regarding access to resources (Kepe et al. 2005). This mainly happens when ecotourism as a highly regarded option for land use does not yield the expected economic benefits for the claimants (Kepe et al. 2005).

3.5 CONCLUSIONS

Biodiversity and ES were threatened under the economic and social development scenarios in both BRs. The portion of the biodiversity conservation area that could be lost under these scenarios was 200 000 ha in VBR and 100 000 ha in WBR. Our results suggested that economic needs were an important driver of land use change in the three scenarios. Our results further showed potential synergies between the ecological development and social development scenarios and potential conflicts between the economic development and ecological as well as social development scenarios.

These results could be used to inform land use planning such as CAs expansion and land reform agenda. Given the importance of both conservation and economic development, BRs should aim at creating a balance between these to promote co-existence and sustainable development. Agriculture as a food production sector needs government support. The focus must be on striking a balance between agriculture and mining development, as both contribute positively to GDP and are more likely to occur in the same BR zone and may therefore compete for resources. For land reform to succeed in agricultural areas, beneficiaries of the land reform program need the necessary support from government.

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3.7 APPENDICES

3.7.1 Appendix 3A Sample questionnaire

Name:		Organisation:		
Issues	1-Highest	2. High	3. Low	4.Lowest
1. Current land use				
2. Land use 10 years ago				
3. Dominant land use 30 years from now				
4. What are the major drivers of land use change?				
5. What kind of land use is desirable?				
6. How can stakeholders influence sustainable land use?				
7. Impacts of land restitution/ claims on current and future land use				
8. Impacts of mining develop-ments on current and future land use				
9. Impacts of conservation				

on the current and future land use				
10. Impacts of agriculture on current and future land use				
11. What are ecosystem services?				
12. How can land use affect ecosystem services?				

CHAPTER 4

ECOSYSTEM SERVICES AND THEIR INDICATORS: IDENTIFICATION AND MAPPING

This chapter is intended for submission to the journal *Ecosystem Services as:*

Ntshane, B.C. and Gambiza, J. Ecosystem services and its indicators: identification and mapping

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Abstract

Ecosystem services (ES) have evolved as an important concept in natural resource management. The Millennium Ecosystem Assessment (MA) combined broad global expertise on the subject of ES, contextualising its linkages with human well-being, something that had been lacking in most studies. The vision of MA is a world in which natural assets are incorporated into decision-making. Spatial representation of the distribution of ES is critical for integrating ES into important decision-making such as land use planning. However, mapping the distribution of ES in a landscape can be constrained by lack of data. The overall aims of this study were: (1) to identify research gaps regarding mapping of ES in SA, and (2) to provide baseline data that will inform the inclusion of ES in land use planning, as well as raising awareness of the concept of ES in SA. The following objectives were addressed in order to achieve the study aims above: (1) reviewed studies that mapped ES in South Africa (SA), using a desktop study, (2) gave an overview of indicators of ES through the stakeholder engagement process, (3) gave a spatial ArcMap GIS representation of 15 indicators of ES (seven provisioning, two regulating, three cultural and three supporting), and two ES (one for provisioning and one for regulating) using existing datasets, and lastly (4) mapped three ES represented by nutrient retention, water yield and soil retention using Integrated Valuation of Ecosystem Services (InVEST) tools. InVEST is a modelling tool used to map, value and model ES using a global information system interface. The results of the review reveal that regulating ES were studied the most with supporting ES being studied the least.

Key words: Biosphere reserve; ecosystem service using; degradation; unsustainable; well-being; utilisation; land use; spatial

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4.1 INTRODUCTION

4.1.1 What are ecosystem services?

The concept of ecosystem services (ES) has gained importance in natural resource management and a great deal of research has been conducted on it (Costanza et al. 1997; Daily 1997; Binning 2001; de Groot et al. 2002; Kremen 2005; MA 2005; Brown et al 2007; Petter et al. 2013). Many definitions and classification structures concerning ES have been developed. In the work of Daily (1997), Binning et al. (2002) and Brown et al. (2007), definitions of ES distinguished between ecosystem goods and services, whereas the Millennium Ecosystem Assessment (MA 2005) and Costanza et al. (1997) grouped them together. For the purpose of this analysis, ES are defined as benefits people derive from ecosystems (MA 2005).

The difference in the definitions referred to above clearly depicts the ongoing debate about the core meaning of ES to people (Boyd and Banzhaf 2007; Wallace 2008; Costanza 2008; TEEB 2010). While it is important to realize that no single definition can be 'one size fits all', especially for complex systems such as ES, what is needed is a standard definition that will capture the complexity of ES generation and how these services translate to benefits that support human well-being (TEEB 2010), what Haines-Young and Potschin (2009) referred to as "definitional rigour". Notwithstanding the proposals by Haines and Young (2009) and TEEB (2010) highlighted above, this study adopted the MA`s (2005) definition, which refers to ES as benefits that are derived from ecosystems for human well-being. On top of the fact that it is clear and concise, the MA`s (2005) definition depicts the important relationship that exists between the human being (as the beneficiary) and the ecosystem (the provider of benefits). More definitions of ES are discussed in detail in the sections that follow.

4.1.1.1 *Ecosystem services as benefits*

Some ES studies differentiate services from benefits (Boyd and Banzhaf 2007; Fisher and Turner 2008), while others consider them to be the same (Costanza et al. 1997; Daily et al. 1997; MA 2005; Wallace 2007; Costanza 2008). According to Costanza et al. (1997), ES are the "benefits human populations derive, directly or indirectly, from ecosystem functions". Turner (2008) and Fisher et al. (2009), in Haines-Young and Potschin (2009), further argued that what the MA (2005) refers to as cultural ES are not services, but benefits contributed by ecosystems. However, these are very confusing arguments, since the MA`s (2005) typology consists of categories (provisioning, regulating, supporting and cultural) of ES (food, climate regulation, recreational, soil formation, etc.), and cultural ES are referred to as benefits of immaterial nature that people derive from ecosystems (MA 2005). For the purpose of this study, the MA`s (2005) definition, which refers to ES as benefits that humans obtain from ecosystems, supporting their survival and quality of life directly and indirectly (McAlpine and Wotton 2009; Harrington et al. 2010), will be adopted.

4.1.1.2 *Ecosystem services as processes*

It is also very important to distinguish ecological and ecosystem processes from functions and benefits, in the sense that for ecosystems to render a service, such as provisioning of clean drinking water, they have to depend on ecological processes, such as primary production or nutrient cycling (TEEB 2010). Ecosystem processes' definition is well articulated in Brown (2006), in which they are referred to as the "cycles and interactions among those abiotic and biotic components that produce ecosystem goods and services". Brown et al. (2006) further outline the connection that exists between ES and ecosystem processes; ES are defined as the specific results of those processes that directly either sustain or enhance human life.

However, other definitions (Daily et al. 1997; ESA 2000; de Groot et al. 2002) confuse ES with processes, conditions or capacity, which can be seen as a means to produce an end result. For example, Daily (1997) defines ES as the "conditions and processes through which natural ecosystems and the species that make them up sustain and fulfil human life." The Ecological Society of America (ESA) (2000) defines ES as "processes by which the environment produces resources that one often takes for granted", such as clean water, timber and habitat for fisheries and pollination of native and agricultural plants (ESA 2000). de Groot et al. (2002) define ES as "the capacity of natural processes and components to provide goods and services that satisfy human needs, directly or indirectly."

4.1.1.3 *Ecosystem services as functions*

Just like other definitions of ES discussed above, there is disagreement about the term ecosystem functions. Some see it as a synonym for processes (Wallace 2007). Another definition related to this is that of Jax (2005), who refers to functions as both processes and capabilities of an ecosystem to produce ES. Ecosystem functions are also referred to as the habitat, biological or system properties or processes of an ecosystem (Costanza et. al. 1997). TEEB (2010) refers to functions as a representation of the potential of an ecosystem to deliver services. Kremen (2005) defines ES as the set of ecosystem functions that is useful to humans. There seems to be a distinction between the processes and functions of an ecosystem, and hence for the purpose of this analysis, de Groot's definition, which refers to functions as "the capacity of natural processes and components to provide goods and services that satisfy human needs, directly or indirectly" (de Groot 1992; de Groot et al. 2002), will be adopted.

4.1.2 Classification of ecosystem services

Just like the definitions of ES, many methods of classification of goods and services have been proposed (Constanza et al. 1997; Daily 1997; Bastian and Schreiber 1999; MA 2005; Wilson and Hoehn 2006; Brown et al. 2007; Mertz et al. 2007; Costanza 2008; de Groot et al. 2010; CICES 2011), with numerous differences in the way ES are grouped and named (TEEB 2010; CICES 2011; Hermann et al. 2011). Appendix 4A presents details of five selected ES classification frameworks. These differences could be brought about by the complexity of the way in which ecosystems produce ES (Costanza 2008; TEEB 2010; CICES 2011; Hermann et al. 2011). This section highlights some of them.

Wilson and Hoehn (2006) and Mertz et al. (2007) divide ES into two main categories: (i) the provision of direct market goods or services such as timber, pulp and carbon; and (ii) the provision of non-market goods or services, which include biodiversity and habitats for plant and animal life. Daily et al. (1997) and Brown et al. (2007) distinguish between goods and services. Bastian and Schreiber (1999) and the recent common international classification of ecosystem services (CICES 2011) classify ES into three main categories. The CICES categories are provisioning, regulating and cultural and exclude what the MA (2005) refers to as supporting categories. This could be associated with the fact that supporting services are not seen as ES that provide benefits to people directly/indirectly, but underpin the production of other services (MA 2005). Bastian and Schreiber (1999) took a different approach, following the three dimensions of sustainability and classifying productive/provisioning services into economic, regulatory services into ecological and the cultural category of ES into social services (Bastian et al. 2012). Daily (1997), de Groot et al. (2010) and the MA (2005) group ES into four primary categories; however, some differences were noted. Following these typologies, de Groot`s category of regulating services includes some of the ES forming part of the supporting category in the MA`s typology, such as pollination and soil formation. Daily`s (1997) typology drops the supporting services category and introduces a different category called preservation of options, which caters for the so-called maintenance function. Moreover, in the work of Daily (1997), cultural services are called life-fulfilling functions and regulating series are called regeneration processes.

Costanza (2008) groups ES into five categories according to their spatial characteristics, while de Groot et al.'s (2002) category of regulation functions mixes what the MA (2005) separated into regulating and supporting services. DEFRA (2005) groups ES into six categories, mainly based on both their ecological and economic functions: purification and detoxification, cycling processes, regulation and stabilisation, habitat provision, regeneration, production and a life-fulfilling role. These classification methods have two categories in common: production/provisioning and regulating services. Stabilising and habitat functions seem to be related to the supporting services, following the MA`s (2005) approach, while the information function is more or less the same as the cultural services of the MA (2005). Recognition of different functions and processes of ecosystems and the contribution of each of these functions/processes to human life are also clear from the classification methods above. Although de Groot et al's (2010) typology also classified ES into four main categories, and three of them (provisioning, cultural and regulating) are similar to those of the MA (2005), the fourth one, called habitat services, only caters for what the MA (2005) calls supporting services to a small extent.

Despite the fact that the MA (2005) forms the focal point of many studies (Haines-Young and Potschin 2009; TEEB 2010; Hermann et al. 2011), including this one, its typology has been widely criticized for mixing ES with functions and ES with benefits, among others (Boyd and Banzhaf 2007; Wallace 2007, 2008; Fisher and Turner 2008; Costanza 2008; Fisher et al. 2009; Haines-Young and Potschin 2009). What also clearly supports these criticisms from one of the latest ES typologies (CICES 2011) and those of Wallace (2007) and Costanza (2008), is the dropping of the supporting role of ecosystems. Some refer to it as the means or the intermediate good (Boyd and Banzhaf 2007; Mäler et al. 2009; Hermann et al. 2011). What this development could mean is that while the roles of its components are known, this category does not necessarily need to be part of the actual classification of the final ES produced. Contrasting views on whether services have to be utilized by people (MA 2005) or not (Costanza 2008; Turner et al. 2008) also emerge from these typologies. Although it is quite clear that research on ES classification will keep evolving to address different contexts, it is important to note that it might be difficult to devises a typology that will fit all purposes. For the purpose of this analysis, the researcher used the MA's typology (2005), as it represents a simple and clear functional way of classifying ES, and moreover reflects better on the social, ecological and economic interactions. Appendix 4A presents selected ES typologies forming part of this review.

The MA (2005) combined broad global expertise in the subject of ES, and classified ES into four categories: supporting (nutrient cycling, soil formation and primary production); provisioning (food, fresh water, wood, fibre and fuel); regulating (climate regulation, flood regulation, disease regulation and water purification), and cultural (aesthetic, spiritual, educational and recreational). The MA approach places the human being in the central context, and has been applied widely ever since its formulation (Beaumont et al. 2006; Balvanera et al. 2006; Haines-Young and Potschin 2009; Nelson et al. 2009; Hermann et al. 2011). The integration of ES into decision-making has been highlighted as one of the key issues to address in the field of ES (MA 2005; Daily et al. 2009). International collaborations, such as the International Platform on Biodiversity and Ecosystem Services (IPBES), recognize the need for integrating values in the science of ecosystem services (Gómez-Baggethun et al. 2014). IPBES was established with the aim of strengthening the interfaces between science and policy for biodiversity and ecosystem services for human well-being, the conservation and sustainable use of biodiversity, as well as sustainable development (Díaz et al. 2015).

4.1.3 Mapping of ecosystem services

Spatial representation on the distribution of ES is critical for integrating ES into important decision-making (Petter et al. 2013), such as land use (LU) planning. However, mapping the distribution of ES in a landscape can be constrained by lack of data (Petter et al. 2013). There is a common understanding that LU decision-making with regard to supply and demand pertaining to ES could be best illustrated spatially (Crossman et al. 2013; Martínez-Harms and Balvanera 2015). The importance of integrating ES into LU planning has also been highlighted by other researchers (Chan et al. 2006; Egoh et al. 2008; Goldstein et al. 2012; Bateman et al. 2013; Sumarga and Hein 2013).

Mapping of ES has grown tremendously since the past decade (Costanza et al. 1997) and various studies have been undertaken on mapping of ES ever since at different scales for different purposes, which include the spatial illustration of supply and demand of ES (Raudsepp-Hearne et al. 2010; Schulp et al. 2012; Burkhard et al. 2012; Kroll et al. 2012. Other reasons for mapping ES were to assess spatial congruence and trade-offs, as well as to quantify biophysical values (Egoh et al. 2009; Nelson et al. 2009; Willemen et al. 2008; Deng et. al. 2011). A number of studies have mapped ES in South Africa (SA) (Rouget et al. 2004; Mills et al. 2005; Egoh et al. 2008); however, focus on the collection of spatial data on ES is limited. Moreover, more primary data are needed to map the demand and supply of the actual ES (Maes et al. 2012).

In this study we gave an overview of spatial representation of ES and indicators used to map ES in SA. Particularly, we: (1) reviewed studies that mapped ES in SA, (2) gave an overview of indicators of ES through a stakeholder engagement process, (3) gave a spatial representation of 15 indicators of ES (seven provisioning, two regulating, three cultural and three supporting), two ES (one for provisioning and one for regulating) using existing datasets, and lastly, (4) mapped three ES, two in the regulating category represented by nutrient retention and soil retention and one in the provisioning category represented by water yield using Integrated Valuation of Ecosystem Services (InVEST) tools. The overall aims of this study were: (1) to identify research gaps regarding mapping of ES in SA, and (2) to provide baseline data that will inform the inclusion of ES in LU planning, as well as raising awareness of the concept of ES in SA.

4.2 MATERIALS AND METHODS

4.2.1 Study area

Limpopo Province is located in the far northern part of SA and it is divided into five district municipalities: Vhembe, Mopani, Capricorn, Sekhukhune and Waterberg. The study was undertaken in Vhembe and Waterberg Biosphere Reserves (BRs), which represent two of the three BRs in Limpopo Province. BRs are internationally recognised under the United Nations Educational, Scientific and Cultural Organisation's (UNESCO) Man and the Biosphere (MAB) programme; they represent terrestrial and coastal ecosystems promoting solutions to reconcile the conservation of biodiversity with sustainable use of natural resources (UNESCO 2010). BRs are therefore special entities for both people and the environment and are living examples of how human beings and nature can co-exist while respecting each other`s needs (GOI 2007). The core zone consists of strictly protected areas, the buffer contains those areas where limited human activity is permitted and the transition represents areas where greater human activity is allowed (UNESCO 2010). The BR concept is being fast-tracked where holistic sustainable solutions that balance environmental conservation needs are sought (UNESCO 2010). However, in BRs, systems where ES have also been recognised as an integral part, ES remain a less researched subject, thus making it difficult to integrate them into decision-making, hence this study.

The Vhembe Biosphere Reserve (VBR) is located on the northern tip of Limpopo Province, bordering Zimbabwe in the north, Mozambique in the east and Botswana in the west, and is situated within the Limpopo River Basin, in the Vhembe district of Limpopo Province. The climate is arid to semi-arid with summer rainfall (Dombo et al. 2006), with the hot dry areas, located mostly in the main Limpopo River Valley itself, receiving about 200-400 mm of rain per annum (Mustafa 2007). The Waterberg Biosphere Reserve (WBR) is the second BR in SA, proclaimed in 2001, and covers an area of 1 727 614 ha (WBR 2012). It is situated in the Waterberg district of Limpopo Province. The climate is semi-arid in the south to arid in the extreme north. Rainfall is seasonal; most rainfall occurs during the summer months and the winters are very dry (WBR 2012). Annual rainfall varies from 500 to 750 mm. The mean annual temperature is 17.6°C (Mucina and Rutherford 2006).

4.2.2 Sources of data

The first stage of information-gathering regarding ES involved stakeholder engagement. This was done with the purpose of examining indicators of ES in a BR context in terms of the type, usage and extent thereof. Fifty key stakeholders were selected from the existing BR forums, representing different constituencies from a total of around 180 members for both WBR and VBR. It should be noted that more than 50% of stakeholders represented in both BRs were individual private landowners; hence it was not necessary to include all of them in the survey. Of the targeted 50 key stakeholders, only 38 participated during the surveys; the representation was as follows: four represented Limpopo Provincial Government responsible for conservation, four represented National Parks, four represented the Nature Conservancy of Waterberg, two represented Soutpansberg Conservancy, two represented the Transvaal Agricultural Union, ten represented private landowners, four represented the national parks forums, four represented local municipalities, two represented BRs and two were independent ecologists.

The second stage of information gathering was through a questionnaire sent by email to a wide range of stakeholders on the stakeholders' lists of both BRs, but only eight stakeholders responded to the questionnaires. These were one ecologist, three private landowners and two representatives of park forums, one representative of a BR and one representative of a nature conservancy. Follow-up was done by telephone in an attempt to involve some of the key stakeholders who had neither responded to the questionnaires nor taken part in face-to-face interviews. Fourteen stakeholders took part in the telephonic interviews out of the 22 whose contact numbers were available on the register and did not form part of the 50 that were targeted for the survey. The representation was as follows: four represented the provincial government responsible for conservation, three represented nature conservancies, two represented the Transvaal Agricultural Union, two represented local municipalities, one represented a BR and two represented private landowners. Twenty-two stakeholders who listed their phone numbers on the register were phoned. Four of them were not available for the interview because of other commitments, two of the phones were not working and two people were not willing to participate in the interviews. Fourteen of them responded.

The last stage of information-gathering involved a literature review. A literature review was conducted during the period 2012 to 2014. We searched electronic databases of Google Scholar, Google, Scopus and Science direct, whose titles included a combination of the key words "ecosystem services" and "mapping", as well as "ecosystem services" and "indicators" and identified 120 papers that mapped and discussed ES and their indicators. Out of these, we selected those that mainly concentrated on SA. The aim was to build on the existing reviews of Egoh et al. (2012), Martinez-Harmse and Balvanera (2012), as well as Crossman et al. (2013), but on a regional level. In the end around10 papers that specifically focused on mapping ES and their indicators in SA formed part of this analysis. (Appendix 4B contains information on the papers that were reviewed). We also investigated spatial datasets on local and national scales that were available and could be useful to map and quantify ES in SA. (Table 4.1 contains information on datasets used.)

Table 4.1 Datasets used

Dataset	Ecosystem services involved	Source
1. South Africa-National Land Cover 2009	Cultivated fields, water bodies, plantations	South African National Biodiversity Institute 2009
2. Cultivated fields	Cultivated fields	Agricultural Research Council
3. Agricultural commodities	Cultivated and horticultural crops	Limpopo Department of Agriculture 2012
4. Forestry plantations	Timber provisioning	Department of Water Affairs and Forestry 2008
5. Wetlands	Regulating	Department of Water Affairs and Forestry
6. Soils	Supporting	Agricultural Research Council
7. Vegetation	Supporting and regulating	Vegetation of Lesotho, Namibia, South Africa, DVD - Mucina and Rutherford 2006
8. Catchments	Water provisioning	Department of Water Affairs and Forestry
9. Dams:	Water provisioning	Department of Water Affairs and Forestry
10. National Protected Areas	Cultural ES	National Biodiversity Assessment 2011
	Land capability	
11. National Spatial Biodiversity Assessment (NSBA 2004)	Carbon sequestration	SANBI-BGIS

4.2.3. Overview of ecosystem services mapping in SA

In the 10 papers identified through electronic databases, two issues were specifically investigated: the type of ES mapped and indicators used to map these services. ES were arranged following the MA's classification (2005).

4.2.4 Mapping of ecosystem services and their indicators

While a considerable number of ES were mapped according to the literature reviewed, data were not easily accessible. For this reason, some of the ES were not included in this review, but only their indicators. However, where data were available, some of the services and indicators were included even if they did not form part of the review in order to fill the gap where data were lacking. In the end a total of 40 maps (20 on each BR), represented by five ES and 15 indicators of ES were produced for the purpose of this study, 17 of which used existing datasets and three used InVEST tools; these were two regulating services (nutrient retention and soil retention), as well as one water provisioning service represented by water yield.

4.2.4.1 Provisioning services

In this category, nine maps were produced. Seven maps representing indicators of provisioning services were represented as follows: three represented food provision, one fodder (grazing), one raw material and two water provisioning. Two ES mapped were water yield and grazing potential.

4.2.4.1.1 Indicators of provisioning services

Indicators of food provisioning were represented by land cover as the secondary indicator to map food crops, as well as areas with high potential for crop production. The third indicator of food provisioning service was represented by game farms. Game farms were mapped from the existing NSBA (2004) protected areas (PAs) layer, which is a combination of various datasets, from the Department of Environmental Affairs, national and provincial conservation organisations. Game farms fall under Type 3 PAs in the NBSA (2004) PA layer.

Indicators of water provisioning were represented by water catchment areas and surface water supply and combined data on dams, rivers and lakes from two datasets, DWAF (2008) and

National Spatial Biodiversity Assessment (NSBA 2004). Indicators of fodder production were represented by LC data in hectares representing lucerne, planted pasture and natural grazing. Horticultural and agricultural datasets from the Limpopo Department of Agriculture (2012) were used to map fodder production indicators. Indicators of raw materials production were represented by national LC (SANBI 2009) representing area coverage in hectares of timber plantation, as well as areas with afforestation potential, using the NSBA (2004) dataset.

4.2.4.1.2 Provisioning ecosystem services

Two provisioning ES, represented by grazing potential and water yield service, were included in this study. Grazing potential was mapped from the national grazing potential dataset, developed by the Council for Scientific and Industrial Research in 1998 on behalf of the Agriculture Research Council (ARC). From this dataset, grazing potential was calculated from the duration of the growing season, the geology, the slope, the degree of woody plant cover and the condition of the vegetation. The method to map water yield was based on the InVEST runoff water yield, which is one of the components of the nutrient retention model. This service determines how much water is available for human use after infiltration, evaporation and plant water uptake processes have been completed. Inputs considered for the mapping of this service include a digital elevation model (Jarvis et al. 2008), rainfall (Lynch 2004), evapotranspiration (Schulze and Horan 2007), soil depth to root-restricting layer (Schulze and Horan 2007), plant available water fraction (Schulze and Horan 2007), national land cover (Van den Berg et al. 2008) and the evapotranspiration co-efficient for each of the LC classes.

4.2.4.2 Regulating services

We focused on three regulating services: carbon sequestration, water purification (nutrient retention) and erosion prevention (soil retention). The following indicators of ES were also mapped: erosion prevention indicator represented by vegetation cover, as well as indicator of regulation of extreme events represented by wetlands.

4.2.4.2.1 Indicators of regulating services

Wetlands were mapped using a point data layer obtained from Cowan (1995) and a vector geospatial wetland layer extracted from the NSBA (2004) dataset. The final wetland layer followed Cowan's (1995) classification system. An erosion prevention indicator was represented by a vegetation map in each BR. Maps were produced using the existing dataset of Mucina and Rutherford (2006) indicating vegetation classification.

4.2.4.2.2 Regulating ecosystem services

A carbon sequestration map was produced from the existing NSBA layer (2004). The authors firstly classified vegetation following Mucina and Rutherford's (2006) vegetation classification. Vegetation types were classified into three categories according to their ability to sequester carbon: low to none (e.g. desert), medium (e.g. grassland), and high (e.g. thicket, forest) (NSBA 2004).

A water purification (nutrient retention) service was mapped using the InVEST water purification nutrient retention model. This model estimates the quantity and value of pollutants (nitrogen and phosphorus) retained for water purification from a landscape. Input data that were used to map nutrient retention in the study were: Digital Elevation Model, soil depth, precipitation, plant available water content, plant available water content fraction, average annual potential evapotranspiration, LU/land cover (LC), watersheds and model coefficients data (a table of LU/LC classes, water purification valuation data, water purification threshold data and annual nutrient load threshold information for each of the points of interest).

Erosion prevention (soil retention service) was mapped using the InVEST soil retention model. This model calculates the average annual soil loss from a land surface as well as the ability of the land surface to retain and capture sediment. The potential soil loss was calculated based on geomorphological, LU and climatic conditions. It used the Universal Soil Loss Equation (Wischmeier and Smith 1978) to estimate average soil loss in tons per hectare on an annual basis. Inputs used include national LC (Van den Berg, et al. 2008), as well as LC and management factors associated with each LU class, rainfall erosivity (Le Roux et al. 2008) and soil erodibility layer (Schulze and Horan 2007).

4.2.4.3 Supporting services

In this category, the actual ES were not included because of data constraints; only indicators were considered and three were mapped. We used biogeographical nodes as indicators of areas/features to support ecological processes. Vegetation types were used to identify biogeographical nodes as those areas where four or more vegetation types co-exist within 500 m. The biogeographical nodes were mapped using the National Spatial Biodiversity Assessment (2004) dataset. The second indicator mapped was critical biodiversity priority areas, using the National Biodiversity Spatial Assessment layer (SANBI 2004). The following were used to identify terrestrial biodiversity priority areas: data on species of special concern, vegetation types and ecological processes. Species of special concern were endemic and threatened plants, birds, frogs, mammals, scarabs and scorpions. Vegetation types were the vegetation types of Mucina and Rutherford (2006).

Soil characteristics were included as the third supporting services indicator. The map was produced using the ARC dataset. The ARC soil dataset combined Van der Watt and Van Rooyen's classification system and that of MacVicar et al. (1977). The soils were classified into soil forms. The soil forms were determined according to diagnostic horizons in a soil profile according to the classification system, and given different names, such as. Clovelly, Hutton, Arcadia, Avalon, etc.

4.2.4.4 Cultural services

In this category as well, only indicators were mapped. One indicator for aesthetic services and two for recreational issues and ecotourism were considered. As most PAs render both aesthetic and ecotourism services, the researcher chose to use the existing PAs as indicators of recreational and ecotourism and the national PA expansion focus areas (NPAEAs) as indicators of aesthetic service. The NPAEAs were recognized as those intact and unfragmented areas that represented high biodiversity and ecological persistence. These NPAEAs were identified through a systematic process of biodiversity planning in 2008 and formed part of the National Protected Area Expansion Strategy.

The existing PA layer was based on the NSBA`s PA layer (NSBA 2004), which combined data sets from provincial and national PA agencies, such as South African National Parks, the Department of Environmental Affairs and provincial conservation organisations and classified PAs into three types: 1, 2 and 3. Type 1 PAs included national parks, provincial nature reserves, local authority nature reserves and forest nature reserves. Type 2 and type 3 PAs included private nature reserves, heritage sites and nature conservancies, among others.

The second indicator of recreational and tourism mapping was important bird areas/routes (IBA). This indicator was mapped using the NSBA layer (2004). IBA areas are based on certain criteria based on the species that occur in the geographic area. Bird species included were those of global or regional conservation concern; species with a restricted range/biome and congregatory bird species with regard to concentrations in terms of numbers.

4.3 RESULTS

4.3.1 OVERVIEW OF ECOSYSTEM SERVICES MAPPING IN SA

The results of the review indicated that around 10 studies mapped ES in SA (Appendix 4B). All four categories of ES following the MA`s classification (2005) were represented; Figure 4.1 displays ES that were mapped in SA.

4.3.1.1 Regulating services

At least 12 different indicators were used to map the above-mentioned services as follows: (1) climate regulation: vegetation map, above ground biomass, soil carbon, nutrient flux, carbon storage and sequestration, (2) regulation of water flows: ground water, (3) erosion prevention: LC, soil characteristics, vegetation map and precipitation, (4) maintenance of soil fertility: soil productivity, soil characteristics, and (5) water purification: soil characteristics, precipitation, LC, watersheds.

Regulating services were given more attention in terms of mapping compared to other types of ES in the reviewed studies. Five ES were mapped in this category. These were climate regulation, regulation of water flows, erosion prevention, maintenance of soil fertility and water purification.

4.3.1.2 Provisioning services

Ten different indicators were used to map provisioning services as follows: (1) food provisioning: the following indicators were mostly considered for mapping this type of service: crop yield, numbers of livestock, LC, grain production, and fodder production, (2) water provisioning: runoff, precipitation and ground water were used mainly as proxies for water availability, and (3) raw materials: indicators for provisioning of raw material included fuel wood and wood production.

Provisioning services were the second mapped services after regulating services based on the reviewed studies. Three ES were considered for mapping by these studies: food provisioning, water provisioning and raw material.

4.3.1.3 Cultural services

Based on the reviewed studies, the following six indicators were used to map recreational and ecotourism services: viewsheds, potential viewing, flower viewing. Aesthetic enjoyment service indicators were mainly represented by protected areas, spiritual, aesthetic and recreational services. From the reviewed studies, two cultural services were mapped representing recreational issues and ecotourism, as well as aesthetic enjoyment.

4.3.1.4 Supporting services

Indicators for the soil accumulation service included soil characteristics and leaf litter, and those for maintenance of soil fertility included soil characteristics and soil productivity. In total, four indicators were used to map two ES in this category.

Supporting services received the least attention in terms of mapping compared to the other three categories of ES mentioned above, possibly because of lack of sufficient data. Only two services were mapped, namely maintenance of soil fertility and soil accumulation.

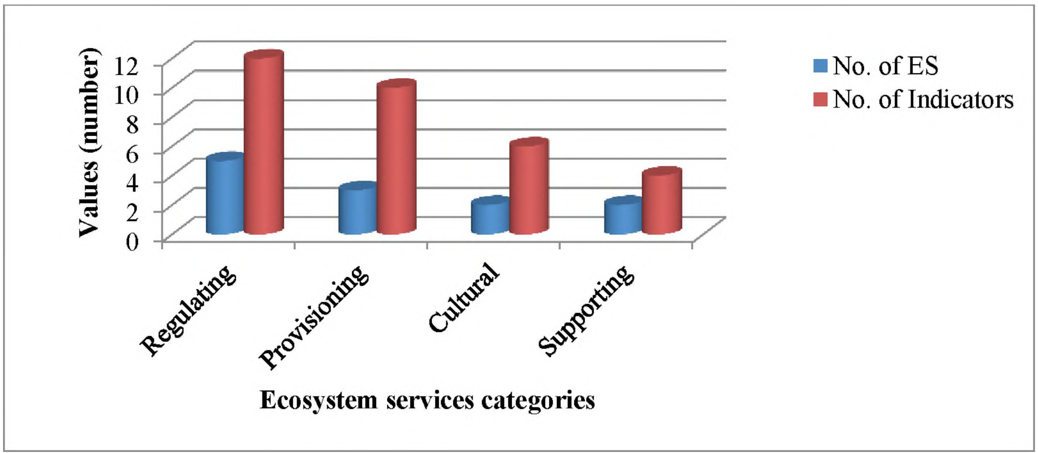

Figure. 4.1 Number of ecosystem services (ES) mapped in SA and number of indicators used to map them.

4.3.2 ECOSYSTEM SERVICES IN A BIOSPHERE RESERVE CONTEXT

Through a stakeholder engagement process, a wide range of ES indicators that could be used to quantify/map ES in both BRs, representing all four categories of the MA (2005), was identified. From the existing national datasets we were able to give a spatial representation of the distribution of some of these indicators and respective services provided by the two BRs. This information is presented as Figures 4C.1-4C.30 in Appendix 4C.

4.3.2.1 Provisioning services

In terms of the first food provisioning indicator represented by land capability, medium land capability was dominating in VBR, with low and high capabilities less pronounced. In WBR high land capability was dominating, with low and medium land capability ranges less represented. With regard to the second food-provisioning indicator (represented by agricultural crops) information received from stakeholders indicated that a variety of horticultural and agricultural food crops existed in the two BRs. In VBR, land was primarily used for agriculture, producing mainly maize and subtropical fruits. At least 13 145 ha were reserved for maize production. *Mangifera Indica* (mango) was an important subtropical fruit covering 4 122 ha, yielding over 100 000 tons per year. *Musa acuminata* (banana) production covered 2 158 ha. Citrus was also an important crop, covering 5 364 ha and yielding over 180 000 tons per year. *Persea americana* (avocado) production covered 4 406 ha and yielded around 40 000 tons per season. Other crops included *Macadamia integrifolia* (macadamia nuts) (5 677 ha), *Psidium guajava* (guava) (652 ha), *Triticum aestivum* (wheat) (830 ha) and different types of vegetables, covering more than 5 000 ha (Figure 4C.2).

In WBR, cultivation of different crops covers 178 963 ha in total. Food-related crops included *Zea mays* (maize) (7440 ha), *Phaseolus vulgaris* (dry beans) (280 ha), wheat (1610 ha), Arachis hypogaea (ground nuts) (490 ha**)**, Macadamia integrifolia (53 ha) and fruit, i.e. Vitis vinifera (grapes), citrus species (808 ha), *Prunus persica* (peaches) (115 ha), *Persea Americana* (35 ha), *Musa acuminata* (16 ha) and Mangifera Indica (32 ha), as well as different vegetables, i.e. *Solanum tuberosum* (potatoes), *Brassica oleracea* (cabbage), *Juglans cinerea* (butternuts) and other seasonal garden crops covering around 10 000 ha (Figure 4C.1). Dairy products and meat, i.e. pork, beef and poultry, were also produced from livestock farming.

Food provisioning occurred through game/livestock and/or fish farming. Both BRs had tourism establishments comprising mainly game farms in both the core and the buffer zones, which practise hunting either in the form of trophy hunting or for meat that some of them supply to butcheries and abattoirs. Fishing did occur on a small scale for subsistence purposes; otherwise, no large successful commercial fisheries were known to exist within these BRs. In WBR food provisioning was derived from 474 825 ha of game farms, 21 635 ha used for mixed farming of livestock and game, as well as 79 704 ha used for livestock. In VBR, livestock covered 9 362 ha and included 77 516 *Capra aegagrus hircus* (goats), 17 477 *Ovis aries* (sheep), 21 818 *Sus domesticus* (pigs) and 180 678 *Bos taurus* (cattle). Poultry was also kept on 204 poultry farms producing approximately 52 000 broilers annually. There were 18 fish projects in the VBR, operating on a small scale (VDMIDP 2012).

Regarding water provisioning indicators, both the VBR and WBR were part of the Limpopo River catchment area. The Matlabas, Sunday, Mamba and Sand Rivers originated from the Waterberg Mountains. There were four large rivers: Lephalala, Mokolo, Matlabas and Mokgalakwena. These rivers were fed by a number of smaller rivers and streams such as the Melkrivier, the Blokland Spruit, the Taaibos Spruit and the Platbos Spruit; all these contributed to freshwater resources in the WBR (Figure 4C.7). The VBR`s Limpopo River catchment area had seven rivers serving as sub-catchments, namely the Nwanedzi, Sand, Ndzhelele, Mokgalakwena, Shingwedzi, Letaba and Levhuvu. The Ndzhelele, Nwanedzi and Luvuvhu Rivers were perennial and the rest were seasonal. There were also freshwater lakes and swamps (Lake Fundudzi, Zwavhavili and Mphaphuli marshes), which contributed to the provisioning of fresh water in the VBR (Figure 4C.8).

As a fodder provisioning indicator, different kinds of grass species were available in the VBR for various purposes, including grazing and as a feeding supplement for livestock and game. The production of grazing in VBR was as follows: Lucerne covered 823 ha, of which 477 ha was planted in winter and 346 ha in summer. This commodity was mainly produced to make profit. Planted pastures comprised 35 876 ha, which was also meant to make profit, of which 12 730 ha were produced in winter and 23 106 ha in summer (Figure 4C.12). By way of comparison, natural grass vegetation covered a larger area (14 510 ha) in the VBR compared to lucerne and planted pastures and was mainly used as open grazing for domestic livestock, with some of the landowners sometimes packaging it for sale during seasons of drought, as it can thrive naturally and survives under dry conditions. In WBR both lucerne and planted pastures were mainly produced for business purposes, while natural grazing was generally not linked to the market; however, some of the landowners indicated that they used it from time to time to make a profit as well. Planted pastures covered 16 673 ha (7 095 ha - winter, 9 578 ha - summer) and 64 760 ha were covered by natural grazing. With regard to lucerne, 1 245 ha were covered, of which 828 ha was winter production and 417 ha was summer production (Figure 4C.11).

Indicators of raw material provisioning in the study area were represented by timber production and areas with potential for afforestation. The indicator for timber production in the study area was represented by LC of areas covered by timber plantation and potential afforestation areas in hectares. More than 200 timber plantations were recorded in VBR, most of which were commercial; the biggest encountered covered more than 10 000 ha. In WBR, timber plantations were only available in small patches and were mainly used for domestic household purposes, covering at least 760 ha. There was no evidence of commercial timber operations in this BR. With regard to afforestation potential in the study areas, both BRs were dominated by areas with low afforestation potential. Areas with high potential for afforestation occurred only in VBR, but on a very small scale. These areas were concentrated in the already forested areas. In WBR there was limited potential for afforestation on a moderate scale.

Regarding a water yield provisioning ecosystem service, consumption in WBR ranges between 0-498 mm per annum, whereas in VBR water yield ranges between 0-1388 mm per annum, as presented by Figures 4.2 and 4.3. The water yield results of this study correspond with those of the NSBA (2004) and are also aligned with important catchment areas.

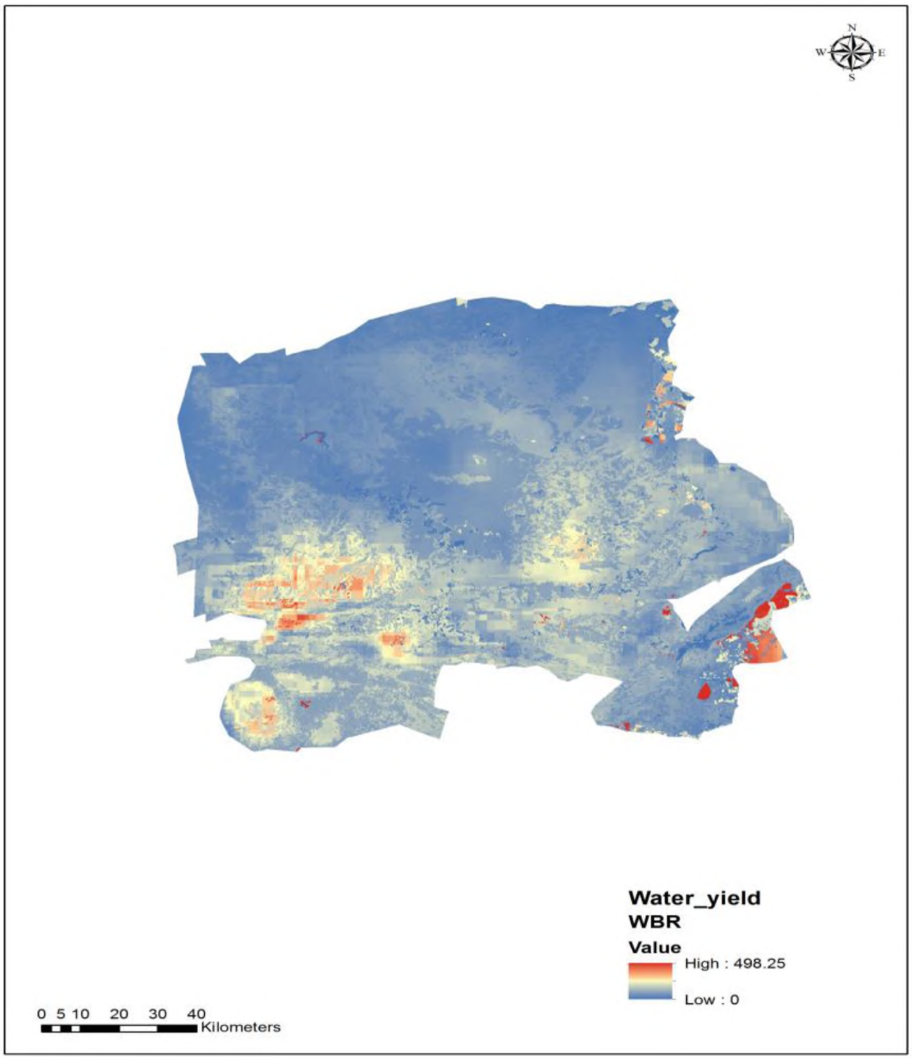

Figure 4.2 Illustration of water provisioning service in WBR indicating areas with high and low water yield.

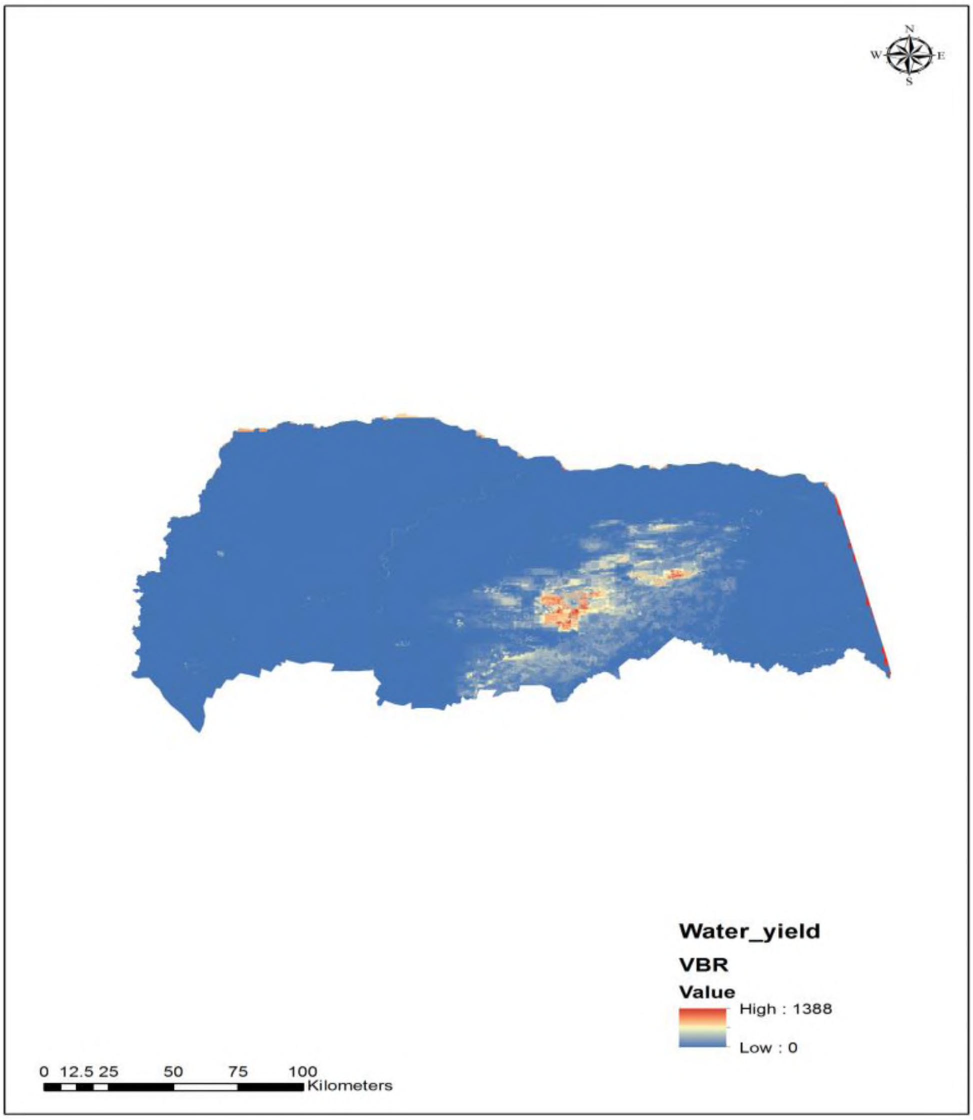

Figure 4.3 Illustration of water provisioning service in VBR indicating areas with high and low water yield.

With regard to grazing provisioning, the results presented by Figures 4.4 and 4.5 indicate that each BR could support 1 to 22 large stock units (LSU) in terms of grazing potential. In WBR grazing potential ranging between 2 and 6 LSU was more pronounced. The highest LSU potential of 18-22 LSU was recorded in the Nyl River Floodplain. In VBR the grazing potential range of 1-2 LSU was dominant. Most areas in both BRs fell within the 0-1 LSU range in terms of grazing potential.

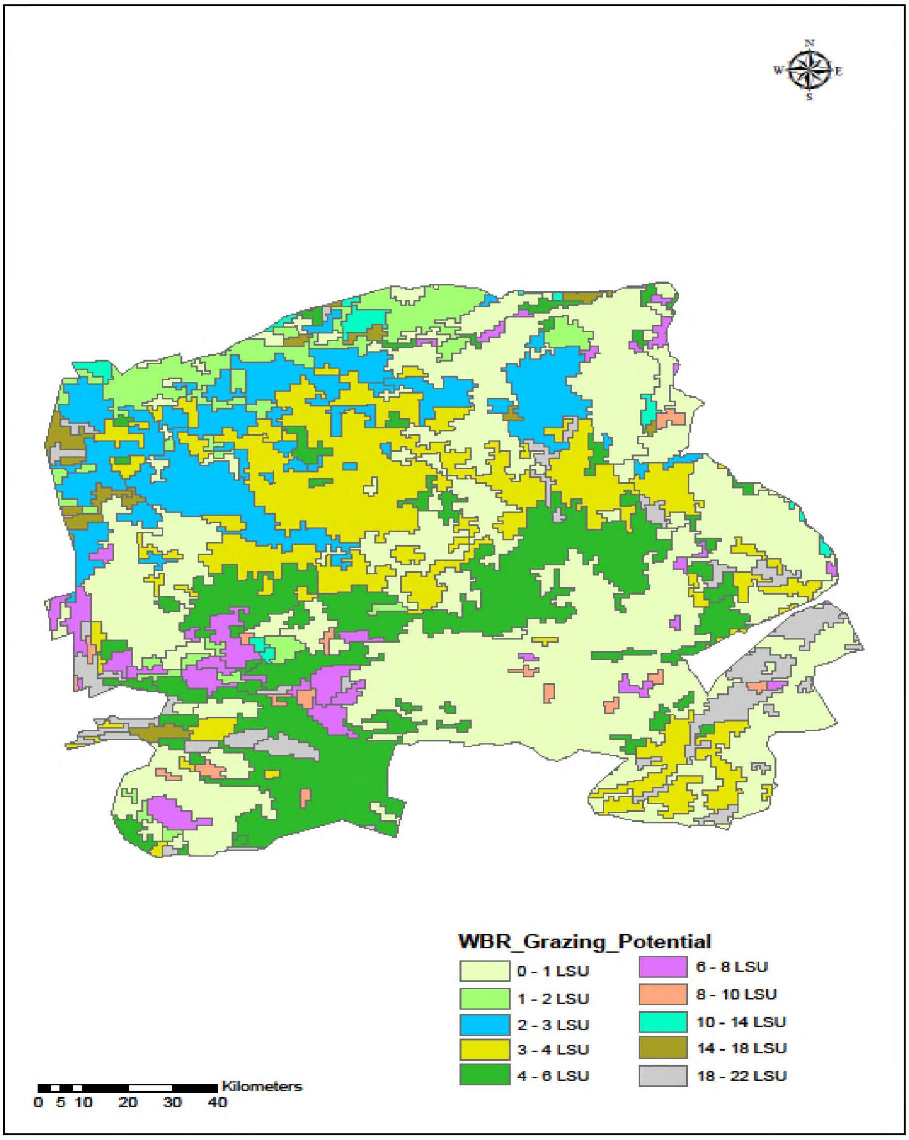

Figure 4.4 Grazing potential in terms of LSU/ha in WBR.

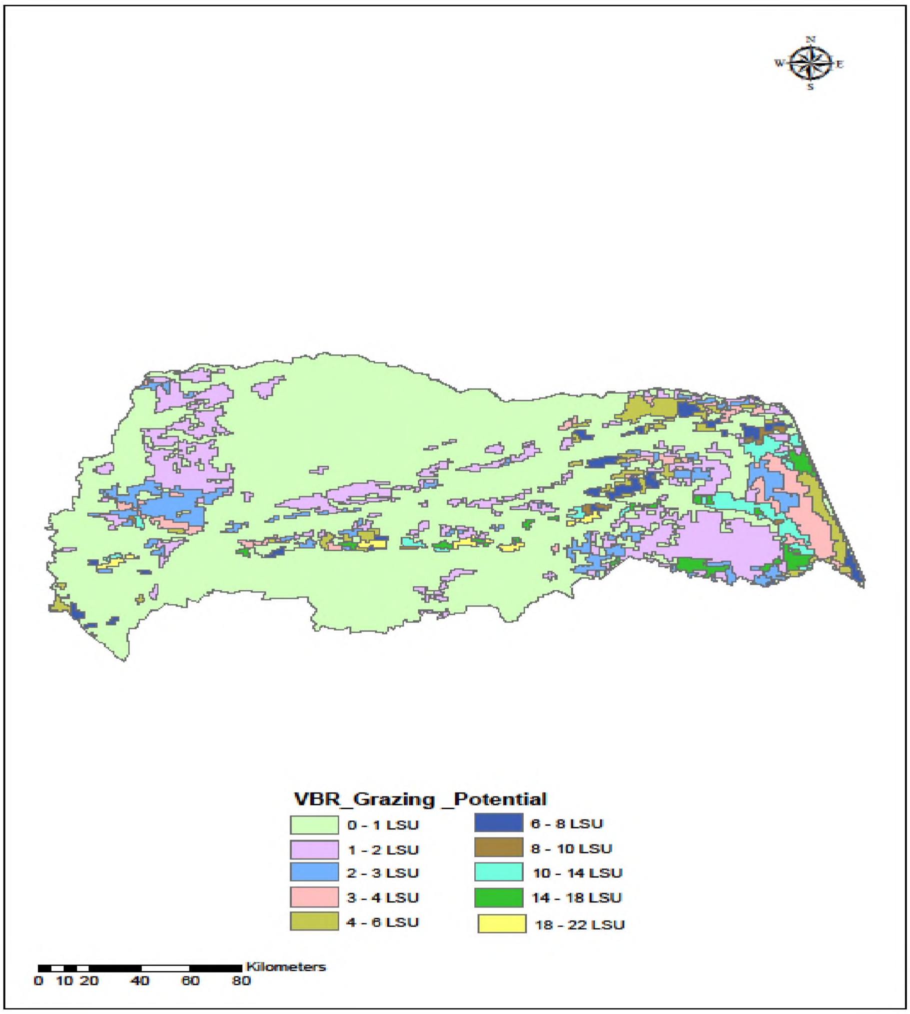

Figure 4.5 Grazing potential in terms of LSU/ha in VBR.

4.3.2.2 Cultural services

In this category, no data were available to give a spatial representation of the actual ecosystem services. Because of this, only indicators were included in this analysis, namely aesthetic enjoyment, recreational issues and ecotourism, cultural heritage and diversity, as well as educational resources indicators.

In WBR, recreation and tourism were represented by seven conservation areas in private ownership, along with most of the areas forming part of the Waterberg conservancy. The main activities in these zones were hunting safaris and nature-based tourism. Nature-based tourism activities included elephant-back safaris, horse riding, guided safari drives and bush walks, fishing, hunting and hiking, as well as mountain and quad biking. There were also around 200 different overnight tourism facilities, with an occupancy rate ranging between 40% and 60%, accommodating up to 500 000 tourists per annum.

In VBR, recreational benefits were provided by more than10 conservation areas in private ownership. There were also over 140 known tourism establishments offering different kinds of tourism products, ranging from overnight facilities, guided trails, game viewing, eco routes, hiking and fishing to bird watching. There were approximately 10 eco routes that guided tourists to different tourism facilities in the VBR. Among them were the Greater Mapungubwe Heritage Route, Land of the Legend Route, Mapungubwe-Kruger Route and Footsteps of the Ancestors Route.

Another indicator of cultural services considered for mapping was important birding routes. In VBR, Ivory Route and Soutpansberg Route together had approximately 40 bird-watching sites and 540 different bird species. Other important birding recognised routes were known as KNP, Blouberg and Mapungubwe. In WBR there were two birding routes, known as the Nyl River Floodplain and Waterberg System birding routes. The Waterberg system was the main one, covering around 50% of the WBR.

With regard to aesthetic enjoyment in both BRs, there was rich landscape diversity with outstanding cultural and biological features that offer high-quality aesthetic enjoyment. In WBR, aesthetic enjoyment was specifically rendered by a national park (Marakele) and six state nature reserves (including Masebe, Nylsvlei; D'nyala, Wonderkop, Mokolo Dam and Moepel). In VBR, the indicator for aesthetic enjoyment was represented by a national park (Mapungubwe) and formally proclaimed state PAs (Blouberg, Happy Rest, Langjan, Musina, Nwanedzi, and Makuya, among others).

There was growing appreciation of the value of cultural heritage and indigenous knowledge generally in the two BRs, which contributed to growth in socio-economic benefits. The areas have a long history of human occupation and have been inhabited by a succession of people over hundreds of thousands of years, with its history spanning more than a million years. There were also a considerable number of sites rich in human history with evidence of graves, rock art and other significant sites related to various eras of early human history.

In the VBR, the Mapungubwe cultural landscape is a world heritage site, which houses remains of the early humans who occupied that area. In one of the hills in the park there are important grave sites, which are believed to be those of members of royal families of the first kingdom that ruled in the area. The site attracts many visitors from all over the world. There are also descendants of the four clans claiming to be related to ancestors buried on Mapungubwe Hill, who visit the area from time to time to appease their ancestors. In addition, there are various centres that support indigenous knowledge systems, e.g. Leseba and Mokgalakwena Craft Art Centre. Individual carvers, crafters and potters work in the area. Approximately 1000 rock art sites have been recorded in VBR.

In the WBR, a few significant memorial sites have been selected and form part of the tourism route. Makapans Valley contains the cave of hearths fossil site bearing evidence of early human (*hominid*) life in the Waterberg. St John`s Church is regarded as a living testament of the early settlers and a spiritual haven for their descendants. A memorial commemorates a skirmish between the Boers and the British forces during the Anglo Boer war, and 24 Rivers is a commemorative cemetery where 544 women and children who died in the concentration camps at Nylstroom were buried. The David Livingstone Memorial is a national heritage site marking the spot where David Livingstone rested during a journey he undertook with his wife from his mission station in Botswana in 1847. The Eugene Marais site is where this famous poet and writer spent many years studying termites.

Education programmes as an indicator of educational resources was important in both BRs to the extent that they have been extended to conservation areas in the form of environmental education. In WBR, there are two educational centres in Marakele National Park and the Lapalala Wilderness Area. The following nature reserves offer ongoing research programmes, especially for post-graduate studies: Masebe, Welgevonden and Nylsvlei Nature Reserves. In VBR, there are four permanent research stations that undertake research projects ranging from ecological and agricultural to socio-economic studies. These are Lajuma Research Centre, Mara Research Centre, the Herbarium Soutpansbergensis and the University of Venda. There are also various establishments that have environmental education support facilities, i.e. Mapungubwe and Kruger National Park (KNP) Education and Interpretation Centres and Schoemansdal Environmental Centre, which accommodates school children. Various provincial and private reserves offer ongoing research programmes for both undergraduate and post-graduate studies.

4.3.2.3 Regulating services

At least three regulating ES were included in this study. These were carbon sequestration, nutrient retention and sediment retention. Indicators of regulating services were also included, namely natural vegetation as well as wetlands.

As an indicator of a regulating service by natural vegetation, both BRs played a role in climate regulation and mitigation of natural disasters. This was evident from the amount of natural forest coverage, which accounted for around 2000 000 ha in VBR and around 1000 000 ha in WBR, giving an indication of good carbon storage. In VBR, natural forested areas, responsible for regulating natural disasters, accounted for over 2 000 000 ha, representing at least 26 vegetation types, following the classification of Mucina and Rutherford (2006). In WBR, natural vegetation covered over 1 000 000 ha, representing 13 vegetation types (Mucina and Rutherford 2006). In both BRs, these areas were mainly dominated by conservation areas and a host of other intact ecosystems.

In the VBR, wetlands regulation services were performed by various wetlands representing at least four South African wetland classes. The Limpopo and Luvuvhu riverine areas consist of floodplains in their lower reaches. Other wetlands in the vicinity are marshes and swamps (Zwavhavili and Mphaphuli); four peat-fens are located in Mutale, Mapungubwe and the farms Ontmoet and Bergplaats. Springs and oases are represented by Madimuhulu Spring, Sulphur Springs, Tshipise and Mphemphu Aventura Resorts and Evangeline hot spring floodplains. Lake Fundudzi, which is the biggest freshwater lake in SA, is also located in this BR. All these form part of regulating ES. The Waterberg is best described as a large wetland, since it is a major catchment area for the Limpopo Basin. The Marakele National Park and surrounding areas contain several important wetland areas, which act as sponges from the Waterberg complex, feeding the BR and including some important sites, such as the Nylsvlei floodplain, a registered Ramsar Site, which is the largest inland floodplain in SA.

The amount of soil retention ecosystem service was 551 769/tons/ha in WBR and 782 801/tons/a in VBR (see Figures 4.6 and 4.7). In VBR, soil retention was more pronounced around water catchment areas and very low around areas surrounded by PAs.

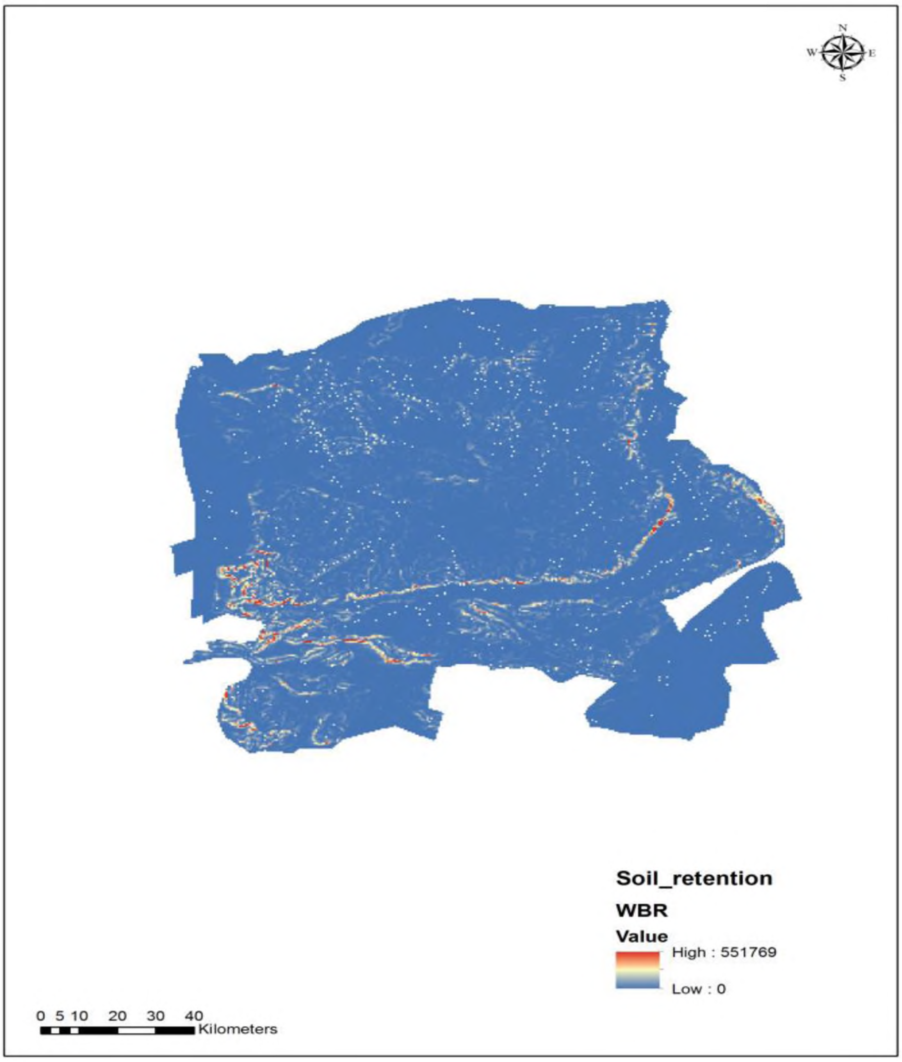

Figure. 4.6 An illustration of erosion prevention service through soil retention in WBR (illustration of high and low soil retention areas)

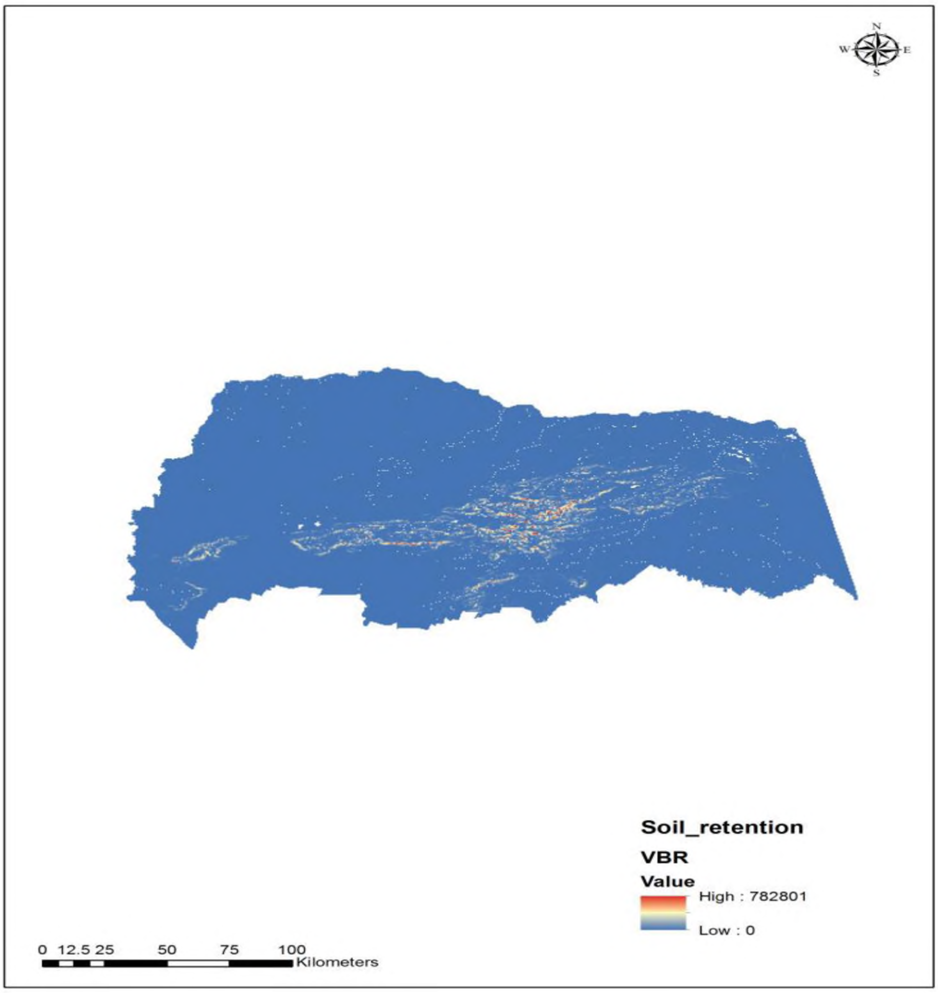

Figure. 4.7 An illustration of erosion prevention service through soil retention in VBR (illustration of high and low soil retention areas)

Climate regulation by carbon sequestration potential in the study areas is represented by Figures 4.8 and 4.9, illustrating areas represented as low, medium and high. In WBR, high carbon sequestration potential was recorded in areas around the Nyl River Floodplain, and low carbon storage potential was recorded around the indigenous forest area in Marakele National Park and some of the bushland-dominated areas. The larger part of the BR was dominated by medium carbon sequestration potential. In VBR, the high carbon sequestration range was more pronounced along the indigenous forest belt, with the major part of the BR dominated by medium carbon sequestration potential.

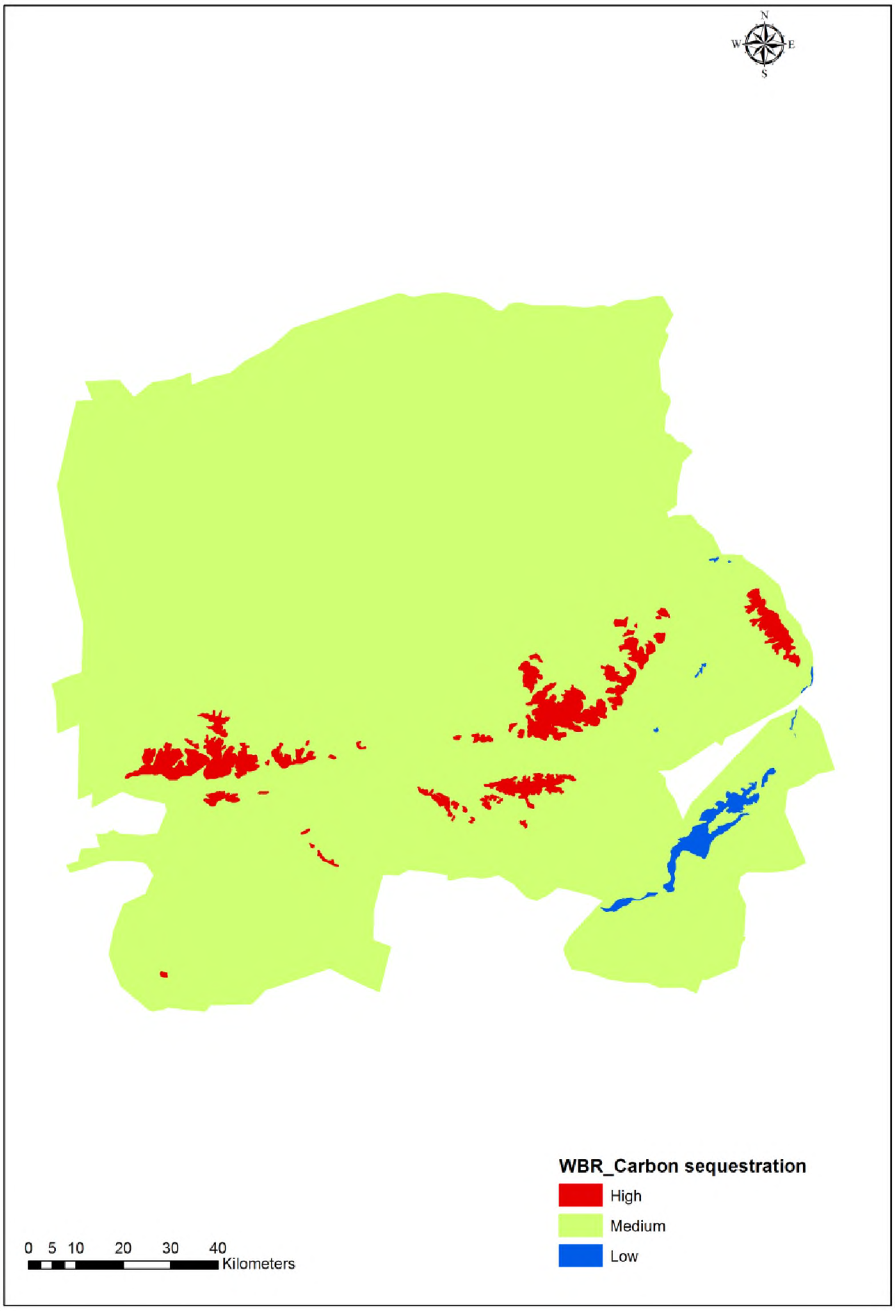

Figure 4.8 An illustration of climate regulating service indicating high, medium and low carbon sequestration areas in WBR.

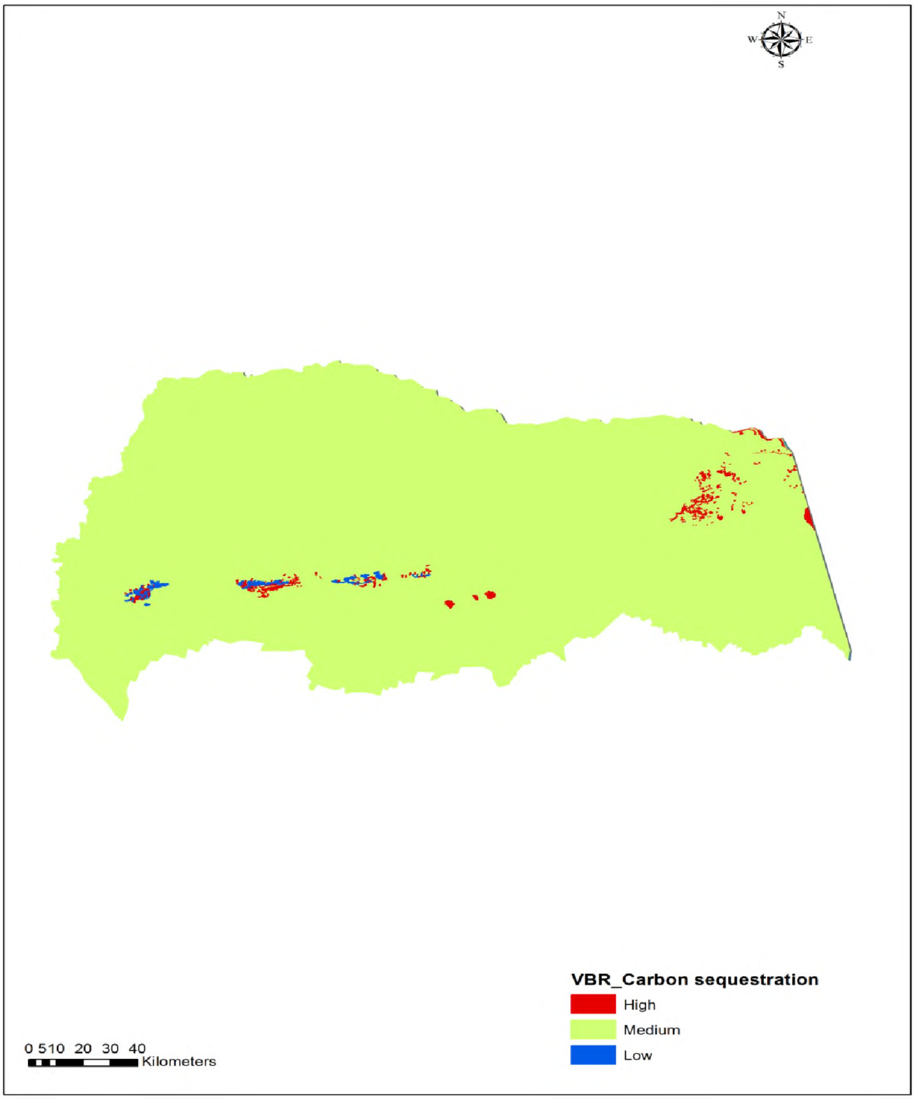

Figure 4.9 An illustration of climate regulating service indicating high, medium and low carbon sequestration areas in VBR.

With regard to the water purification service nutrient retention, more nitrogen (2 349-37 462 kg/ha) was retained than phosphorus (983-11 255 kg/ha) in WBR (Figure 4.10). In VBR, nitrogen retention ranged between 5 398 and 93 723 kg/ha, whereas phosphorus retention ranged between 2 823 and 27 989 kg/ha (Figure 5.11). With regard to nutrient export, up to 81476 kg/ha of nitrogen and 15273 kg/ha of phosphorus were exported per year in VBR. In WBR, the highest records of nutrients exported per year were as follows: 40426 kg/ha for nitrogen and phosphorus 8312 kg/ha.

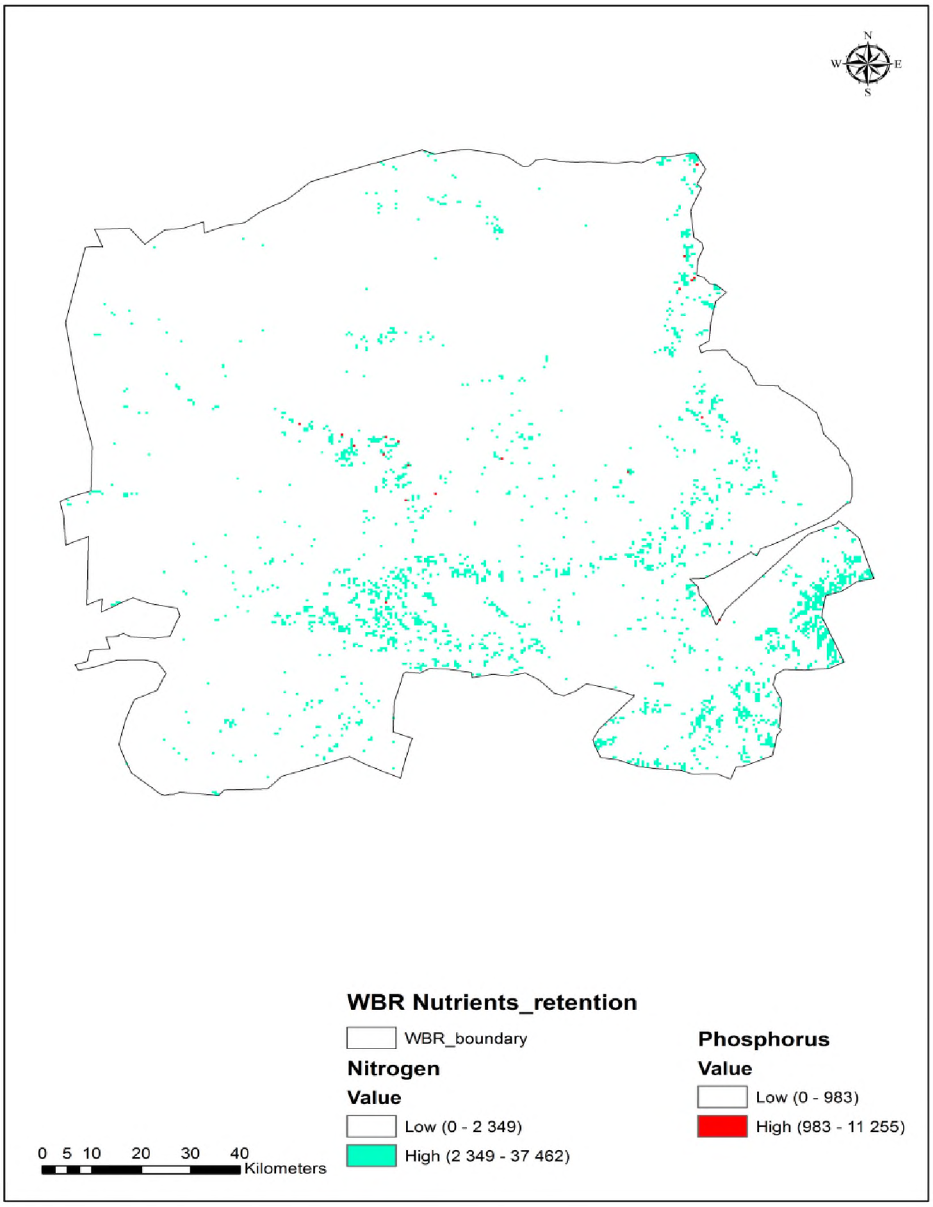

Figure 4.10 An illustration of nutrients (nitrogen and phosphorus) export in the WBR study area indicating low and high export values.

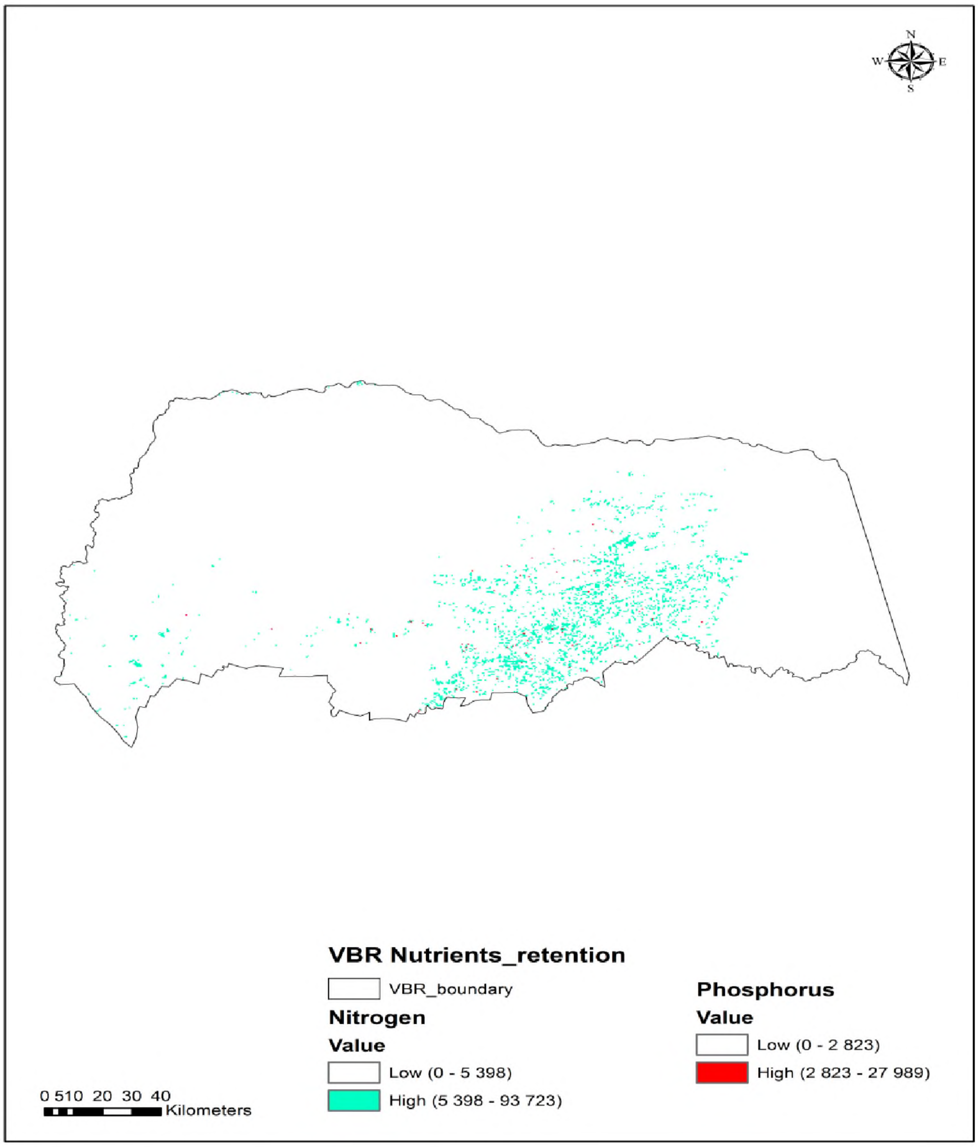

Figure 4.11 An illustration of nutrients (nitrogen and phosphorus) retention (kg/ha) in the VBR study area indicating low and high nutrient retention values.

4.3.2.4 Supporting services

No data were available to map supporting ES in either BR, therefore only indicators were mapped. We used critical biodiversity areas and biogeographical nodes as indicators of supporting services.

With regard to indicators of biodiversity, both BRs showed abundance in terms of critical biodiversity areas that have the potential to support a range of species. These areas were mainly located in intact ecosystems and included existing PAs and identified PA expansion priority areas. These areas were more pronounced in WBR than the VBR.

With regard to the second indicator of supporting services (ecological processes support), results indicated that low ecological support areas represented by biogeographical nodes were dominant in both BRs. Apart from this, VBR also contained medium ecological support areas and WBR contained four isolated patches of high ecological support areas.

4.4 DISCUSSION

4.4.1 OVERVIEW OF ECOSYSTEM SERVICES MAPPING IN SA

4.4.1.1 Provisioning services

This category of ES ranked second out of the four MA (2005) categories, in terms of mapping. This finding was the same in other studies (Egoh et al. 2008; Martínez-Harms and Balvanera 2015; Crossman et al. 2013). Despite the fact that it came second with regard to mapping in the current review, this type of service was expected to have exceeded the current levels in terms of studies undertaken, as it forms the basis of human well-being because of its direct contribution to basic human needs, such as health and nutrition (MA 2005). Owing to the direct link of provisioning services with human well-being, spatial representation of their distribution could aid decision-making regarding their supply and demand (MA 2005; Crossman et al. 2013).

4.4.1.2 Regulating services

The finding of regulating services as the most mapped ES compared to the other three (supporting, cultural and provisioning) concurs with that of Egoh et al. (2012); Crossman et al. (2013), as well as Martínez-Harms and Balvanera (2015). Since ES mapping is regarded as an important tool for decision-making (Martínez-Harms and Balvanera 2015), high consideration for regulating services, especially carbon storage and sequestration, could be attributed to its association with climate change mitigation and adaption decision-making (IPCC 2007).

4.4.1.3 Cultural services

This type of service was ranked third in this study with regard to ES mapping studies undertaken. This finding was the same in previous reviews (Egoh et al. 2008; Crossman et al. 2012; Martínez-Harms and Balvanera 2015). However, it was not expected that services in this category would receive less attention, since they are directly linked to human well-being, as they represent important aspects related to culture, aspirations, diversity and values (MA 2005). We expected recreational and tourism ES to have received more attention, as they represent the fastest growing industries in the world that contribute to countries' economies, including the economy of SA (Dilys and Urquhart 2001; Van der Merwe and Saayman 2003; WTTC 2012; VDMIDP 2013). However, less attention being paid to this type of services was not very surprising, since it is only recently that it has been receiving attention at all (MA 2005; TEEB 2010).

4.4.1.4 Supporting services

Supporting services were found to have been mapped least often by the studies reviewed. This finding was expected, as this type of service was associated with major data gaps that also made it difficult to quantify (TEEB 2010, Egoh et al. 2012). Another contributing factor was that it contained fewer services, e.g. two under TEEB`s classification (2010) (TEEB 2010; Egoh et al. 2012), and the services included were mainly soil-related (MA 2005; Egoh et al. 2012). Despite these challenges, soil characteristics were used by most of the studies forming part of this review as proxies to map mainly regulating services.

4.4.2 ECOSYSTEM SERVICES IN A BR CONTEXT

4.4.2.1 Provisioning services

With regard to food provisioning service indicators, results suggest that the VBR had more agricultural areas than the WBR, thus producing more food crops, despite the fact that on district level, Waterberg had more land (4 360 262 ha) under agriculture than Vhembe (2 076 390 ha), (LDA 2012). More agricultural areas in VBR could be attributed to the fact that the VBR was larger than the WBR in size and included the whole Vhembe district municipality area (Dombo et al. 2006). Moreover, large agricultural areas in VBR could have been influenced by the presence of a human population of over 1 million (StatsSA 2001; Dombo et al. 2006), whereas human settlement in WBR consisted of only 30 rural settlements, with fewer than 100 000 inhabitants (WBR 2012). The differences in climate might also have contributed to the difference in crops produced. In VBR, agricultural areas were furthermore aligned with important catchment areas, although that was not the case in WBR.

In terms of the water provisioning indicator, water catchments, the results indicated that there were more water catchments in VBR than in WBR. This finding could be associated with the fact that the VBR was situated within the Limpopo River catchment, which served as the main catchment for streams flowing downstream northwards, including those from the WBR (Dombo et al. 2006; WBR 2012). Otherwise the WBR was known to be better water-resourced than the VBR mainly because of its association with the Waterberg Mountains and semi-arid climate (WBR 2012). Water yield as well seems to be correlating with catchment areas, and followed the same pattern as in strategically water-resourced areas of NSBA (2004).

However, despite the findings above, it should be noted that water is a very scarce resource in SA (NWRS 2004), where more than 80% of rivers' ecosystems are threatened and endangered (NSBA 2004). Moreover, the quality and quantity of most rivers globally are affected by various anthropogenic activities (Townsend 1997; Parker 2000; Hancock 2002; Govorushko 2005; Tafangenyasha and Dzinomwa 2005). Among these activities, agriculture accounts for the highest water usage, followed by mining (NWRS 2004). With water functioning as both a provisioning service and a supporting service, the consequence of water shortage is detrimental to the provisioning of other ES. The MA (2005) also identified water supply as one of the 15 ES that were in a poor condition because of unsustainable use, therefore the sustainability of this ES for future use will be determined by the efforts put into its conservation by the present generation.

In respect of raw material provisioning indicators, results indicate that there was higher potential for afforestation, mainly for species consuming less water, in WBR than the VBR. This involved mainly areas located in the buffer zones. The finding of high afforestation potential in WBR, compared to the VBR, could be attributed to the fact that these areas had a mild climate with average rainfall of 500-700 mm per annum (WBR 2012), whereas VBR was situated in a very dry area with a hot climate, receiving 200-400 mm of rainfall per annum (Dombo et al. 2006; Mustafa 2007). Contrary to this finding, the VBR currently has plantations yielding high timber production for commercial purposes; meanwhile no timber plantations are known to exist in WBR for commercial purposes. However, the current high-production timber plantations in VBR were mainly concentrated in areas that have been identified as having high potential for afforestation (NBSA 2004). On the other hand, existing plantation areas were aligned with high water yield areas.

There is no dispute that forests are an important source of raw materials, including timber and fibre (MA 2005), which are both essential in construction and agricultural industries around the world. However, the forest ecosystem is one of the systems in a degraded state (MA 2005), to the extent that natural intact forests cover only 0.4% of land surface in SA (DAFF 2011). Continued unsustainable utilisation may therefore lead to severe degradation that might have a negative impact on the provisioning of fibre and timber. Although forestry plantations have the potential to fulfil some functions provided by natural forests, i.e. provisioning of fibre and timber, they consume too much water (Duncan 1993; Fahey 1994). Despite this shortcoming, in SA forestry plantations are an important commodity, contributing at least 2% to the country`s GDP, of which Limpopo contributes 0.5% (DAFF 2013).

The provisioning of grazing is regarded as an important service required to maintain the health of livestock (LDA 2012), which in turn contributes to nutrition for human well-being in both BRs. The indicators for grazing, which were illustrated by lucerne, natural grazing and planted pastures, were found to be scattered in areas that had low to medium land capability. However, a high concentration of these crops was aligned with a high land capability range. This observation suggests that farmers were influenced by climate for their fodder production, as they seemed to be concentrating on high rainfall areas and fertile soils to produce their crops, which is a common-sense approach expected to be applied in this situation.

In terms of grazing capacity, we found both BRs to have the potential of supporting up to 22 ha/LSU. A minor correlation was found between grazing potential and land capability in VBR, e.g. areas around the KNP in VBR; although they were dominated by a grazing capacity of between 2 and 6 ha/LSU, they fell in the low-medium land capability range. The rest of the PAs could support only up to two LSU. The same observation was made for WBR, where most of the PAs seemed to fall in the 0-2 ha/LSU range. In essence PAs could support fewer LSU, with the exception of the KNP. This finding was not surprising, as most of the PAs were conserving game species with different dietary requirements, not merely based on grazing, as some were browsers.

4.4.2.2 Regulating services

High soil retention areas were found within the same range as areas with high soil accumulation potential in the study conducted by Egoh et al.(2008). The finding of high soil retention in areas prone to high soil accumulation concurs with that of Egoh et al. (2008). Since soil retention is a function of slope (Mukhlisin et al. 2011), high soil retention areas were concentrated in flat areas, as expected. Meanwhile, areas around the Soutpansberg complex in VBR were found to be prone to soil erosion, which was expected, since they were situated at a high altitude (Dombo et al. 2006).

High carbon sequestration potential areas were associated with some of the PAs in the study areas, including the northern tip of KNP. In the case of the WBR, some of the areas around Marakele National Park were associated with low carbon sequestration. The finding of high carbon sequestration in PAs could be attributed to the fact that these areas were aligned with high carbon storage (Egoh et al. 2008). High carbon storage areas were therefore expected to have high sequestration potential. The finding of low carbon sequestration potential around the indigenous forest belt was expected, as the remaining indigenous forests in SA are highly protected (NFA 1998). The finding of a medium carbon sequestration range in both BRs was aligned with the medium carbon storage range, as the areas were also situated within the savanna biome, which has been found to contain medium carbon storage, according to Egoh et al. (2008).

A high water purification service in the study areas was associated with high catchment areas. Other workers also found higher nutrient fluxes in areas with more rainfall and freshwater discharge (Howarth et al. 2006a). In this case, the finding of high nitrogen export could be associated with the fact that most of the highly productive agricultural areas were found in high concentration in the water catchment areas (NSBA 2004). High nutrient retention was also closely aligned with transformed areas, specifically those carrying out agricultural activities, as they rely on the administration of excessive nutrients/fertilizers to enhance the productivity of their crops and pastures (Zaimes and Schulz 2002; Ator and Denver 2015). Nutrient export is determined by the amount of fertilizers/nutrients applied. Phosphorus exports were lower than nitrogen; moreover, more nitrogen is retained than phosphorus.

The finding of less phosphorus being exported has been attributed to the fact that this nutrient has been found to be generally less mobile (Zaimes and Schulz 2002) and mainly exported through surface water (Ator and Denver 2015), which could be limited by rainfall. On the other hand, we expected less phosphorus to be retained, as it remains on the soil surface and is thus easily washed away by surface water (Lourenzi et al. 2014; Ator and Denver 2015). High retention of nitrogen could be attributed to the fact that this nutrient is mainly absorbed into the soil through ground water and ground water transport is generally slow (Lourenzi et al 2014; Ator and Denver 2015). The main factor contributing to more nutrient export is the administration of more nutrients, and more nitrogen has been found to be administered than phosphorus (Lourenzi et al. 2014; Ator and Denver 2015). Another factor contributing to more nitrogen export is a more permeable ground water table that easily allows nutrients to pass through (Lourenzi et al. 2014).

Since most of the regulating services form part of the 15 ES that the MA (2005) has found to be degraded, mainly through anthropogenic activities (Coetzee 1995; Kling et al. 2003; MA 2005) these BRs cannot be exempted from this in view of various human activities taking place in the transition zone. Evidence of mining prospecting applications granted even in the buffer and core zones (Department of Minerals and Energy register), and mining being identified as one of the economic growth catalysts (VDMIDP 2012; WDMIDP 2013) suggest the likelihood of more mining activities taking place in the foreseeable future. Mining activities are associated with various impacts on aquatic ecosystems (Klemow 2000), affecting these habitats (Butler 2006; Besser et al. 2009) and water quality (Phillips 2001; Besser et al. 2009). Since BRs do not have formal legal protection, it might be difficult to counter these activities. It is therefore important to note that the sustainability of wetlands and associated ecosystems providing regulating ES lies in the hands of the surrounding human communities, and degradation of such areas will affect the delivery of important ES.

4.4.2.3 Cultural services

The finding of more bird areas as indicators of cultural services in WBR than in the VBR could be attributed to the prevailing naturalness in this BR, especially its less developed state. Although most of these important bird areas have already been incorporated in some of the PAs, some have been left out. However, it was comforting to realise that most of these areas were recognised as part of critical biodiversity areas.

Results suggested great potential for economic growth and employment through cultural ES, i.e. recreation, in the study area. Tourism contributes an average of over two million rands annually in Vhembe (VDMIDP 2012). Although no information was available on the contribution of tourism to the Waterberg region, it was clear that this type of LU contributed positively to the rest of the Limpopo Province, where it was acknowledged as a catalyst for economic growth and job creation (LGDS 2005; VDMIDP 2012; WDMIDP 2013) and also as a driver of LU change (De Klerk 2003; LDA 2011). The situation in the WBR and VBR in terms of tourism development was also influenced by the fact that the recreational and tourism industries were among the fastest growing industries in the world (Dilys and Urquhart 2001; Van der Merwe and Saayman 2003; WTTC 2012), serving as an important source of income and employment. (Dilys and Urquhart 2001; McMichael et al. 2003; MA 2005). SA was no exception.

4.4.2.4 Supporting services

Although critical biodiversity areas were well represented in both BRs, they were found not to be aligned with the national PAs expansion strategy, and very small portions fell within the existing PAs in both BRs. It was clear that the current PAs expansion strategy for SA (2008) was not informed by the critical biodiversity areas, despite the fact that this information was already available (since 2004). We were expecting critical biodiversity areas to inform the PAs expansion strategy.

Although it seemed that there were abundant supporting services and most were found to be reasonably intact in both BRs, evidence suggested that in the sphere of supporting ES, various human activities, such as mining, agriculture and tourism (FAO 1998; MA 2005), were affecting these kinds of services negatively. Although the impact of supporting ES directly or indirectly can only be proven after a long time (MA 2005; UNEP 2009), there is no doubt that their degradation is likely to affect the direct delivery of basic ES, i.e. food and water necessary for human well-being. In both BRs mining is more likely to affect mountain ecosystems in the near future, when considering current trends and prospects that there are sought-after minerals in the Waterberg and Soutpansberg complex, as evidenced by prospecting applications. The impact of mining on these mountains could affect ES such as water resources, since mountains are instrumental in hydrological cycles (Beniston et al. 1997; MA 2005) and most rivers and wetlands in the BRs originate from the mountain slopes. Indicators contributing to soil formation will also be affected, since soil originates from the weathering process of geological formations (AgriInfo 2011) such as mountains.

4.5 CONCLUSIONS

This study has identified and provided a spatial representation of some of the ES services mapped in SA to date and indicators used to map them on a local scale represented by VBR and WBR. Information provided by this study will thus assist in bridging the gap of lack of baseline information regarding ES in a BR context. Although data collated in this analysis will assist in raising awareness about BRs and ES in general, more work needs to be done to make societies aware of the value of ES to human well-being. Insufficient data on the case study areas highlight research gaps that need to be addressed if the concept of ES is to be successfully adopted and integrated in decision-making on LU planning. Information provided by this study will serve as baseline data for future ES related studies, including mapping and valuation in SA and BRs elsewhere.

Since some of the indicators in SA were found to be threatened and endangered, including wetlands and rivers (NSBA 2004), government-funded programmes such as Working for Water, responsible for the removal of alien species along some of the major rivers, and Working for Wetlands, focusing on wetland rehabilitation, should be encouraged in order to improve the functioning of these ES in both BRs. Government intervention is also needed to inform legal means that will protect the status of BRs in SA. Perhaps the inclusion of the BR concept as one of the International Union for the Conservation of Nature's formal PA categories could assist globally, in ensuring the sustainability and protection of BRs from anthropogenically driven degradation. Ways and means should also be found to encourage research studies, which could be collated in a BR database, raising further awareness of the BR concept.

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4.7 APPENDICES

4.7.1 Appendix 4A: Selected ES typologies/classification frameworks.

Daily (1997)	MA (2005)	Bastian and Schreiber (1999)	de Groot et al. (2010)	CICES (2011)
Production of goods	Provisioning services	Economic services	Provisioning services	Provisioning
Food	Food	Renewable resources (herbal and animal) biomass/non-renewable resources (mineral raw materials and fossil fuel)	Food	Nutrition -
				Plants and animals (terrestrial, marine and freshwater
-	Fresh water supply	Available renewable resource: water	Water	Potable water
Pharmaceuticals	Biochemicals - natural medicines and pharmaceuticals	-	Biochemical products and medicinal resources	Materials
				Medicinal resources
Genetic resources	Genetic resources	-	Genetic materials	Genetic resources,
-	Ornamental resources - animals and plant products (skin, shells, flowers)	-	Ornamental species and/or resources	Skins, shells, bones
Energy (biomass fuel)	Fibre - wood, cotton, wool, silk, timber	-	Fuel, fibre and other raw materials	Timber

	Biomass fuel			Energy Wood, energy crops, dung, fat, oils
Industrial products	-	-	-	-
Regeneration processes	Regulation services	Ecological services	Regulation services	Regulation and maintenance
Partial stabilization of climate	Climate regulation - of temperature and precipitation and/or greenhouse emission or sequestration	Regulation of materials and energy cycles	Climate regulation	Physical environment regulation
Moderation of weather extremes			Air quality regulation	Atmospheric regulation (climate, carbon sequestration)
Water purification and waste treatment - the filtering out, detoxification and decomposition of organic waste in water bodies through soil processes	Water purification and waste treatment - the filtering out, detoxification and decomposition of organic waste in water bodies through soil processes		Waste treatment	Water quality regulation (purification and oxygenation), water cooling
			Soil formation and regeneration	Paedogenesis and soil quality regulation (maintenance of soil fertility)
Control of pests and species	Disease regulation - control of human pathogens (e.g cholera) and disease vectors (e.g mosquitoes)	Regulation and regeneration of population and biocoenose	Biological regulation	Regulation of biotic environment
				Pest and disease control

Stabilising processes	Pollination	-	Pollination	Life cycle maintenance and habitat protection (pollination and seed dispersal)
Translocation processes (seed dispersal)				
Cycling and filtration processes		-	-	Gene pool protection (nursery)
	Erosion regulation	-	Erosion protection	Flow regulation
				Mass flow regulation (erosion and avalanche protection)
Coastal and river channel stability	Storm protection	-	Natural hazard mitigation	Airflow regulation (windbreak, shelter belts)
Regulation of hydrological cycle	Water regulation	-	Water regulation	Water flow regulation
Life-fulfilling functions	Cultural services	Social services	Cultural and amenity	Cultural
-	Recreation and ecotourism	Recreational function	Recreation and tourism	Intellectual and experiential
				Recreation and community activities (charismatic or iconic wildlife or habitats)
Scientific discovery	Educational values and knowledge systems	Information function (science and education)	Education and science	Information and knowledge (scientific, educational, prey for hunting or collection)
Cultural, intellectual and spiritual inspiration	Cultural heritage and diversity	Psychological function (aesthetic, ethic)	Cultural heritage and identity	Symbolic
				Heritage (cultural landscapes, landscape)

	Spiritual and religious values, inspiration		Spiritual and religious inspiration	Spiritual (wilderness, naturalness, sacred places or species)
Aesthetic beauty	Aesthetic values		Aesthetic	Aesthetic
Serenity	Sense of place		-	Sense of place, tranquillity
Existence value	-	-	-	-
Preservation of options	Supporting services		Habitat or supporting services	
Maintenance of the ecological components and systems needed for future supply	Nutrient cycling	-	Nursery habitat	
	Pollination	-	Gene pool protection	
-	Primary production	-		
	Photosynthesis			
-		-		
-	Soil formation	-		

4.7.2 Appendix 4B: Literature reviewed

Extent of the study	Ecosystem services involved	Primary indicator	Secondary Indicators	Source
Local	Food provision	Fodder provision	Livestock	O'Farrell 2011
Local	Food provision	Fodder provision	Livestock	Reyers 2009
Local	Food provision	Fodder provision	Vegetation map	Egoh 2010
Local	Food provision	Grain production	Crop yield	van Jaarsveld 2005
National	Water provision	Fodder provision	Livestock	Wilgen 2008
Local	Water provision	Water supply	Surface water	O'Farrell 2011
Local	Water provision	Water supply	Ground water	O'Farrell 2011
Local	Water provision	Water supply	Surface water	Egoh 2011
National	Water provision	Water supply	Surface water	Egoh 2009

Local	Water provision	Water supply	Surface/ground water	van Jaarsveld 2005
National	Water provision	Water supply	Surface water	Wilgen 2008
National	Water provision	Water supply	Surface water	Egoh et al. 2008
Local	Raw materials	Fuel wood	Wood production	van Jaarsveld 2005
Local	Raw materials	Raw material	Raw material	Chisholm 2010
National	Climate regulation	Carbon storage	Vegetation map	Egoh et al. 2008
National	Climate regulation	Carbon storage	Vegetation map	Egoh 2009
Local	Climate regulation	Carbon storage	Above ground biomass	Reyers 2009
Local	Climate regulation	Carbon storage	Above ground biomass Vegetation map	Egoh 2010
Local	Climate regulation	Carbon storage	Soil carbon	Egoh 2011
Local	Climate regulation	Carbon sequestration	Above ground	Egoh 2011

			biomass	
Local	Climate regulation	Carbon sequestration	Nutrient flux	Chisholm 2010
National	Regulation of water flows	Water regulation	Ground water	Egoh 2008
National	Regulation of water flows	Water regulation	Ground water	Egoh 2009
Local	Regulation of water flows	Water regulation	Flow regulation Water regulation	Reyers 2009
Local	Regulation of water flows	Water recharge	Ground water Water characteristics	Egoh 2010
National	Regulation of water flows	Water regulation	Ground water	Egoh 2011
National	Erosion prevention	Soil retention	Vegetation map	Egoh 2008
National	Erosion prevention	Soil retention	Vegetation map	Egoh 2009
Local	Erosion prevention	Soil retention	Vegetation map	Egoh 2011
Local	Erosion prevention	Soil erosion	Precipitation	Reyers 2009

National	Soil accumulation	Soil depth	leaf	Egoh 2008
National	Maintenance of soil fertility	Soil productivity	Soil characteristics	Egoh 2009
Local	Maintenance of soil fertility	Soil productivity	Soil characteristics	Egoh 2011
Local	Aesthetic enjoyment	Spiritual, aesthetic, recreational services	Protected areas	van Jaarsveld 2005
Local	Recreation and tourism	Potential Tourism	Viewsheds	Reyers 2009
Local	Recreation and tourism	Potential Tourism	Viewsheds	Reyers 2009
Local	Recreation and tourism	Tourism	Flower viewing	O'Farrell 2011 .
Local	Recreation and tourism	Tourism	Viewsheds	O'Farrell 2011

4.7.3 Appendix 4C: Spatial representation of indicators of ecosystem services in Waterberg and Vhembe Biosphere Reserves

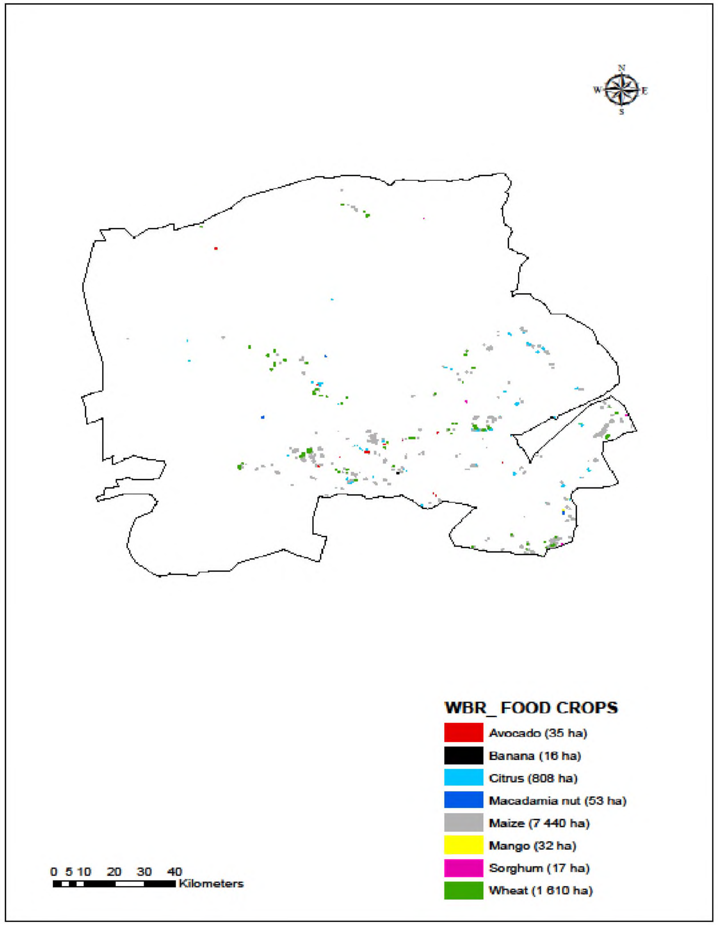

Figure 4C.1 An illustration of an indicator of food provisioning service in WBR, represented by horticultural and agricultural crops.

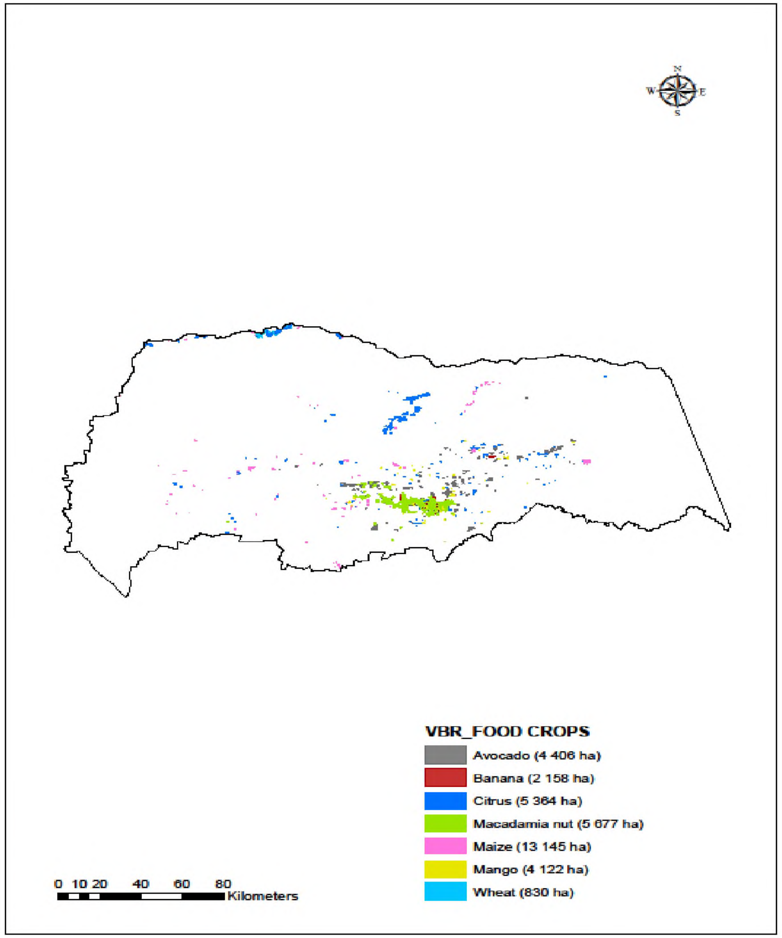

Figure 4C.2 An illustration of an indicator of food provisioning service in VBR, represented by horticultural and agricultural crops.

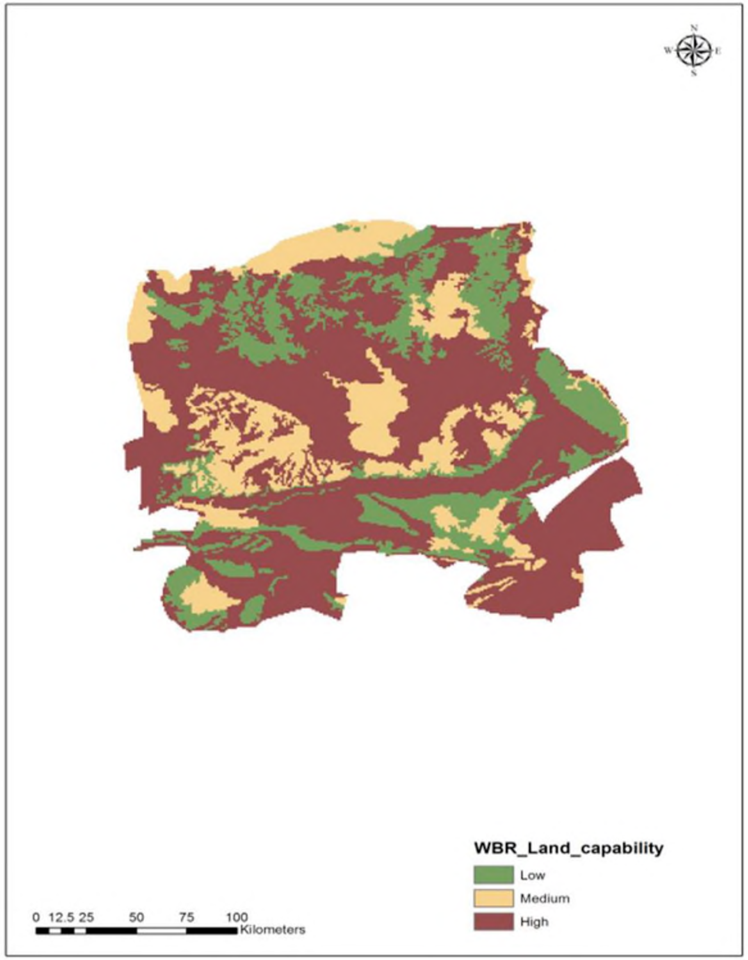

Figure 4C.3 An illustration of an indicator of food provisioning service in WBR, represented by land capability to produce agricultural crops.

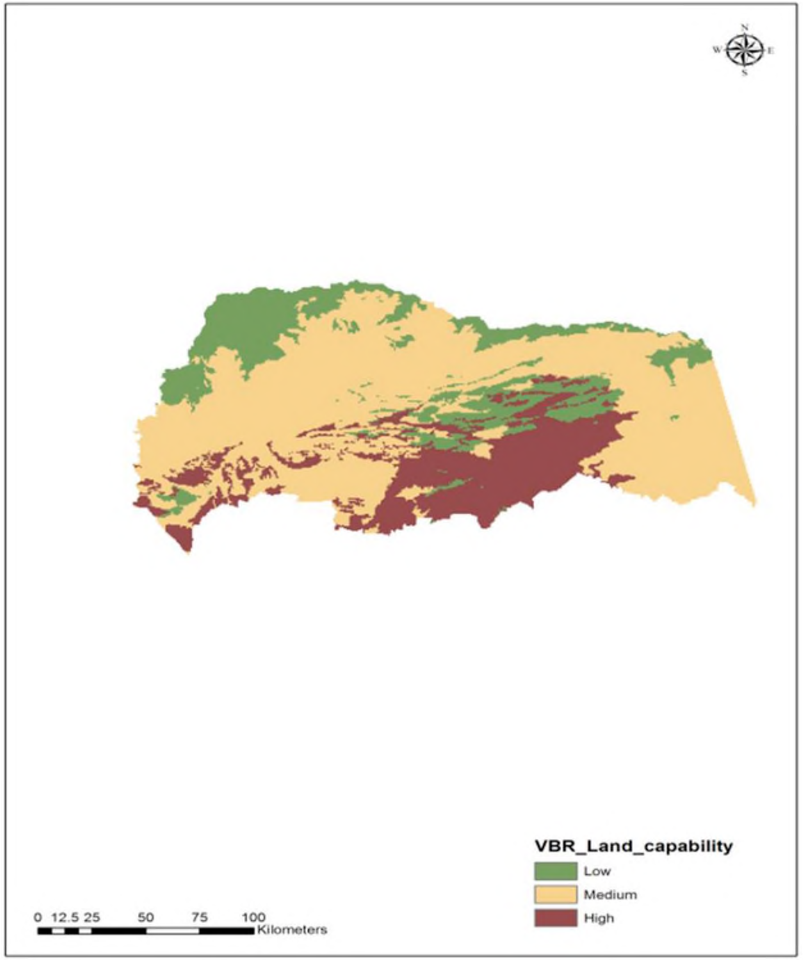

Figure 4C.4 An illustration of an indicator of food provisioning service in VBR, represented by land capability to produce agricultural crops.

Figure 4C.5 An illustration of food provisioning indicator in WBR, represented by game farms.

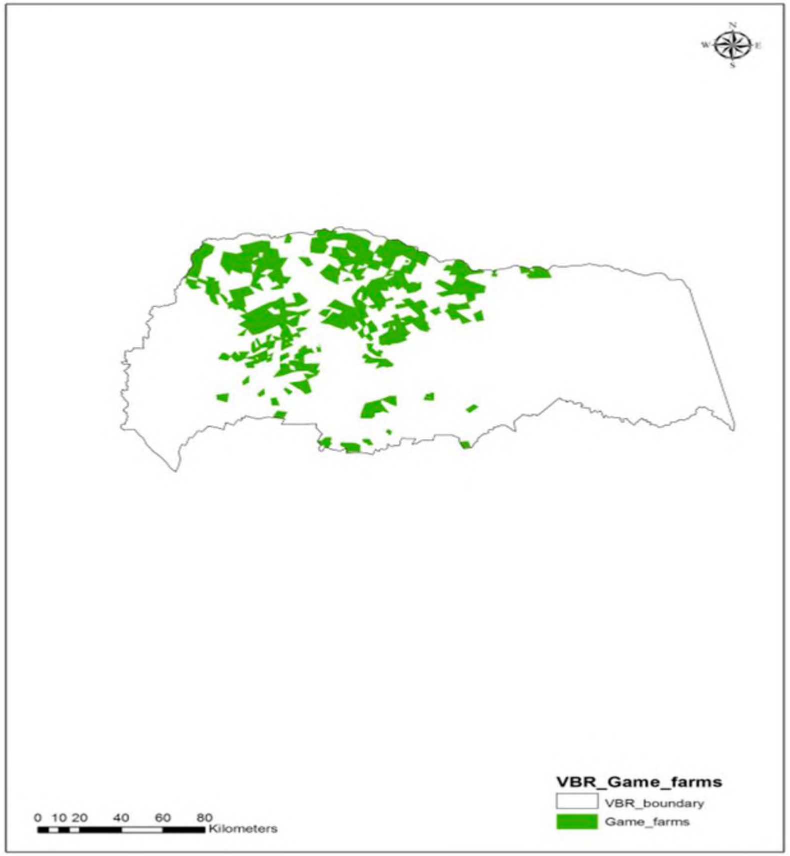

Figure 4C.6 An illustration of food provisioning indicator in VBR, represented by game farms.

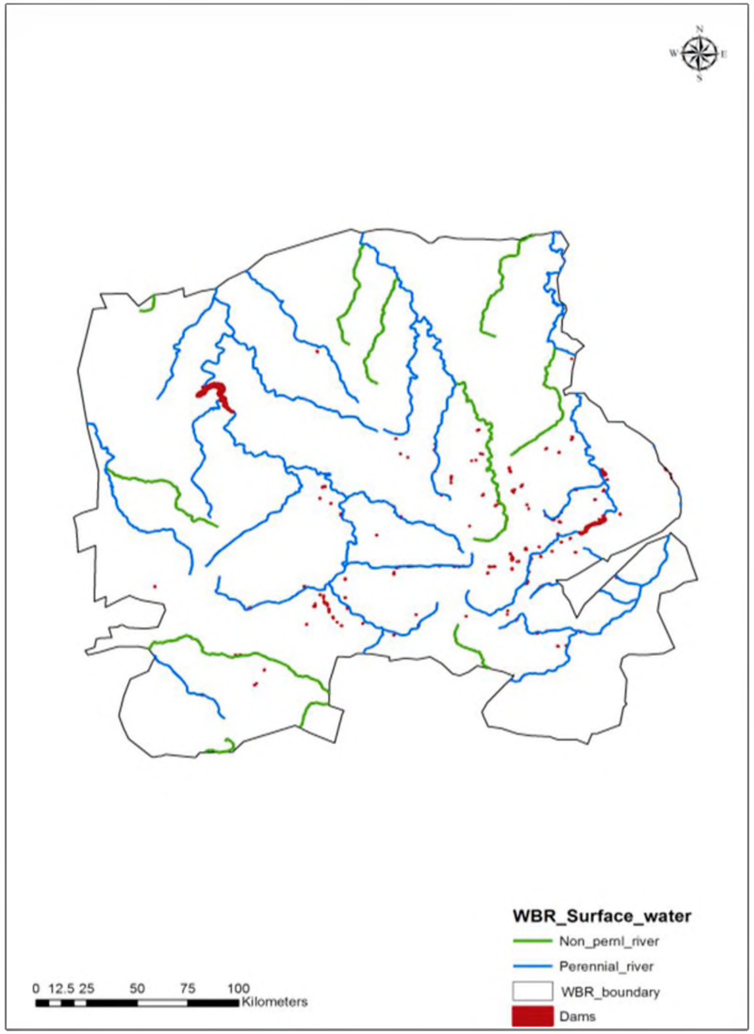

Figure 4C.7 An illustration of an indicator for water provisioning service in WBR, represented by surface water supply by rivers and dams

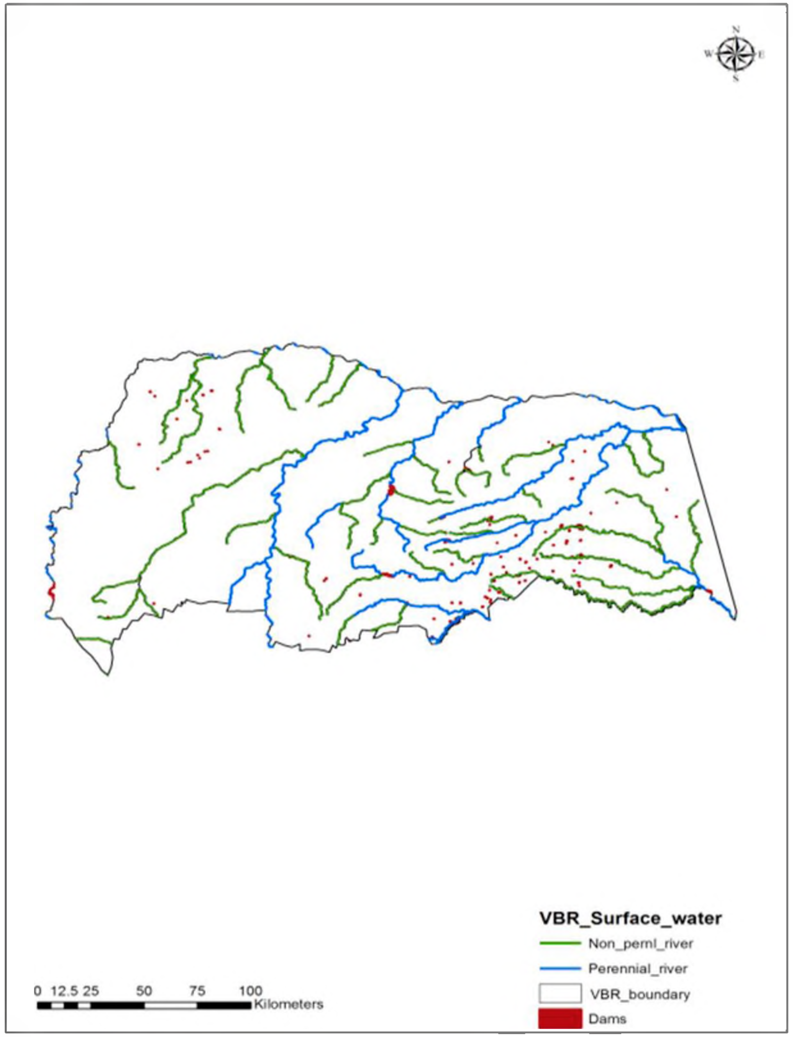

Figure 4C.8 An illustration of an indicator for water provisioning service in VBR, represented by surface water supply by rivers and dams

Figure 4C.9 An illustration for an indicator of water provisioning service in WBR, represented by important catchment areas. (calculated using mean annual runoff MAR)

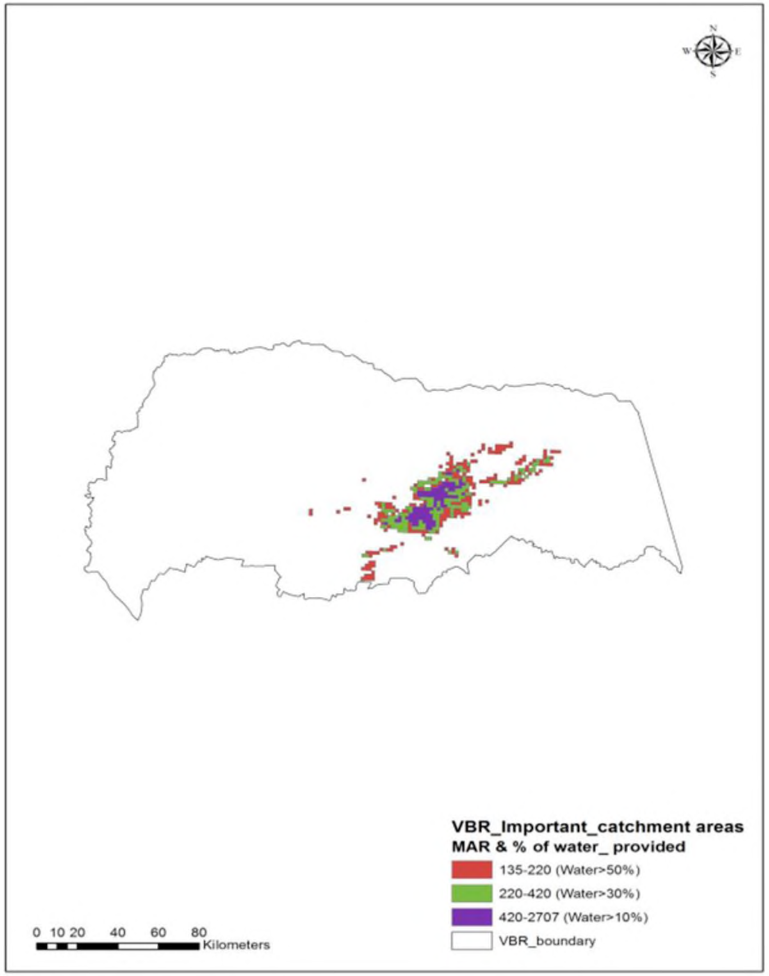

Figure 4C.10 An illustration of an indicator of water provisioning service in VBR, represented by important catchment areas. (calculated using mean annual runoff MAR).

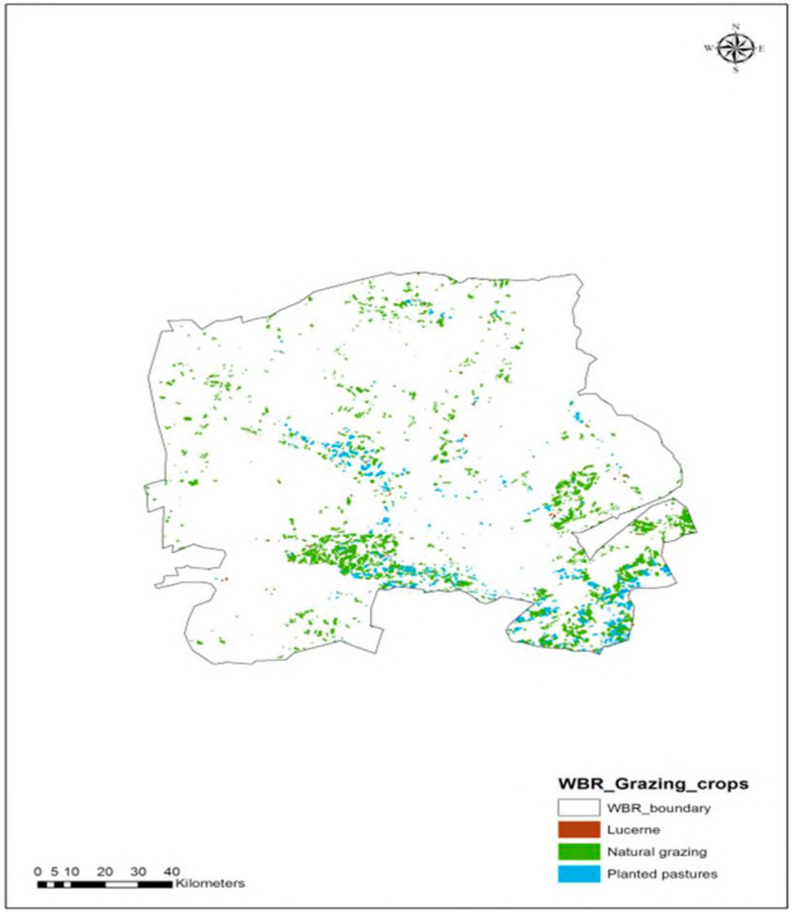

Figure 4C.11 An illustration of an indicator of fodder provisioning service in WBR represented by hectares of land covered by grazing crops (natural grazing, lucerne and planted pastures)

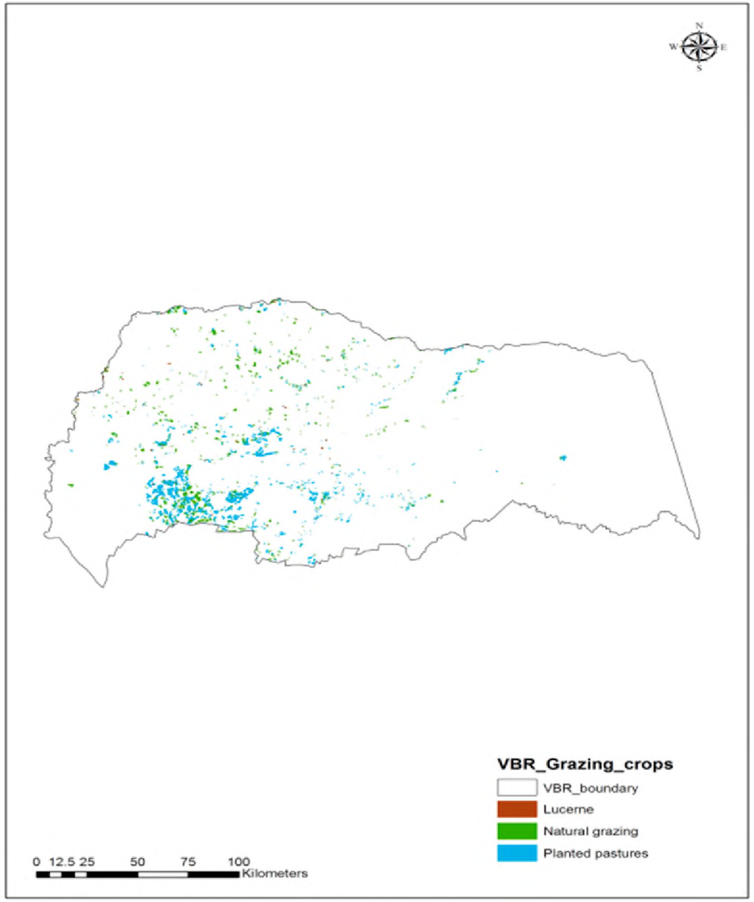

Figure 4C.12 An illustration of an indicator of fodder provisioning service in VBR represented by hectares of land covered by grazing crops (natural grazing, lucerne and planted pastures)

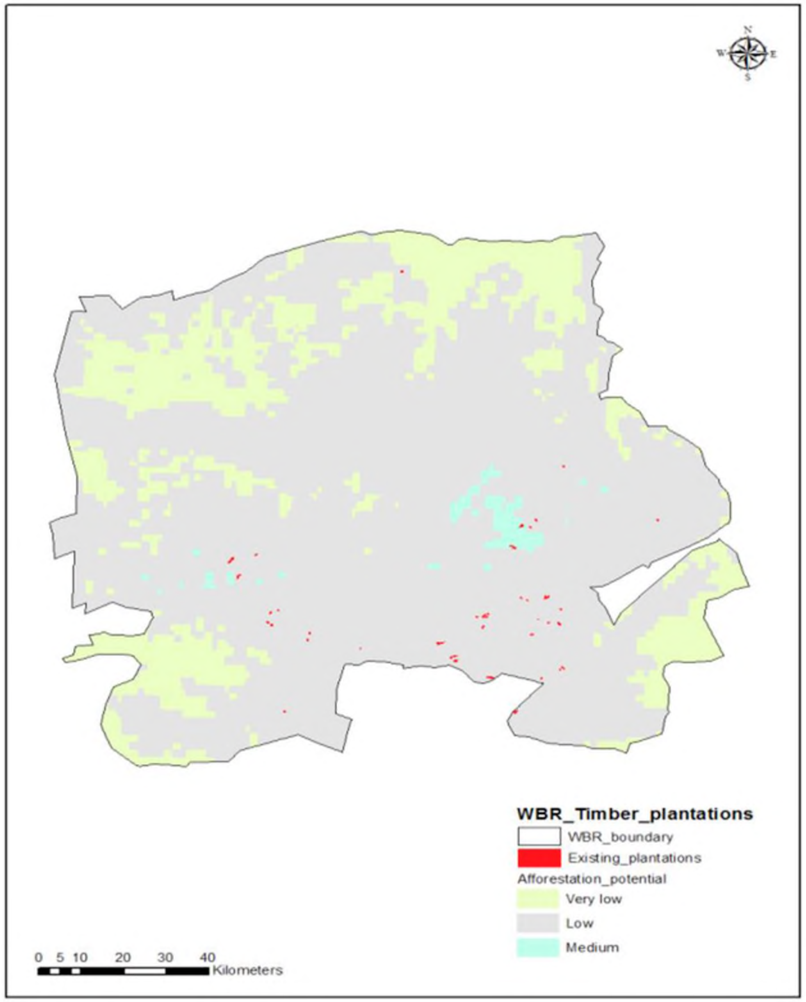

Figure 4C.13 An illustration of an indicator of raw material provisioning service in WBR, represented by land covered by timber plantations and potential afforestation areas.

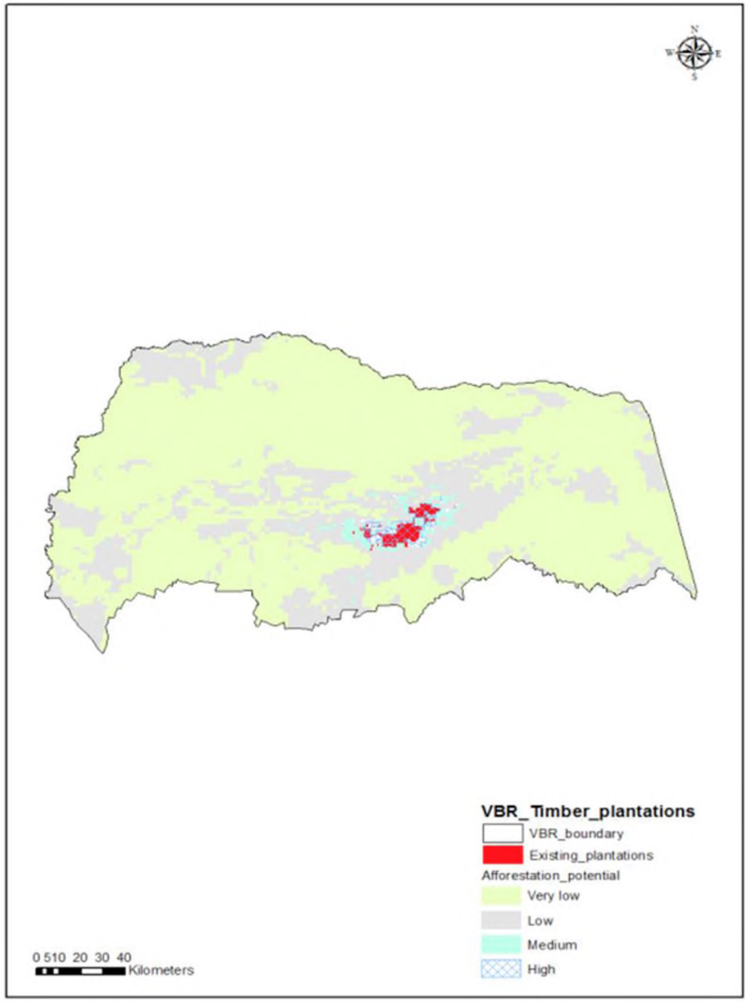

Figure 4C.14 An illustration of an indicator of raw material provisioning service in VBR, represented by land covered by timber plantations and potential afforestation areas.

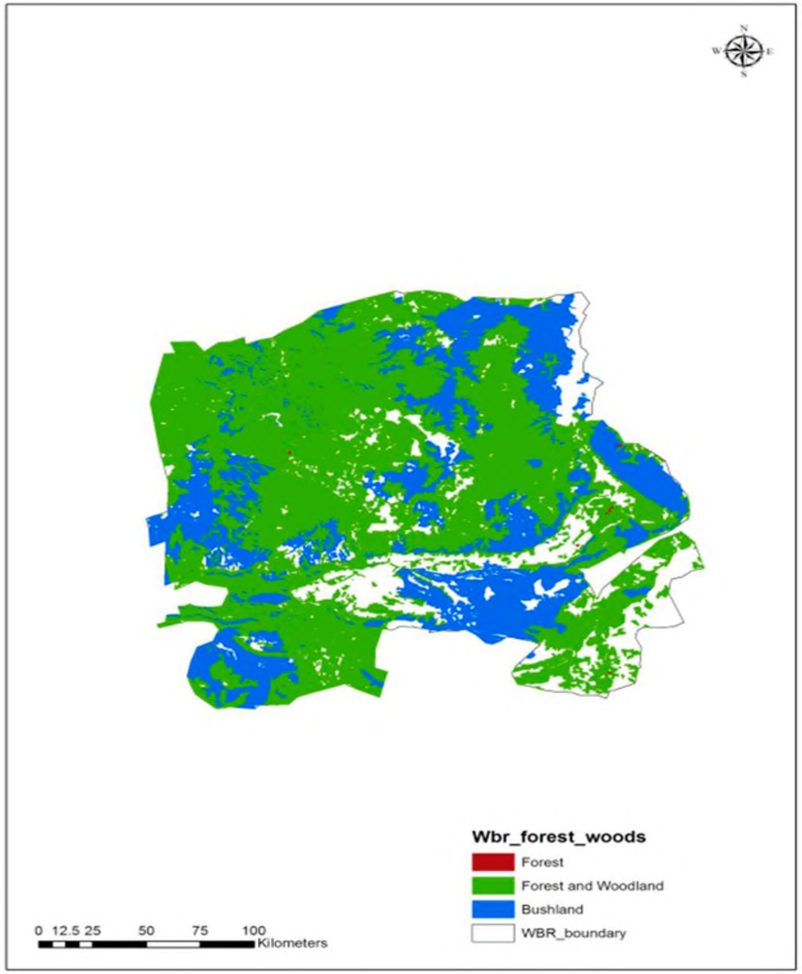

Figure 4C.15 An illustration of an indicator of regulating service in WBR, represented by vegetation cover.

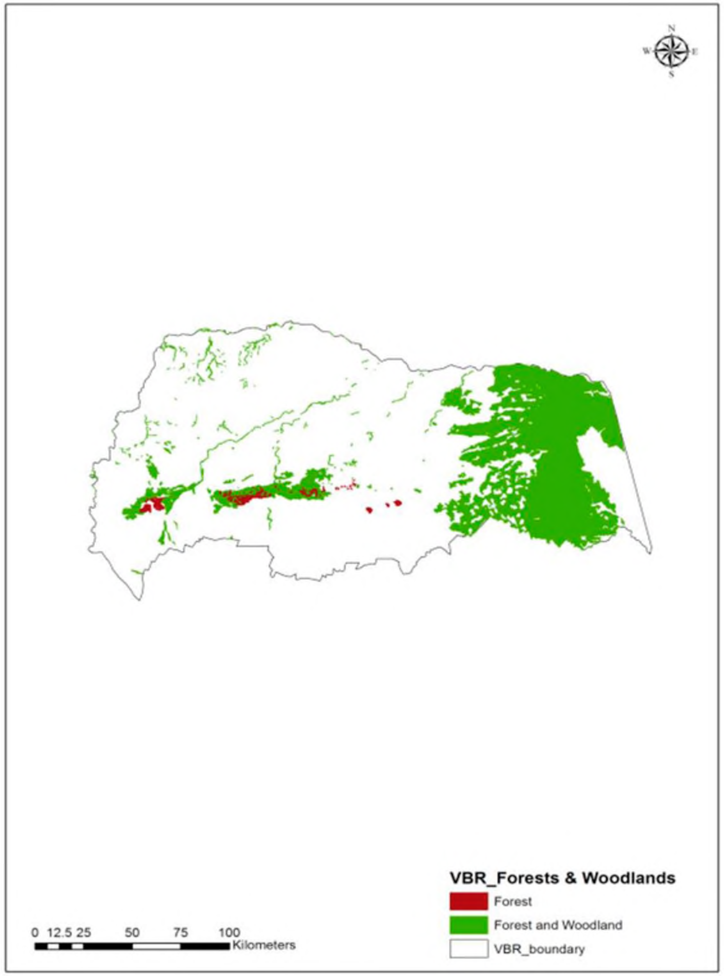

Figure 4C.16 An illustration of an indicator of regulating service services in VBR represented by vegetation cover.

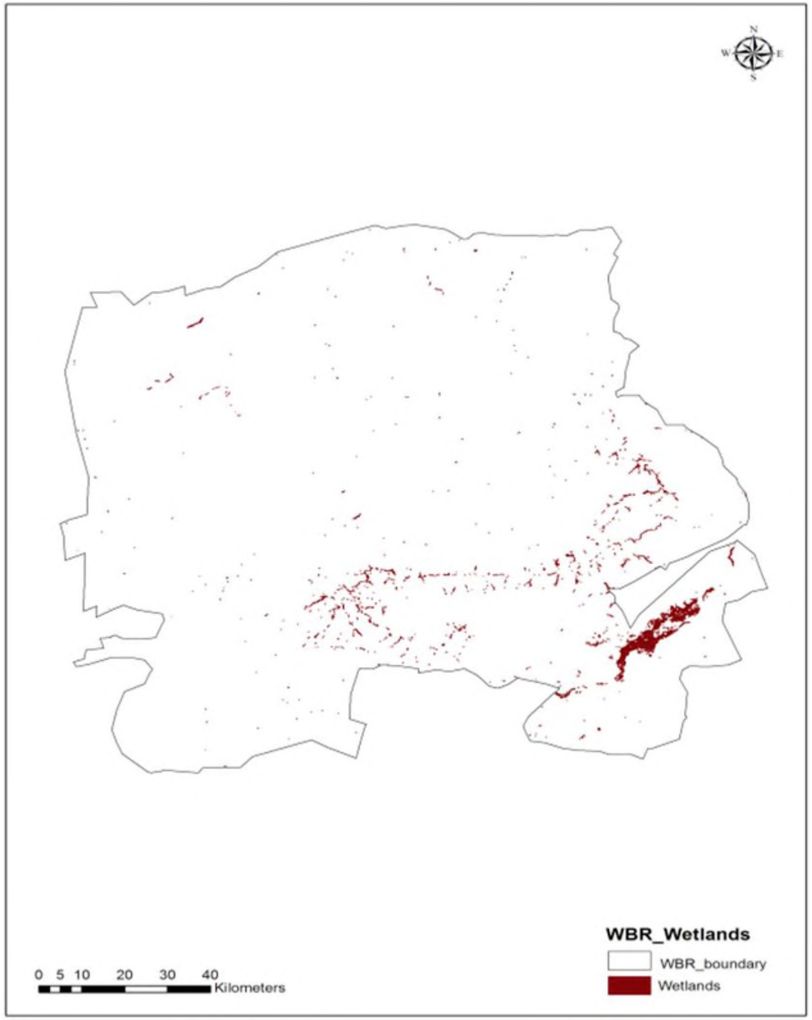

Figure 4C.17 An illustration of an indicator of regulating service in WBR, represented by areas covered by wetlands.

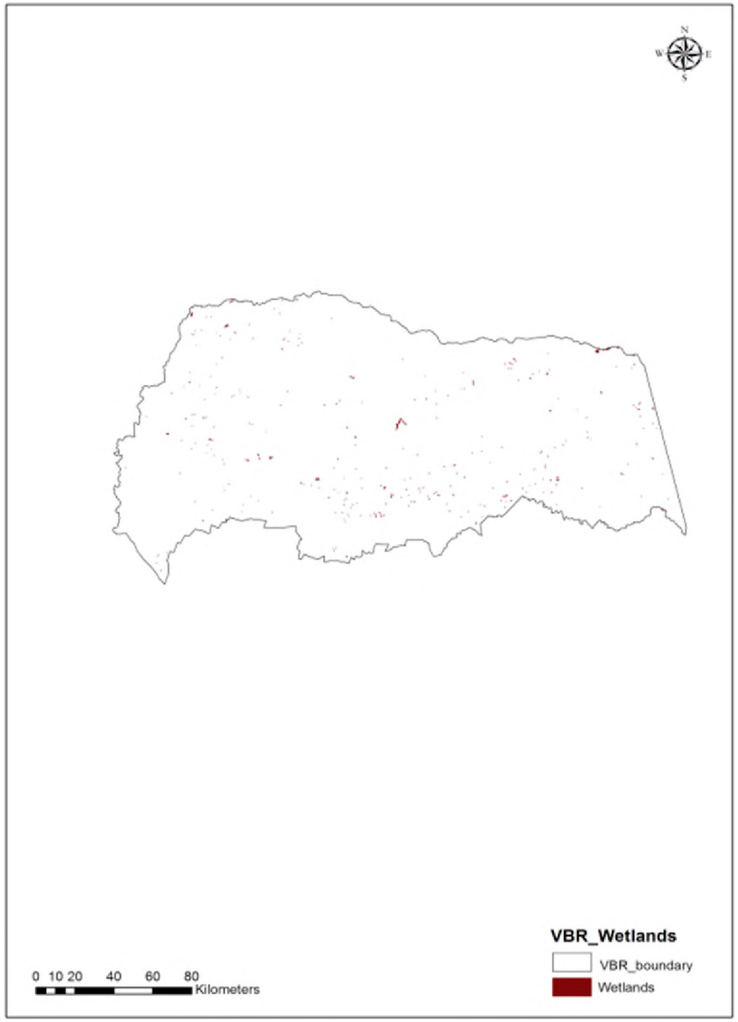

Figure 4C.18 An illustration of an indicator of regulating service in VBR, represented by areas covered by wetlands.

Figure 4C.19 An illustration of biodiversity support indicator
in WBR, represented by biogeographic areas (ecological support areas)

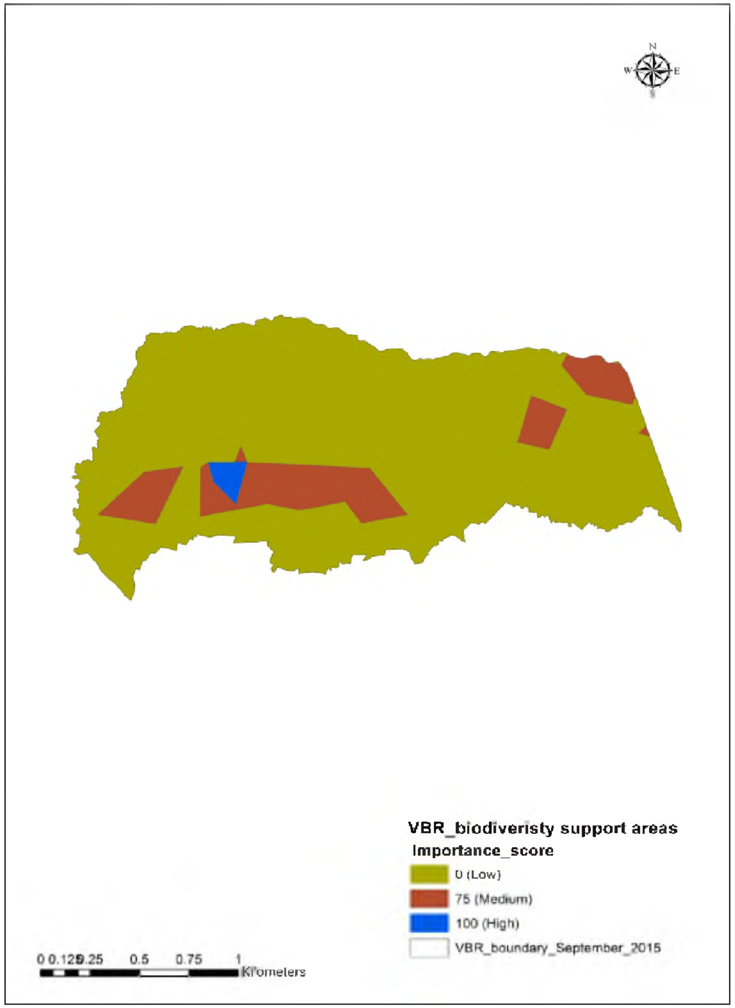

Figure 4C.20 An illustration of biodiversity support indicator
in VBR, represented by biogeographic areas (ecological support areas)

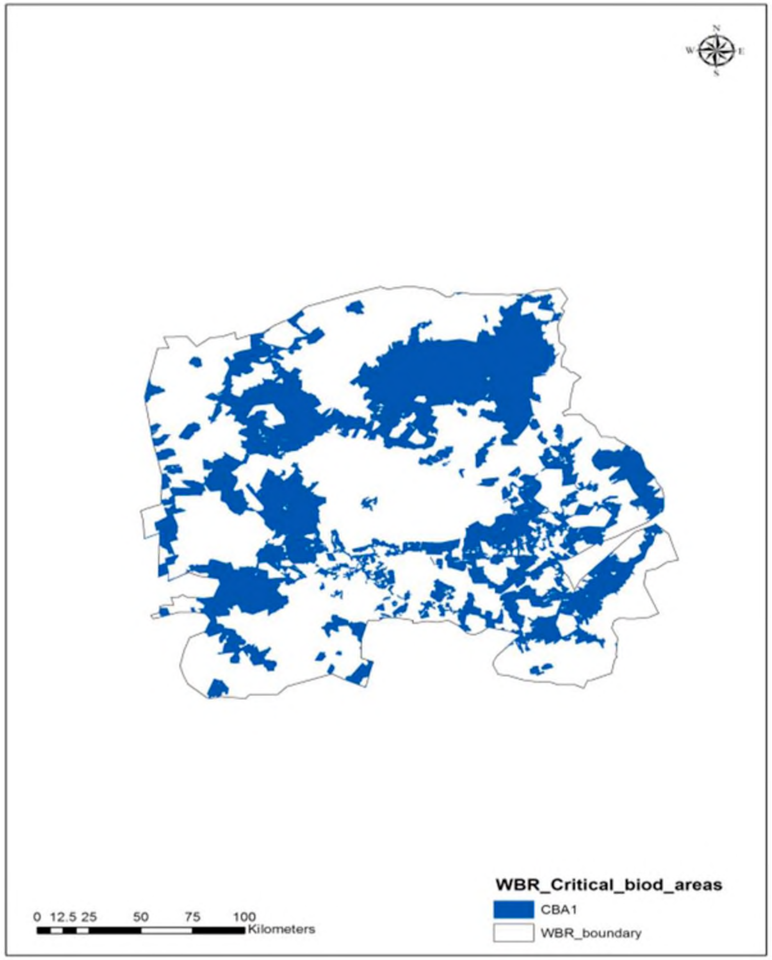

Figure 4C.21 An illustration of an indicator of supporting service in WBR represented by critical biodiversity areas.

Figure 4C.22 An illustration of an indicator of supporting service in VBR represented by critical biodiversity areas.

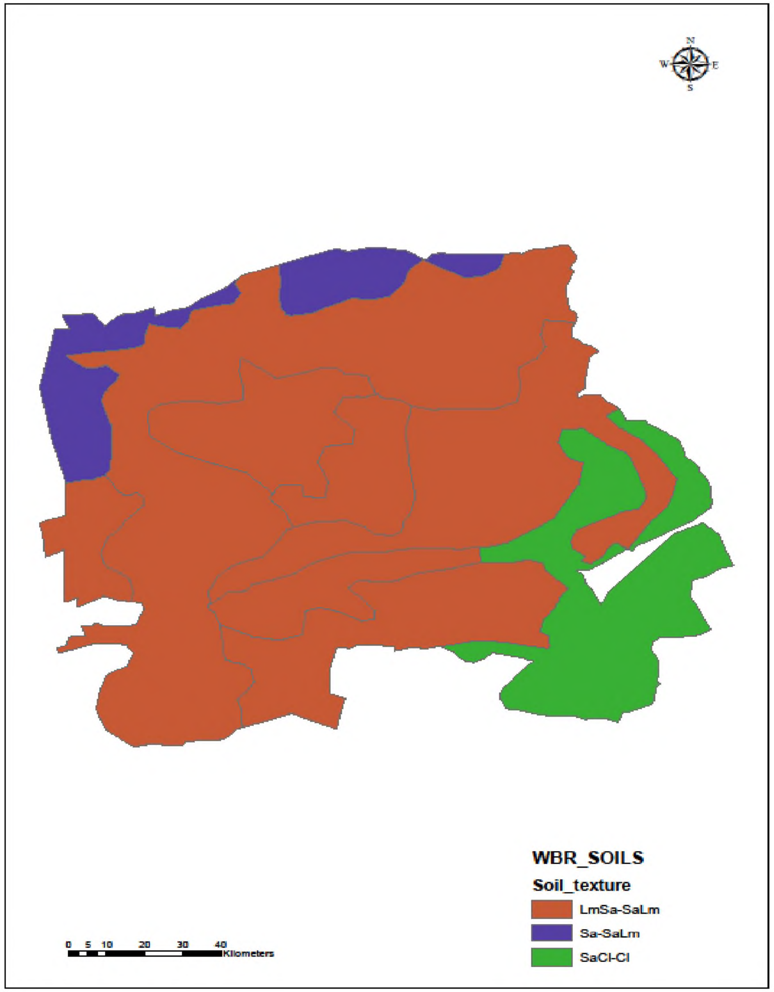

Figure 4C.23 An illustration of a supporting service indicator in WBR represented by soil characteristics (forms).

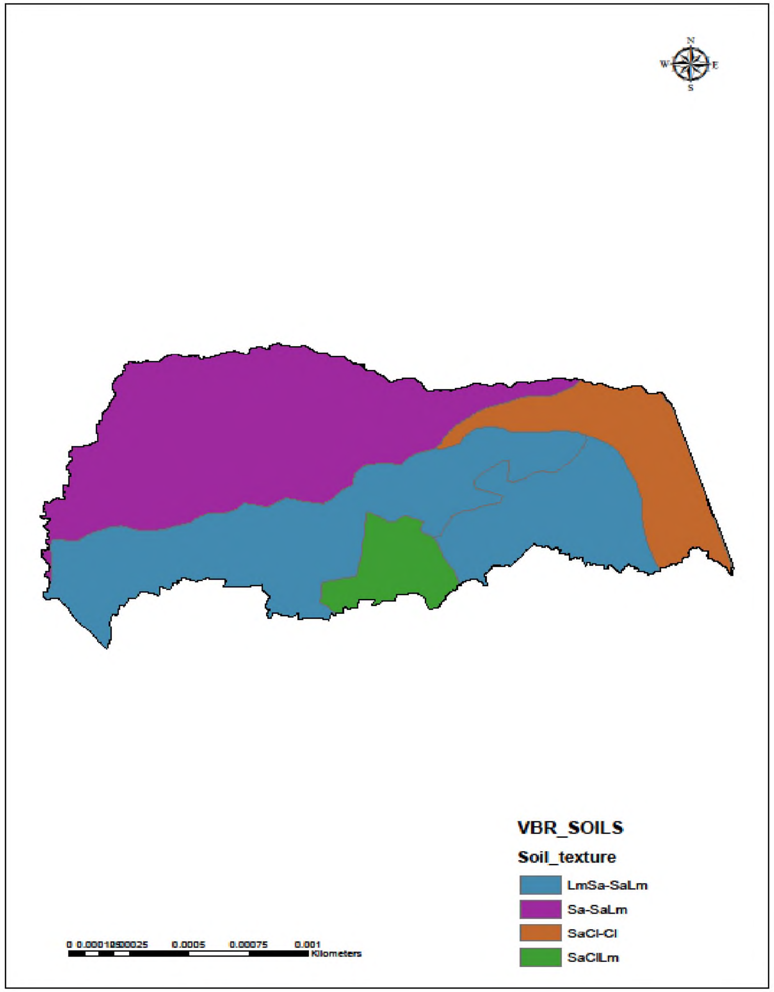

Figure 4C.24 An illustration of a supporting service indicator, in VBR, represented by soil characteristics (forms).

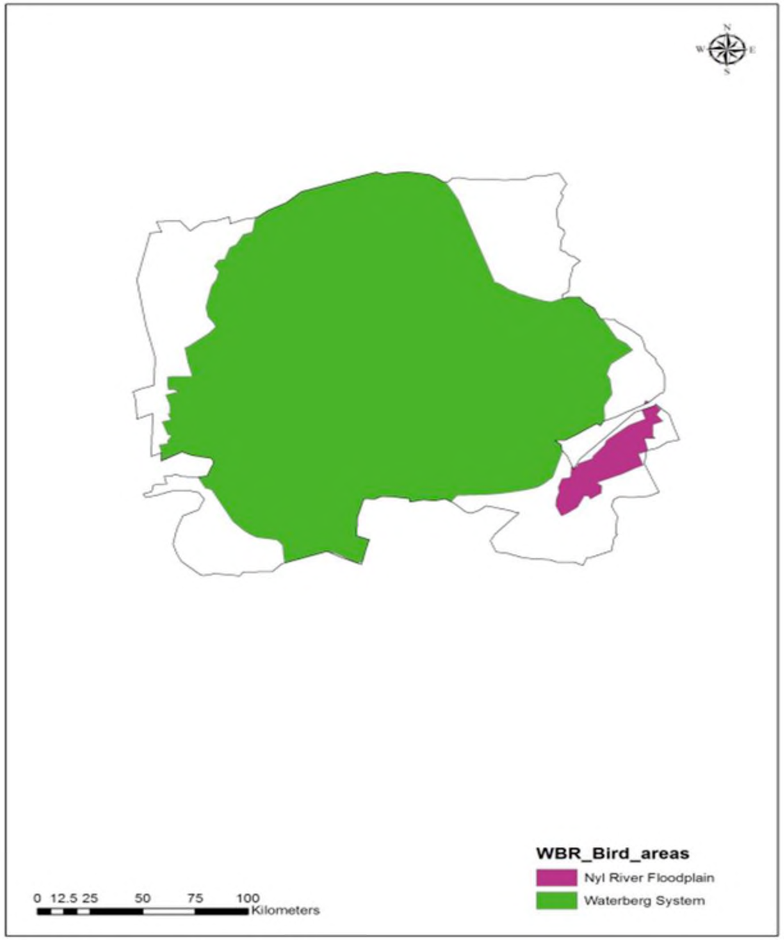

Figure 4C.25 An illustration of an indicator of cultural Service (recreational and ecotourism) in WBR, represented. by important bird areas.

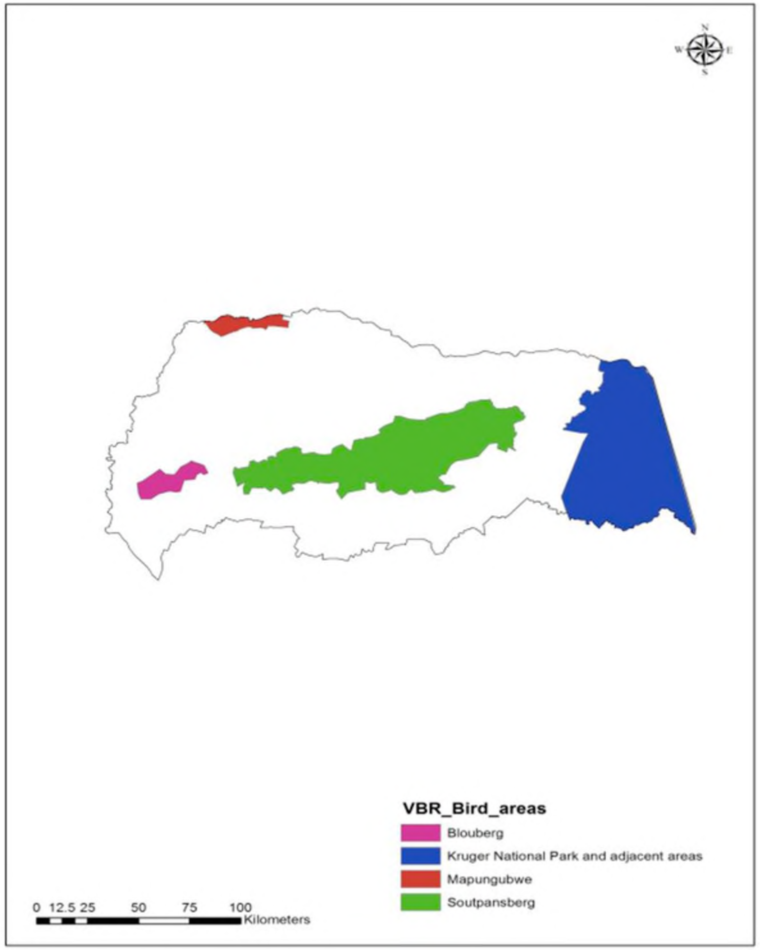

Figure 4C.26 An illustration of an indicator of cultural services (recreational and ecotourism) in VBR, represented by important bird areas.

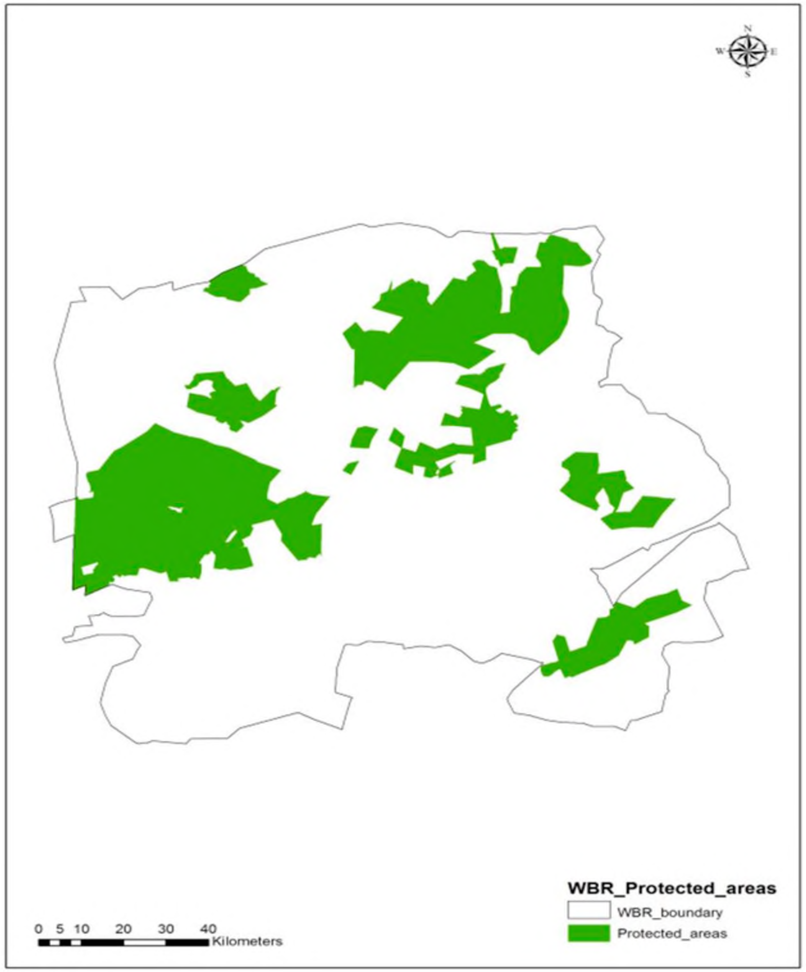

Figure 4C.27 An illustration of an indicator of cultural service (recreational and ecotourism) in WBR, represented by by protected areas.

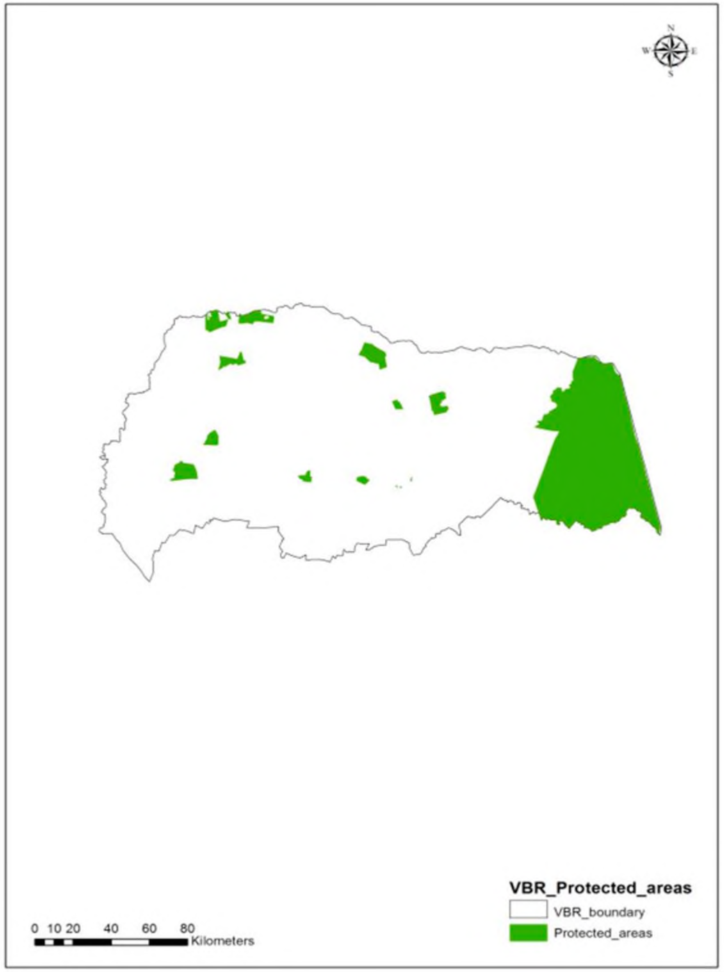

Figure 4C.28 An illustration of an indicator of cultural service (recreational and ecotourism) in VBR, represented by protected areas.

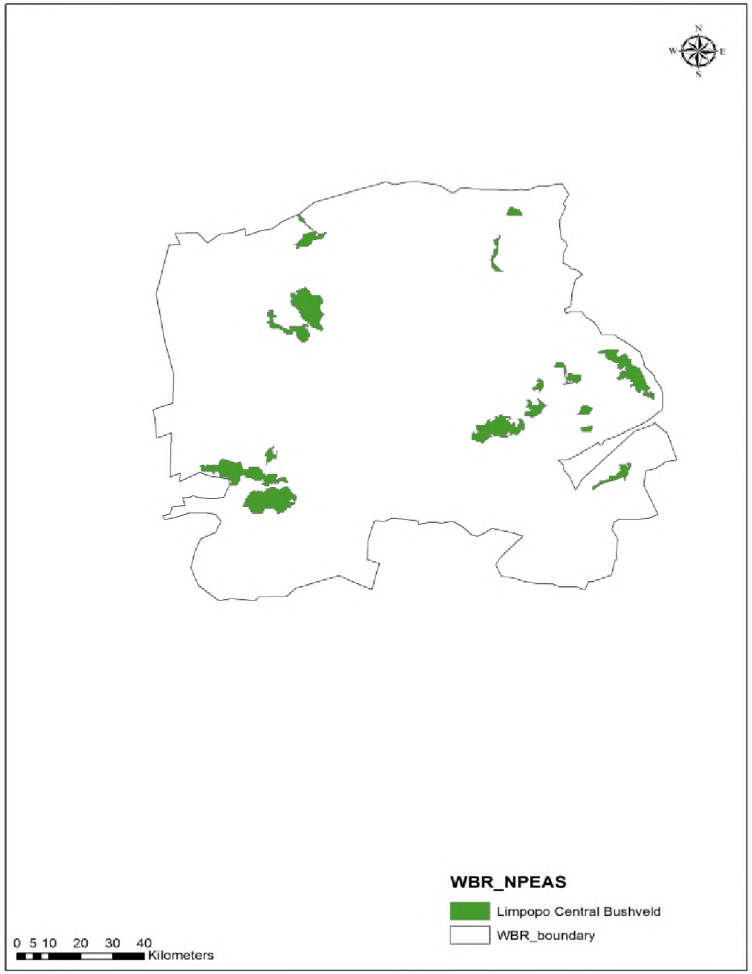

Figure 4C.29 An illustration of an indicator of cultural service in WBR (aesthetic quality), represented by protected expansion focus areas.

Figure 4C.30 An illustration of an indicator of cultural service in VBR (aesthetic quality), represented by protected expansion focus areas.

CHAPTER 5

HABITAT CONDITION ASSESSMENT FOR ECOSYSTEM SERVICES

This chapter has been published on *International Journal of Biodiversity Science, Ecosystem Services & Management* as: Ntshane B.C and Gambiza, J. Habitat condition assessment for ecosystem services.

Abstract

Biodiversity is the foundation of life-support systems on earth and underpins the delivery of ecosystem services (ES) important for human well-being. The loss of biodiversity worldwide, however, remains one of the most daunting challenges. Among the major causes of biodiversity loss is habitat loss due to transformation of land to agricultural, mining and urban areas. We applied the Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) modelling tool to assess the condition of habitats as a service that provides living spaces for plants and animals, and as a supporting service for the delivery of other ES in a biosphere reserve in South Africa. Results indicated that 72% of the surveyed habitats were of high quality to provide the necessary services. However, some of the habitats were found to be affected by threats as follows: low (0-20%) to moderate (20-32%) habitat loss was recorded in habitats adjacent to mining and plantation areas, and high (32-56%) to severe (56-95%) habitat loss was recorded in habitats in close proximity to urban and cultivated areas. At least 56% of the vegetation types found in the study area were threatened by transformation to agriculture, mining and urban areas. We strongly recommend that existing biodiversity policies and legislation should be enforced to avoid habitat loss and degradation.

Key words: *biodiversity; ecosystem services; habitat loss; habitat quality; valuation; human well-being.*

5.1 INTRODUCTION

The protection of biodiversity is an international obligation, with approximately 200 nations committing to it (CBD 1992). The term biodiversity originates from the concept of biological diversity, which was coined during the 20^{th} century (Dasmann 1968; Soule and Wilcox 1980) and has been in use for almost three decades (Wilson 1988; Bibby et al. 1992; Eldredge 1992; Harper and Hawksworth 1994; Gaston 1996). The Convention on Biological Diversity (CBD 1992) defines biodiversity as "the variability amongst living organisms from all sources including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part, this includes diversity within species, between species and ecosystems". The definition of the International Union for the Conservation of Nature (IUCN 2010) refers to biodiversity as a "wide range of ecosystems and living organisms, plants, animals, their habitats and their genes". This study adopts the Millennium Ecosystem Assessment (MA), (2005), which defines biodiversity as "the diversity of life on Earth" and "an essential component that contribute[s] to the functioning of ecosystems that underpin the provisioning of ecosystem services (ES) that ultimately affect human well-being", because of its association with ES.

For biodiversity protection and safeguarding to be effective, sound conservation strategies must exist. A protected areas (PAs) system was established with the primary goal of protecting and conserving biodiversity (IUCN 2004; Tallis et al. 2011; Stolton 2010). Other conservation strategies include stewardship programmes, implying ongoing commitment to putting more land aside for conservation purposes (CBD 2011; Venter et al. 2014) and biosphere reserves (BRs) (UNESCO 2010). A BR consists of different zones representing different kinds of land use (LU). These include conservation areas represented in the core zones, agricultural systems and settlements represented in the buffer and transition zones of a BR. Vhembe Biosphere Reserve (VBR) is the biggest savannah BR in South Africa (SAMABNC 2014). It has a good balance of representation in terms of the main LUs, such as conservation areas, human settlements, industries and other cooperatives, which include mining developments and agricultural systems.

The increasing loss of biodiversity remains a daunting challenge facing the world at large (Gurevitch and Padilla 2004; MA 2005; Rockström et al. 2009). Various human-induced threats and forces (Chapin et al. 2000; Díaz et al. 2006) continuously alter and degrade the environment, causing habitat loss, species extinction and climate change (Wilcove et al. 1998; Venter et. al. 2006; Stuart et al. 2000; Scholes and Biggs 2004; MA 2005). Among these threats are agriculture (Stolton and Dudley 1999; Swift et al. 2004; Power 2010), urbanisation (McKinney 2002; Marzluff et al. 2001; McKinney 2008) and mining developments (Brewer et al. 2003; MA 2005).

Agriculture is regarded as one of the most severe threats (Stolton and Dudley 1999; MA 2005). Evidence suggests that agricultural activities might affect biodiversity and ES (Swift et al. 2004; Power 2010; Rouget et al. 2003), among others through high consumption of water (Scholes and Biggs 2004; MA 2005). The use of pesticides could also kill non-target organisms (Power 2010; Swift et al. 2004). Agricultural intensification has been found to cause a reduction in the diversity of organisms responsible for nutrient cycling, as well as ground water pollution (Swift et al. 2004; Scholes and Biggs 2004).

Urbanisation refers to an increase in the number and extent of population and cities (Uttara et al. 2012). Concerns about the impact of urbanisation on biodiversity have been raised by a number of researchers (Marzluff et al. 2001; McKinney 2002; McKinney 2008; Uttara et al. 2012). Urbanisation has been found to have an impact on biodiversity and ES in a number of ways, including indigenous species' extinction and habitat loss (Marzluff et al. 2001; McKinney 2002; McKinney 2008; Uttara et al. 2012), as well as indigenous vegetation removal (Uttara et al. 2012).

While industrial developments, such as mining, are seen as a quick solution to economic development (Turner 2012), these kinds of LU come with a cost to the natural environment (IUCN 2011a; 2011b). Mining has been associated with habitat destruction due to removal of vegetation (Ashton et al. 2001; Phillips 2001), high water consumption (DWAF 2004; MA 2005) and high consumption of natural resources (Brewer et al. 2003; MA 2005). Mining activities have been found to degrade and alter both terrestrial and aquatic habitats, causing the decline of indigenous species (Ashton et al. 2001; Phillips 2001). Many world heritage sites and PAs around the world were found to be affected negatively by various activities related to mining (Turner 2012). A study undertaken by the IUCN (2011a; 2011b) found that at least 25% of PAs were threatened by mining in West Africa. In another study (Osti et al. 2011), 27% of World Heritage sites in Sub-Saharan Africa were found to have oil and gas concessions. This situation presents a challenge in terms of dealing with a threat whose solution is beyond the employment of conservation strategies, i.e. PAs.
Perhaps what the above-mentioned forms of LU have in common is the effect on habitats (MA 2005; McKinney 2008; Power 2010; Uttara et al. 2012). Some of the examples of how LU has affected habitat quality include various types of pollution and vegetation removal associated with agriculture, urban development and mining activities (Czech et al. 2000; Ashton et al. 2001; Rouget et al. 2003; Power 2010; Uttara et al. 2012). A habitat can be defined as an area's condition and resources that contribute to the reproduction and continuous existence of species (Hall et al. 1997; Tallis et al. 2011). The state of biodiversity in an area can be determined through the condition of its habitat; the importance of a habitat, on the other hand, depends on its quality. Habitat quality is defined as the environment`s ability and capacity to provide adequate support and conditions to enable the persistent survival of species (Tallis et al. 2011).

A habitat's role regarding ecosystem services is two-fold. The first role is that of being a service itself, by for example providing refuge for wildlife. The second role is that of being a supporting service that underpins the delivery of other services, such as provisioning (e.g. food and water), cultural (e.g. recreation, aesthetic quality) and regulating (climate regulation, flood regulation) services (MA 2005). Ecosystem services are defined as benefits that people derive from ecosystems (MA 2005). It is important to note that LU choices result in trade-offs between/among services, e.g. the advancement of agriculture as a LU instead of conservation in a specific area will have an impact on biodiversity and water resources because of chemicals used to intensify agricultural productivity (Foley et al. 2005).

If managers are to reach their biodiversity conservation goals, they should conduct biodiversity condition/threat assessments (Margoluis and Salafsky 2001; Tallis et al. 2011). Modelling and biodiversity assessment, which include the impact of LU on habitat quality in a given area, assist in (1) understanding the patterns of distribution and richness of biodiversity in the landscape, (2) comparison of spatial patterns of biodiversity and ES, (3) identification of synergies and trade-offs in different scales and scenarios and (4) development of strategies for biodiversity conservation (Tallis et al. 2011.) Information on habitat quality allows one to make informed decisions about different conservation strategies, i.e. conservation area expansion, introduction and removal of species and identification of the habitats that provide high ES, as well as the type of ES provided by different habitats. Several studies (Nelson et al. 2009; Polasky et al. 2011; Kovacs et al. 2013; Bhagabati et al. 2014) undertook threat assessment and modelling to determine the impact of threats on a suite of biodiversity features and ES, on different scales and densities.

This study applied the Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) biodiversity habitat quality model described in Tallis et al. (2011) to assess the condition of habitat as an ES and that of providing a supporting service for the delivery of other ES The model combined information on land use (LU)/land cover (LC) and threats to determine the degradation and extent thereof, on different habitat types in a biosphere reserve (BR). We selected InVEST because: (1) it can provide estimates of the level and value of ES that are provided by a given area, and (2) its models are spatially explicit, with a flexible spatial resolution, thereby enabling users to address questions at different scales.

5.2 MATERIALS AND METHODS

5.2.1 Study area

A BR consists of different zones representing different kinds of land use. These include conservation areas represented in the core zones, agricultural systems and settlements represented in the buffer and transition zones of a BR. Vhembe Biosphere Reserve (VBR) is the biggest savannah BR in South Africa (SAMABNC 2014). It has a good balance of representation in terms of the main land uses such as conservation areas, human settlements, industries and other cooperatives, which included mining developments and agricultural systems. Despite its size of 3 070 000 ha, this study purposefully extended the VBR study area to cover the whole of the northern section of one of the two major core areas, the Kruger National Park and the whole western section up to the end of the existing BR boundary. This extension enabled us to obtain additional information on the status of biodiversity within the VBR and its most important buffer areas.

There are diverse land uses in the study area (Dombo et al. 2006). Conservation is one of the dominant forms of land use with about 1 000 000 ha of land under formal protection, including state-owned land (two national parks and provincial reserves) (Dombo et al. 2006). Agricultural systems are also well represented in the Vhembe region. Human settlements are fairly well developed and the human population size is about 1 500 000 (Stats SA 2012). There is also good diversity of vegetation types in the study area, with more than 30 types represented (Mucina and Rutherford 2006).

5.2.2 InVEST biodiversity model

InVEST is a modeling suite that uses land use/ land cover patterns to estimate values and levels of biodiversity found in a landscape (Tallis et al. 2011). The InVEST biodiversity model 2.2.0 as described by Tallis et al. (2011) uses information about threats to biodiversity together with LU/LC to produce habitat quality and degradation maps, which provide information about the quality and degradation of different types of habitat in an area over time. The LU/LC map for the VBR was derived from a 2009 LU/LC map for South Africa (SANBI 2009) which was the most recent one at the time of our study. We selected the InVEST habitat quality modelling tool because it allows for a rapid assessment of the impacts of different threats and land uses on biodiversity and ES (Tallis et al. 2011; Guerry et al. 2012). More details regarding the InVEST biodiversity quality model are contained in Appendix 5A.

5.2.3 Running the InVEST biodiversity model

The following process was followed in this study to run the InVEST biodiversity model, as described in Tallis et al. (2011):

Step 1- Creation of workspace

For each InVEST model, including biodiversity and conservation, a separate workspace was created on the computer hard drive. This was followed by the creation of a folder under the workspace where all output files were stored.

Step 2 - Running the model

After completion of step one, an ArcMap document was opened followed by adding an InVEST toolbox located on the hard drive. This was followed by double-clicking on the biodiversity InVEST toolbox which created an interface where all required values were authorised.

Step 3 - Progress dialogue

The completion of step two brought about a dialogue on the interface, which indicated the model running progress. After the model had been run successfully, it produced either an output or an intermediate folder which contained degradation and quality maps with values. The results were viewed on the ArcMap through an add data button (ESRI 2013). The maps attribute tables contained degradation and habitat quality values.

5.3 RESULTS

Among the seven land cover types represented in the study area, two were regarded as natural habitats (water bodies and natural areas), and five as transformed habitats (cultivation, mining, plantation, degraded and urban built-up). Three of these (cultivation, mining and urbanisation) were found to have impacts on natural habitats.

5.3.1 Habitat quality

The distribution of habitats with high quality service in relation to those with low quality service in the landscape is shown in Figure 5.1. About 72% of the habitats were of a high quality and were associated with natural areas. The remaining habitats were of a low quality (28%) and were found in areas under different land uses that excluded conservation.

Figure 5.1. Habitat quality in the Vhembe Biosphere Reserve and the northern parts of Kruger National Park study areas.

5.3.2 Habitat loss and degradation

The results of habitat service loss are shown in Figures 2, 3 and 4 and habitat service degradation is presented in Figure 5. Figure 2 indicates that 35% of the habitat services were lost. In sharp contrast, 65% of the habitat services were intact. We further quantified the extent of habitat service loss across the landscape as follows: low habitat loss from 0-20%, moderate habitat loss represented by 20-32%, high habitat loss represented by 32-56% and 56-95% representing severe habitat loss (Figure 5.3).

Areas affected by habitat services loss are shown in Figure 5.4. Natural areas and water bodies in formal PAs and privately owned natural areas surrounding PAs had low habitat service loss. Moderate habitat service loss was recorded in areas surrounding cultivation, urbanisation, mining and plantations. Areas adjacent to mining, urban development and cultivation had high habitat service loss and severe habitat service loss was mainly recorded in areas in close proximity to

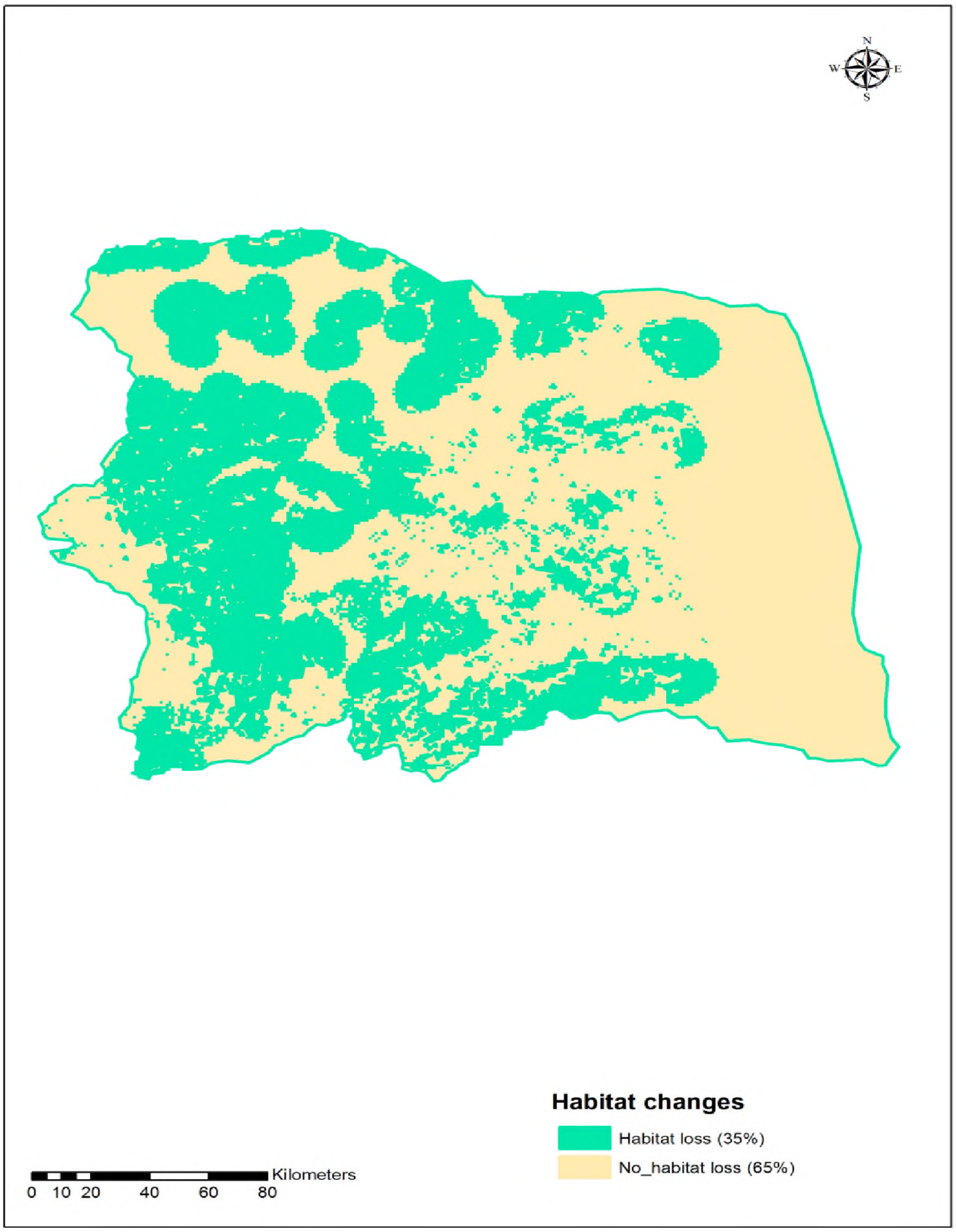

Figure 5.2 Habitat changes in the Vhembe Biosphere Reserve and the northern parts of Kruger National Park study areas.

We further quantified the extent of habitat loss across the landscape as follows: low habitat loss from 0-20%, moderate habitat loss represented by 20-32%, high habitat loss represented by 32-56% and 56-95% representing severe habitat loss (Figure 5.3).

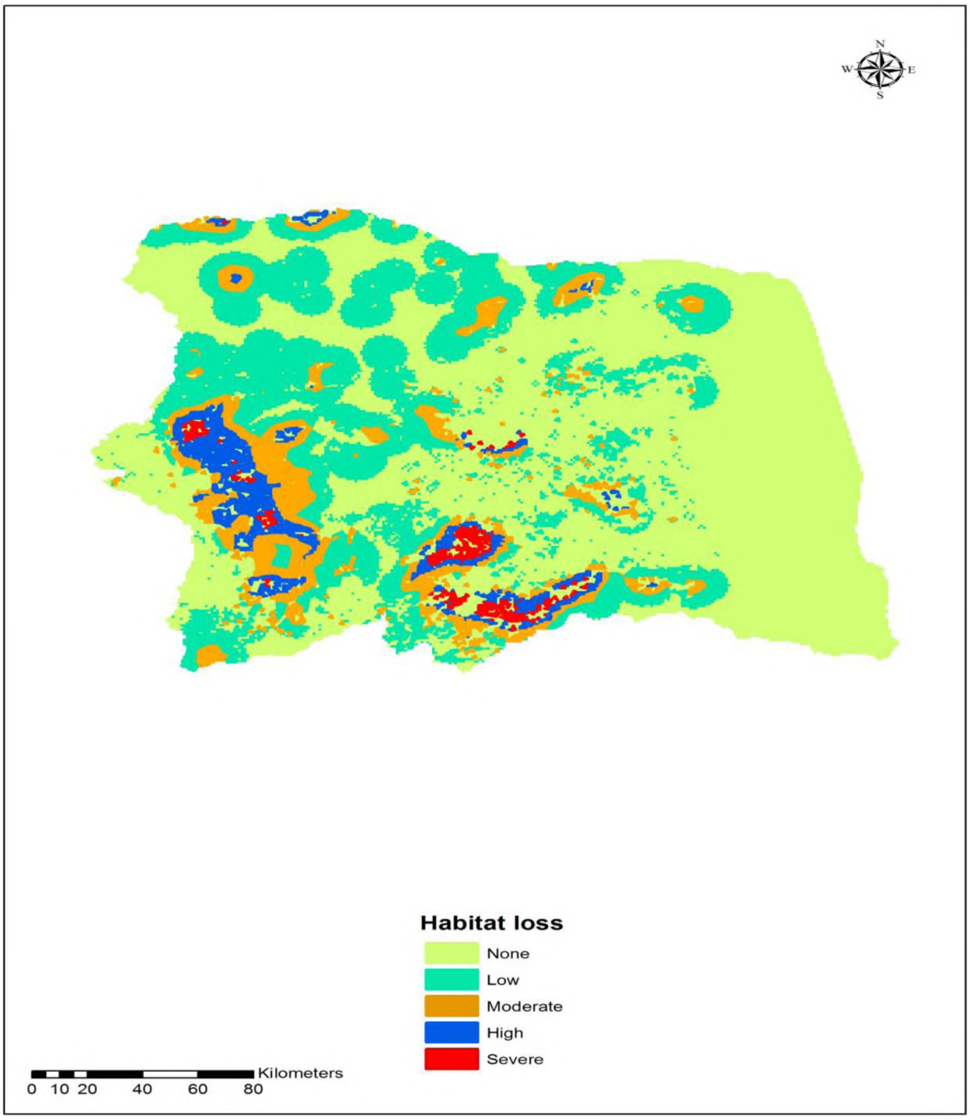

Figure 5.3. The extent of habitat loss in the Vhembe Biosphere Reserve and the northern parts of Kruger National Park study areas.

Habitat types affected by habitat loss are shown in Figure 5.4. Natural areas and water bodies in formal PAs and privately owned natural areas surrounding PAs had low habitat loss. Moderate habitat loss was recorded in areas surrounding cultivation, urbanisation, mining and plantations. Areas adjacent to mining, urban development and cultivation had high habitat loss and severe habitat loss was mainly recorded in areas in close proximity to cultivated areas.

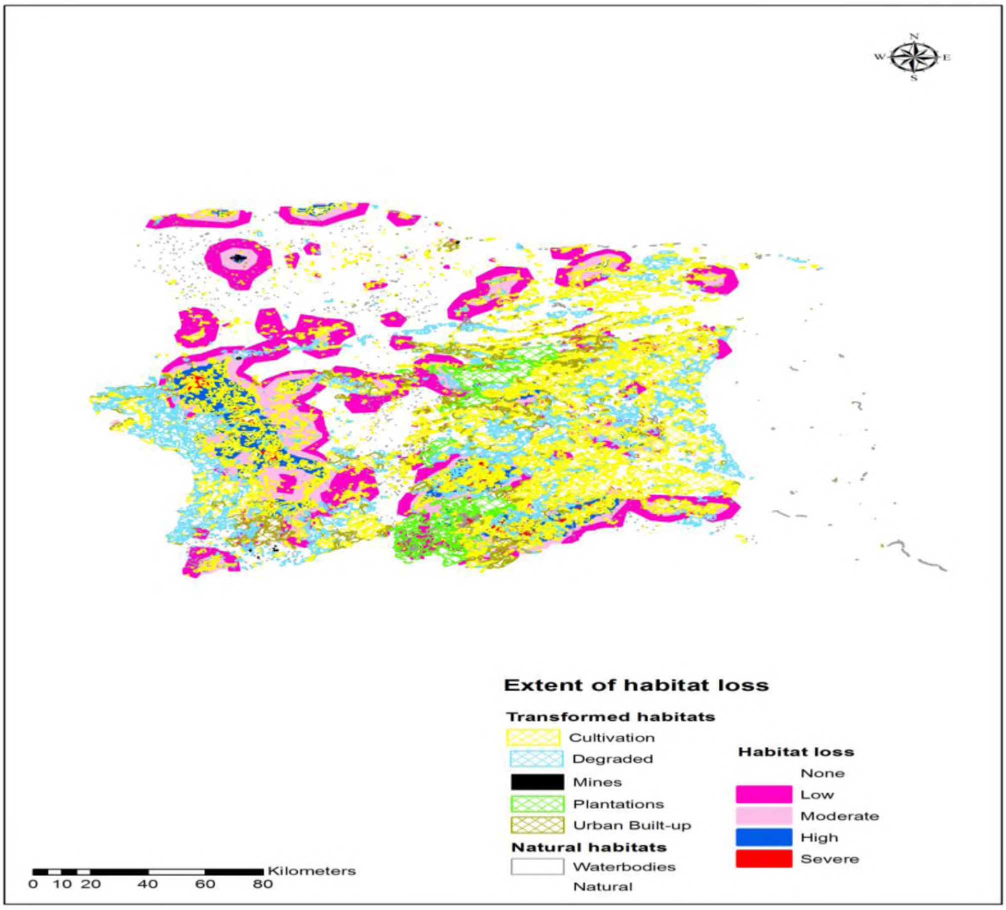

Figure 5.4. The extent of transformed habitats and natural habitats in the Vhembe Biosphere Reserve and the northern parts of Kruger National Park study areas.

5.3.3 Degradation of vegetation in the study area

The degradation of vegetation types in the study area is illustrated in Figure 5.5. At least 19 of the 34 vegetation types (i.e., 56%) were degraded[1]

[1] The affected vegetation types were Granite Lowveld Bushveld, Gravellote Rocky Bushveld, Makhado Sweet Bushveld, Roodeberg Bushveld, Tzaneen Sour Lowveld, Polokwane Plateau Bushveld, Lowveld Rugged Mopane Veld, Tsende Mopane Veld, Mmabolo Mountain Bushveld, Northern Mistbelt Forest, Woodbush Granite Grassland, Soutpansberg Mountain Bushveld, Musina Mopane Bushveld, Soutpansberg Summit Sourveld, Strydpoort Summit Sourveld, Subtropical Alluvial Vegetation, Limpopo Ridge Bushveld, Limpopo Sweet Bushveld and Makuleke Sandy Bushveld. Of these, Makhado Sweet Bushveld was found to [1]be most degraded. Moderate degradation was recorded in Roodeberg Bushveld, Polokwane Plateau Bushveld, Mmabolo Mountain Bushveld, Northern Mistbelt Forest, Soutpansberg Mountain Bushveld, Tzaneen Sour Lowveld, [1]Musina Mopane Bushveld, Woodbush Granite Grassland and Gravellote Rocky Bushveld. Low degradation was recorded in the following vegetation types; Granite Lowveld Bushveld, Lowveld Rugged Mopane Veld, Tsende Mopane Veld, Soutpansberg Mountain Bushveld, Strydpoort Summit Sourveld, Subtropical Alluvial Vegetation, Limpopo Ridge Bushveld, Limpopo Sweet Bushveld and Makuleke Sandy Bushveld. Despite the fact that some of the vegetation types are well protected, such as Musina Mopane Bushveld and Limpopo Ridge Bushveld, they are still affected by degradation.

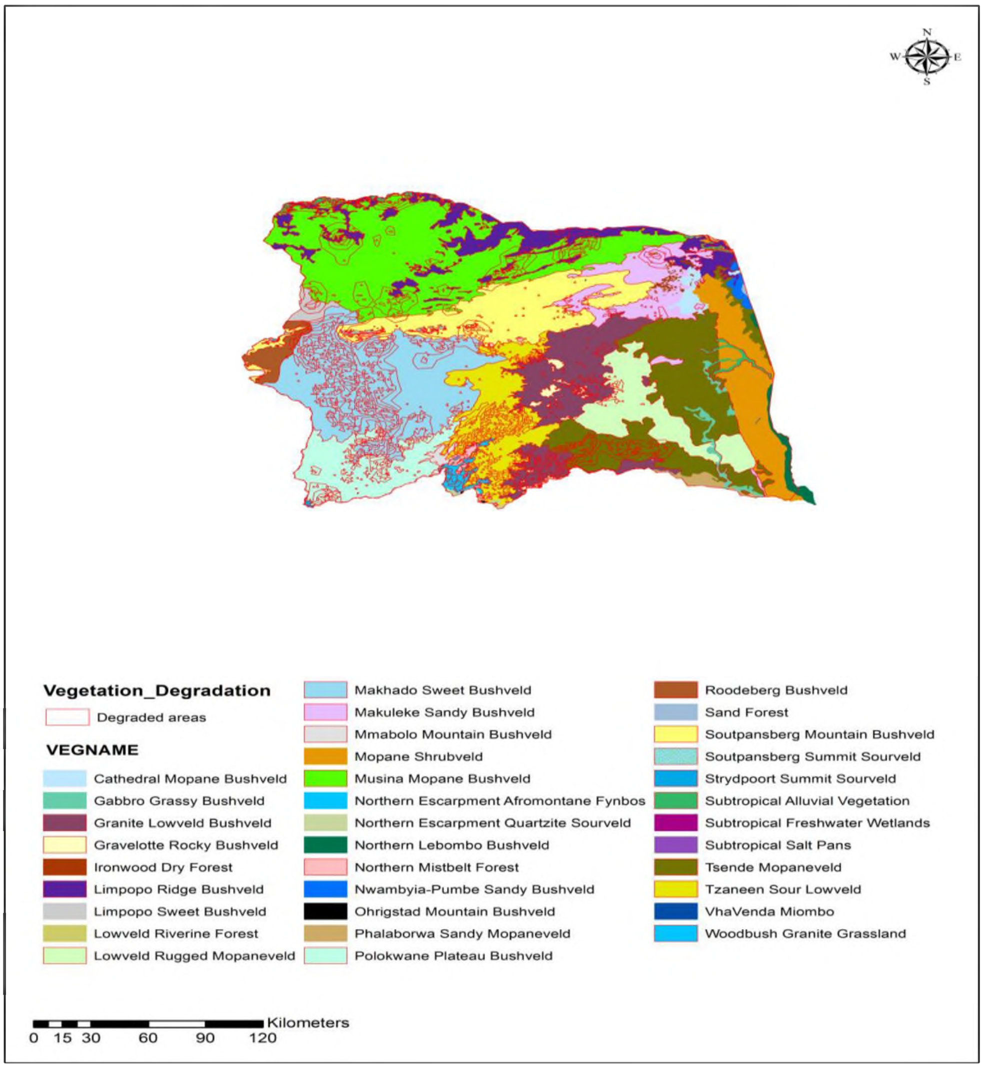

Figure. 5.5. The extent of degradation of vegetation types in the Vhembe Biosphere Reserve and the northern parts of Kruger National Park study areas.

5.4. DISCUSSION

Our results as discussed above demonstrated that the InVEST habitat quality model is useful for the following reasons: First, it has the ability to characterize the sensitivity of habitats types to various threats. Second, it takes into account the different impacts of threats on habitats. Third, it allows estimation of the relative impacts of one threat over another. Guerry et al. (2012) highlighted other advantages of the InVEST, tool which included its applicability to marine systems to evaluate different effects of management practices on the delivery of ES. InVEST, however, has some drawbacks and therefore should be applied with caution, as it does not provide detailed species occurence data. It also provides some difficulties for modelling changes in the occurrence of multiple species, their persistence, or vulnerability under future conditions. The following sections contain more discussions on the specific results as per the set objectives.

5.4.1 Habitat quality

Most habitats (72%) were in good condition. A habitat in a good state has the capacity to deliver a service of providing suitable living conditions for plants and animal species, and as a supporting service which underpins the delivery of other services such as provisioning, cultural and regulating services (MA 2005). Furthermore, a habitat is considered to be in good quality due to the high quality resources that maximise species survival such as food and nesting sites among other things (Morrison et al. 2006; Johnson 2007). Habitat quality is also influenced by the proximity of sources of degradation (Tallis et al. 2011). High quality habitats are associated with intact ecosystems with minimal human influence (Tallis et al. 2011). An area dominated by high-quality habitats represents high biodiversity (Johnson 2007). We attributed the dominance of high quality habitats in PAs to their regulation (NEMPAA 2003), the presence of deterrents and law-enforcement, which in privately owned conservation areas were moderately provided (*Ntshane B.C, personal observation*). Other researchers have also shown that legal protection of habitats mitigates the impacts of threats on biodiversity (Stolton and Dundley 1999; Tallis et al. 2011).

The presence of high quality habitats within conservation areas suggested that these areas had the potential to support the delivery of a suite of ES such as cultural (recreation), provisioning (medicinal plants and timber), and regulating services (Dombo et al. 2006; Stolton et al. 2010; WBR 2012). Although the habitats were generally found to be of good quality, they could still be vulnerable to degradation, since human pressure/threats are likely to intensify in future. This normally happens with growing demands on ES due to growing human populations (MA 2005). The adverse impacts of agriculture, mining and urban developments on natural ecosystems are thus expected to continue especially in developing countries where poverty and population growth are high (Tilman et al. 2002; MA 2005).

About 28% of the habitats were of a low quality due to anthropogenic threats. These habitats were in close proximity to mining, plantations, cultivated areas and urban settlements. Low quality habitat was attributed to habitat destruction due to removal of vegetation which is usually carried out during implementation of different land use activities (Ashton et al. 2001; McKinney 2008; Koh and Gardner 2010). Conversion of natural systems to agriculture was found to reduce some ES (Rouget et al. 2003; Power 2010). However, low quality habitats in areas designated for agricultural activities were found to be doing well in delivering food-provisioning services such as crops and livestock (Dombo et al. 2006; LDA 2012; WBR 2012). Nevertheless, these low quality habitats are poor in terms of biodiversity value (Rouget et al. 2003; Tallis et al. 2011). Low habitat quality has been associated with degraded areas (Lindenmayer 2008; Koh and Gardner 2010). Low habitat quality has furthermore been associated with low biodiversity in general (Bender et al. 2003; Fahrig 2003; Tischendorf et al. 2003), since a habitat in a poor state has limited ability to provide suitable conditions for species and to support the provision of other services needed to support human well-being (MA 2005).

5.4.2 Habitat loss and degradation

About 35% of the habitats were lost. This resulted in loss of services associated with the provision of suitable living conditions for wildlife and with supporting the delivery of other ES. Cultivation was the greatest cause of habitat loss, followed by urbanisation and plantations, with mining causing the lowest impact. Other researchers have also recorded the contribution of different land uses such as agriculture (Rouget et al. 2003; Venter et al. 2006; McKinney 2008; Polasky et al. 2011), mining (Ashton et al. 2001; Phillips 2001) and urbanisation (Rouget et al. 2003; Venter et al. 2006; McKinney 2008; Uttara et al. 2012) to habitat loss. For example, Rouget et al. (2003) found that 30% of sub-tropical thicket had been transformed due to conversion of land to agriculture leading to significant loss of biodiversity in this global biodiversity hotspot.

Areas with low habitat loss fell within the core areas (represented by PAs) of the BR (Dombo et al. 2006; WBR 2012). Low habitat loss in areas represented by PAs means insignificant loss of habitat services such as living spaces for wildlife and gene pool protection, thus protecting species from decline. Low habitat loss in PAs provides an opportunity for the delivery of recreational, raw materials and a host of regulating services, among others (Stolton et al. 2010). Low habitat loss in natural areas was not surprising since PAs are expected to be effective tools for conserving and protecting biodiversity (IUCN 2004; Stolton 2010; Tallis et al. 2011). Moreover, core areas are strictly protected by legislation and activities in these areas are highly regulated (NEMPAA 2003).

Areas that suffered significant habitat loss were surrounded by human dominated landscapes such as urbanization, agriculture and mining. These landscapes fall within the transition zone of the BR which caters for different land use systems (Dombo et al. 2006; WBR 2012). It is important to note that, urbanization, mining and agriculture are spatially disparate land use systems as permitted by the current land use zone management (Dombo et al. 2006; WBR 2012) and are not necessarily degraded areas. However, these land uses are regarded as major threats which lead to habitat service loss and ultimately to biodiversity and other ES loss (Ashton et al. 2001; MA 2005; Uttara et al. 2012; Chaplin-Kramer et al. 2015).

The finding of high habitat loss in areas surrounded by urban areas confirms the conclusions of other workers who found urbanisation to be the second highest driver of habitat loss (Czech et al. 2000; Venter et al. 2006; McKinney 2008; Uttara et al. 2012). Severe habitat loss in areas adjacent to cultivated areas confirms the findings of other studies (Stolton and Dudley 1999; MA 2005; Venter et al. 2006; Power 2010). Agriculture has been found to be the greatest cause of habitat loss in many landscapes (Rouget et al. 2003; Chaplin-Kramer et al. 2015). Habitat service loss is regarded as the main cause of extinction of species (Foley et al. 2005; MA 2005; Lindenmayer et al. 2008; Rockström et al. 2009). Mining has been found to have a negative impact on biodiversity (Ashton et al. 2001; Brewer et al. 2003; MA 2005). South Africa is not exempted from this phenomenon (DWAF 2004; Munnik et al. 2010; van der Burg 2012). Legislation has been put in place to address the negative impacts of mining activities on biodiversity (DEA et al. 2013), although more resources need to be channelled towards implementation of the policies (DEA et al. 2013).

The finding that Makhado Sweet Bushveld was the most degraded vegetation type of the 19 vegetation types found in the study areas (Figure 5), is not surprising, as this vegetation type has been found to be hardly protected (Mucina and Rutherford 2006). Similarly, vegetation types found to have been moderately affected by habitat loss were also at great risk, as they were poorly protected or unprotected (Mucina and Rutherford 2006). The degradation of vegetation under protection might be a result of threats such as pollution, edge effects and habitat fragmentation which are not prevented by the presence of physical/legal or other types of protection (Tallis et al. 2011). Degradation of vegetation has a negative impact on the delivery of ES (MA 2005; Tallis et al. 2011).

Our study could be compared to that of La Notte (2012) with regard to the use of environmental indicators such as habitat sensitivity to threats and the impact of human pressure on habitats, as well as the application of the mapping approach. However, thorough comparison of La Notte (2012) and our findings was difficult due to the following differences. First, La Notte (2012) used the BT technique to value the services, we used InVEST. Second, it valued services in monetary terms, in our study services were valued in biophysical terms. Lastly, our study assessed and mapped habitats for ecosystem services in response to human pressure such as urbanisation, mining, and cultivation, La Notte`s (2012) study valued and mapped habitat services using three different indicators (ecological value, ecological sensitivity and human pressure).

Our results demonstrated that the InVEST habitat quality model is useful because of the following reasons. First, it has the ability to characterize the sensitivity of habitats types to various threats. Second, it takes into account the different impacts of threats on habitats. And third, it allows estimation of the relative impacts of one threat over another. Guerry et al. (2012) highlighted other advantages of the InVEST tool which included its applicability to marine systems to evaluate different effects of management practices on the delivery of ES. InVEST, however, has some drawbacks and therefore should be applied with caution as it does not provide detailed species occurrence data. It also provides some difficulties for modeling changes in the occurrence of multiple species, their persistence, or vulnerability under future conditions.

5.5. CONCLUSIONS

We demonstrated the contribution of anthropogenic threats to habitat loss. Habitat loss often followed a pattern with more degradation found in human-dominated systems, than in natural systems such as conservation areas. Although PAs systems are still crucial for preserving and protecting biodiversity, they are vulnerable to threats. Human-induced impacts resulted in loss of habitat service and degradation that negatively affected the delivery of other ES. There were trade-offs between human-induced land uses and biodiversity conservation.

Land uses such as urbanisation, agriculture and mining should find ways to accommodate biodiversity conservation. Strategies should be put in place to inform management of vegetation types that are threatened by degradation. Habitat condition assessment is highly recommended to serve as a basis for assessing delivery of ES and for informing land use planning.

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5.7 APPENDICES

5.7.1: Appendix 5A: InVEST habitat quality model data requirements

5.7.1.1 Data needed to run the model

Human-modified land use/land cover (LU/LC) types such as urbanisation, cultivation and mining that cause habitat fragmentation or an edge effect (McKinney 2002; Tallis et al. 2011) were identified as threats. Table 1 presents data required to run the model. The model also uses data on habitat threat density and its effects on habitat quality; here the model considered human-modified LU/LC types that cause habitat fragmentation, edge effect, and degradation in neighbouring habitats as threats, e.g. the conversion of a habitat LU/LC to non-habitat LU/LC reduces the size and continuity of neighbouring habitat patches. Each threat source was mapped on a raster grid, with a grid cell value indicating the presence (1) or absence (0) of a threat (i.e. crop field, etc.). Table 5.1 presents threat data used to run InVEST.

Threat	Maximum_distance	Weight	Decay
Cultivation	0.2	0.7	0
Mines	30	1	0
Urban	60	1	0

Threat - the name of the specific threat.
Maximum distance - the maximum distance over which each threat affected habitat quality (measured in kilometres).
Weight - the impact of each threat on habitat quality, relative to other threats. Weights ranged from 1 at the highest, to 0 at the lowest.
Decay - indicated whether the impact of the threat decreased linearly or exponentially across space. The value could be either 0 or 1. A value of 1 indicated a linear decline in impact, while 0 indicated an exponential decline.

Table 5.1. Threat data used to run InVEST

5.7.1.2 The impact of threat on habitat condition

According to Tallis et al. (2011), there are four factors that determine the impact of a threat on habitat condition. The first is the relative impact of each threat. Some threats may be more damaging to a habitat, and a relative impact score quantifies this. A degradation source's weight indicates the relative destructiveness of a degradation source to all habitats. The weight can take on any value from 0 to 1; e.g., if an urban area has a threat weight of 1 and the threat weight of roads is set to equal 0.5, then the urban area causes twice the disturbance, all else being equal, to all habitat types (Tallis et al. 2011).

The distance between the habitat and the source of the threat and between the source and the impact of the threat across space is the second mitigating factor (Tallis et al. 2011). Tallis et al. (2011) further highlight that the impact of a threat on a habitat decreases as the distance from the source of degradation increases; grid cells that are in close proximity to threats will experience more impacts. The impact of a threat source on a habitat in the grid cell will partly depend on how quickly it decreases, or decays, over space. The user can choose either a linear or an exponential distance-decay function to describe how a threat decays over space (Tallis et al. 2011). In this study, an exponential decay function was applied.

The level of legal/institutional/social or physical protection from disturbance in each cell is the third factor that may mitigate the impacts of threats on habitats; if the grid cell is in a formal PA it will be represented by the value 0, but if it is completely accessible it will be assigned a value of 1. It is assumed that the more protection there is for a system acting as a barrier to degradation, the less it will be affected by nearby threats, regardless of the type (Tallis et al. 2011). According to Tallis et al. (2011), the relative sensitivity of each habitat type to each threat to the landscape is the last mitigating factor; when generating the total degradation in a cell with habitat, values closer to 1 indicates greater sensitivity. The model uses [0,1] to indicate the sensitivity of LU/LC (habitat type) to a threat; values closer to 1 indicate greater sensitivity. Tallis et al. (2011), further indicate that the more sensitive a habitat type is to a threat, the more degraded the habitat type will be by that threat.

The study applied general principles of landscape ecology and conservation biology to determine the sensitivity of a particular habitat type to degradation, following Forman (1995); Lindenmayer et al. (2008) and Tallis et al. (2011). Sensitivity weights were determined as in Tallis et al. (2011). Table 5.2 presents data showing sensitivity of the habitats to threats. Following other studies (MacArthur and Wilson 1967; Tallis et al. 2011), we considered biodiversity generally and it was assumed that human-modified landscapes (transformed habitats) surrounding natural habitats were unsuitable for species use (MacArthur and Wilson 1967; Tallis et al. 2011). In this case 0 was assigned to managed LU/LC types (transformed habitats) and 1 to unmanaged types (natural habitats). As in Tallis et al. (2011), the inputs used for the model are applicable to biodiversity in general, not specifically to a certain guild or species.

5.7.1.3 Habitat quality and degradation scores

A landscape habitat quality score was generated by summing all the grid cell scores on habitat quality, as in Tallis et al. (2011). The relationship between habitat quality and degradation scores is not linear, but depends on a half saturation function (*k* parameter) (Tallis et al., 2011). Again following Tallis et al. (2011), a half saturation function was used to translate the degradation score of a grid cell into a habitat quality, biodiversity model interface set $k = 30$. Habitat quality will decrease when a grid cell`s degradation score increases (Tallis et al. 2011).

Table 5.2. Sensitivity of different habitat types to threats

ROWID	LU/LC CODE	NAME	HABITAT	L_cultivation	L_urban	L_mines
0	1	Natural	1	0.5	0.8	1
1	5	Water bodies	1	0.8	0.5	0.8
2	2	Cultivation	0	0	0	0
3	3	Degraded	0	0	0	0
4	4	Urban built-up	0	0	0	0
5	6	Plantations	0	0	0	0
6	7	Mines	0	0	0	0

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Habitat assessment for ecosystem services in South Africa

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ABSTRACT
Biodiversity is the foundation of life-support systems on earth and underpins the delivery of ecosystem services (ES) important for human well-being. The loss of biodiversity worldwide, however, remains one of the most daunting challenges. Among the major causes of biodiversity loss is habitat loss due to transformation of land to agricultural, mining and urban areas. We applied the Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) biodiversity modelling tool to assess the condition of habitats to support the delivery of ES in a biosphere reserve (BR) in South Africa. Results indicated that 72% of the surveyed habitats were of high quality to provide the necessary services. However, some of the habitats were found to be affected by threats as follows: low (0–20%) to moderate (20–32%) habitat loss was recorded in habitats adjacent to mining and plantation areas, and high (32–56%) to severe (56–95%) habitat loss was recorded in habitats in close proximity to urban and cultivated areas. At least 56% of the vegetation types found in the study area were threatened by transformation to agriculture, mining and urban areas. We strongly recommend that existing biodiversity policies and legislation should be enforced to avoid habitat loss and degradation.

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1. Introduction

The protection of biodiversity is an international obligation, with approximately 200 nations committing to it (CBD 1992). The term biodiversity originates from the concept of biological diversity, which was coined during the twentieth century (Dasmann 1968; Soule et al. 1980) and has been in use for almost three decades (Wilson & Peter 1988; Bibby et al. 1992; Eldredge 1992; Harper & Hawksworth 1994; Gaston 1996). There are several definitions of biodiversity (CBD 1992; MA 2005; IUCN 2010). Our study adopted the Millennium Ecosystem Assessment's (MA) (2005) definition which is 'the diversity of life on Earth' and 'an essential component that contribute[s] to the functioning of ecosystems that underpin the provisioning of ecosystem services (ES) that ultimately affect human well-being'. We adopted the MA definition because of its association with the supply of ES.

Sound conservation strategies are needed to effectively protect biodiversity. A protected areas (PAs) system was established with the primary goal of protecting and conserving biodiversity (IUCN 2004; Stolton 2010; Tallis et al. 2011). Despite the presence of conservation strategies such as PAs, biosphere reserves (BRs), stewardship programmes (NPEAS 2008; Stolton 2010; UNESCO 2010; Kurdoğlu & Çokçaliskan 2011) and the ongoing commitment of putting more land aside for conservation purposes (CBD 2011; Venter et al. 2014), the increasing loss of biodiversity remains a daunting challenge facing the world at large (Gurevitch & Padilla 2004; MA 2005; Rockström et al. 2009). Various human-induced threats and forces (Chapin III et al. 2000; Diaz et al. 2006) continually alter and degrade the environment, causing habitat loss, species extinction and climate change (Wilcove et al. 1998; Stuart et al. 2000; Scholes & Biggs 2004; MA 2005; Venter et al. 2006). Among these threats are agriculture (Stolton & Dudley 1999; Rouget et al. 2003; Swift et al. 2004; Power 2010), urbanisation (Marzluff et al. 2001; McKinney 2002, 2008) and mining developments (Brewer et al. 2003; MA 2005).

Agriculture is regarded as one of the most severe threats (Stolton & Dundley 1999; Rouget et al. 2003; MA 2005). Evidence suggests that agricultural activities might negatively affect biodiversity and ES (Swift et al. 2004; Power 2010), among others through high consumption of water (Scholes & Biggs 2004; MA 2005). The use of pesticides could also kill non-target organisms (Swift et al. 2004; Power 2010). Other obvious adverse effects of agricultural intensification on biodiversity are the eutrophication of water systems through use of inorganic fertilizers; reduction in the diversity of organisms responsible for nutrient cycling as well as ground water pollution (Scholes & Biggs 2004; Swift et al. 2004; Bukola et al. 2015).

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Urbanisation refers to an increase in the number of cities and size of populations (Uttara et al. 2012). A number of researchers have raised concerns about the impact of urbanisation on biodiversity (Marzluff et al. 2001; McKinney 2002, 2008; Uttara et al. 2012). Urbanisation has been found to adversely affect biodiversity and ES through indigenous species' extinction and habitat loss (Marzluff et al. 2001; McKinney 2002, 2008) as well as the removal of indigenous vegetation (Uttara et al. 2012).

Although industrial developments such as mining are seen as a quick solution to economic growth (Turner 2012), these kinds of land use (LU) come with a cost to the natural environment (IUCN 2011a, 2011b). Mining may result in habitat destruction due to removal of vegetation (Ashton et al. 2001; Phillips 2001) and high consumption of water and other natural resources (Brewer et al. 2003; DWAF 2004; MA 2005). Mining activities have been found to degrade and alter both terrestrial and aquatic habitats, causing a decline in the abundance of indigenous species (Ashton et al. 2001; Phillips 2001). Many world heritage sites and PAs around the world have been negatively affected by various activities related to mining (Turner 2012). IUCN (2011a, 2011b) found that mining threatened at least 25% of PAs in West Africa. Osti et al. (2011) found that 27% of World Heritage sites in Sub-Saharan Africa were threatened with oil and gas mining. This situation presents a major challenge in dealing with a threat whose solution is beyond the employment of conservation strategies such as PAs.

Perhaps what the above-mentioned forms of LU have in common is the effect on habitats (MA 2005; McKinney 2008; Power 2010; Uttara et al. 2012). Examples of LU effects on habitat quality include various types of pollution and vegetation removal associated with agriculture, urban developments and mining activities (Ashton et al. 2001; Czech et al. 2000; Rouget et al. 2003; Power 2010; Uttara et al. 2012). A habitat can be defined as an area's condition and resources that contribute to the reproduction and the continuous existence of species (Hall et al. 1997; Tallis et al. 2011). The state of biodiversity in an area can be determined by the condition of its habitat whereas the importance of a habitat depends on its quality. Habitat quality is defined as the environment's ability and capacity to provide adequate support and conditions to enable the persistence of species (Tallis et al. 2011).

A habitat's role regarding ES is two-fold. The first role is that of being a service itself by, for example, providing refuge for wildlife. The second role is that of being a supporting service that underpins the delivery of other services such as provisioning (e.g., food and water), cultural (e.g., recreation, aesthetic quality) and regulating (e.g., climate regulation, flood regulation) services, according to MA's (2005) framework. Due to the fact that the most updated classifications of ES (TEEB 2010; CICES 2011) exclude the supporting service category, this study adopted the MA (2005) framework because it classifies habitat as a supporting service. The MA (2005) further defines ES as the benefits that people derive from ecosystems. However, in the most recent classifications of ES (TEEB 2010; CICES 2011), ES are defined as contributions of ecosystems to human well-being. What is important to note from these definitions is that humans derive something from ecosystems for their well-being. It is worth mentioning that LU choices result in trade-offs between and among services. For example, the conversion of land from conservation to agriculture may have a negative impact on biodiversity and water resources because of the clearing of land and pollution from chemicals used to intensify agricultural production (Rouget et al. 2003; Foley et al. 2005).

If managers are to reach their biodiversity conservation goals, they should conduct biodiversity condition/threat assessments (Margoluis & Salafsky 2001; Tallis et al. 2011). Modelling and biodiversity assessment, which include assessing the impacts of LU on habitat quality in a given area, assist in (1) understanding the patterns of distribution and richness of biodiversity in the landscape, (2) comparison of spatial patterns of biodiversity and ES, (3) identification of synergies and trade-offs across different scales and scenarios and (4) development of strategies for biodiversity conservation (Tallis et al. 2011.) Information on habitat quality allows one to make informed decisions about different conservation strategies (Rouget et al. 2003) such as conservation area expansion, introduction and removal of species and identification of habitats that provide high ES, as well as types of ES provided by different habitats. Modelling is a useful tool for assessing the impacts of threats on a suite of biodiversity features and ES (Nelson et al. 2009; Polasky et al. 2011; Kovacs et al. 2013; Bhagabati et al. 2014).

This study applied the Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) biodiversity habitat quality model described in Tallis et al. (2011) to assess the condition of habitat as an ES and that of providing a supporting service for the delivery of other ES. The model combined information on LU/land cover (LC) and threats to determine the degradation and extent thereof, on different habitat types in a BR. We selected InVEST because: (1) it can provide estimates of the level and value of ES that are provided by a given area and (2) its models are spatially explicit, with a flexible spatial resolution, thereby enabling users to address questions at different scales.

2. Materials and methods

2.1. Study area

A BR consists of different zones representing different kinds of LU. These include conservation areas represented in the core zones, agricultural systems and settlements represented in the buffer and transition zones of a BR. Vhembe Biosphere Reserve (VBR) is the biggest savannah BR in South Africa (SAMABNC 2014). It has a good balance of representation in terms of the main LUs such as conservation areas, human settlements, industries and other cooperatives, which included mining developments and agricultural systems. Despite its size of 3,070,000 ha, this study purposefully extended the VBR study area to cover the whole of the northern section of one of the two major core areas, the Kruger National Park and the whole western section up to the end of the existing BR boundary. This extension enabled us to obtain additional information on the status of biodiversity within the VBR and its most important buffer areas.

There are diverse LUs in the study area (Dombo et al. 2006). Conservation is one of the dominant forms of LU with about 1,000,000 ha of land under formal protection, including state-owned land (two national parks and provincial reserves) (Dombo et al. 2006). Agricultural systems are also well represented in the Vhembe region. Human settlements are fairly well developed and the human population size is about 1,500,000 (Stats SA 2012). There is also good diversity of vegetation types in the study area, with more than 30 types represented (Mucina & Rutherford 2006).

2.2. Invest biodiversity model

InVEST is a modelling suite that uses LU/LC patterns to estimate values and levels of biodiversity found in a landscape (Tallis et al. 2011). The InVEST biodiversity model 2.2.0 as described by Tallis et al. (2011) uses information about threats (Table 1) to biodiversity together with LU/LC and information on the sensitivity of habitat types to threats (Table 2) to produce habitat quality and degradation maps, which provide information about the quality and degradation of different types of habitat in an area over time. The LU/LC map for the VBR was derived from a 2009 LU/LC map for South Africa (SANBI 2009) which was the most recent one at the time of our study. We selected the InVEST habitat quality modelling tool because it allows for a rapid assessment of the impacts of different threats and LUs on biodiversity and ES (Tallis et al. 2011; Guerry et al. 2012). More details regarding the InVEST biodiversity quality model are contained in Annexure A.

Table 1. Threat data used to run InVEST.

Threat	Maximum_distance	Weight	Decay
Cultivation	0.2	0.7	0
Mines	30	1	0
Urban	60	1	0

Threat – the name of the specific threat.
Maximum distance – the maximum distance over which each threat affected habitat quality (measured in kilometres).
Weight – the impact of each threat on habitat quality, relative to other threats. Weights ranged from 1 at the highest, to 0, at the lowest.
Decay – indicated whether the impact of the threat decreased linearly or exponentially across space. The value could be either 0 or 1. A value of 1 indicated a linear decline in impact, while 0 indicated an exponential decline.

2.3. Running the InVEST biodiversity model

The following process was followed in this study to run the InVEST biodiversity model, as described in Tallis et al. (2011):

Step 1 – Creation of workspace

For each InVEST model, including biodiversity and conservation, a separate workspace was created on the computer hard drive. This was followed by the creation of a folder under the workspace where all output files were stored.

Step 2 – Running the model

After completion of step 1, an ArcMap document was opened followed by adding an InVEST toolbox located on the hard drive. This was followed by double-clicking on the biodiversity InVEST toolbox which created an interface where all required values were authorised.

Step 3 – Progress dialogue

The completion of step 2 brought about a dialogue on the interface, which indicated the model running progress. After the model had been run successfully, it produced either an output or an intermediate folder which contained degradation and quality maps with values. The results were viewed on the ArcMap through an add data button (ESRI 2013). The maps attribute tables contained degradation and habitat quality values.

Table 2. Sensitivity of different habitat types to threats.

ROWID	LU/LC CODE	NAME	HABITAT	L_cultivation	L_urban	L_mines
0	1	Natural	1	0.5	0.8	1
1	5	Water bodies	1	0.8	0.5	0.8
2	2	Cultivation	0	0	0	0
3	3	Degraded	0	0	0	0
4	4	Urban built-up	0	0	0	0
5	6	Plantations	0	0	0	0
6	7	Mines	0	0	0	0

3. Results

Among the seven LC types represented in the study area, two were regarded as natural habitats (water bodies and natural areas) and five as transformed habitats (cultivation, mining, plantation, degraded and urban built-up). Three of these (cultivation, mining and urbanisation) were found to have impacts on natural habitats.

3.1. Habitat quality

The distribution of habitats with high-quality serv in relation to those with low-quality service in landscape is shown in Figure 1. About 72% of habitats were of a high quality and were associa with natural areas. The remaining habitats were c low quality (28%) and were found in areas un different LUs that excluded conservation.

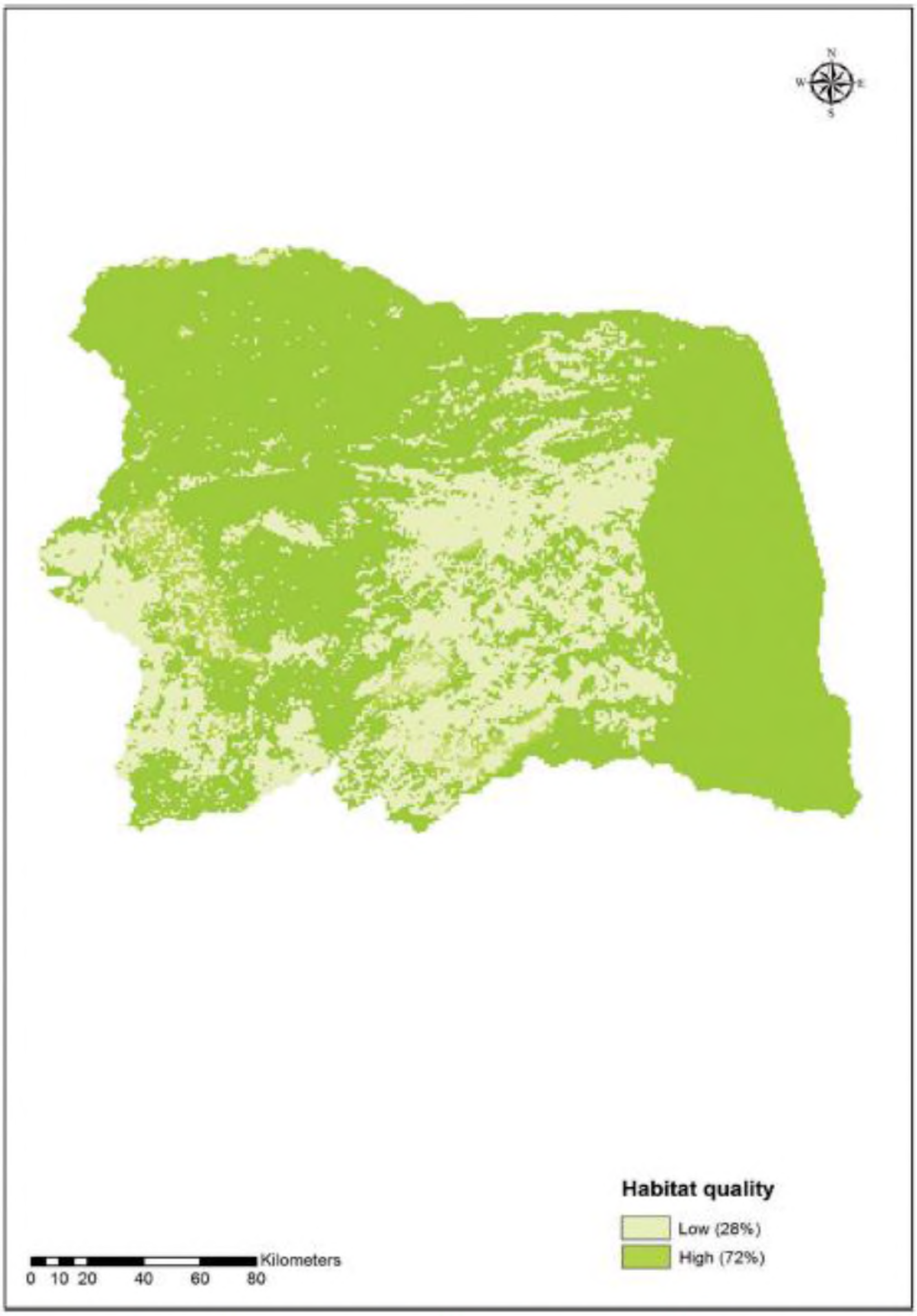

Figure 1. Habitat quality in the Vhembe Biosphere Reserve and the northern parts of Kruger National Park study areas.

3.2. Habitat loss and degradation

The results of habitat service loss are shown in Figures 2–4 and habitat service degradation is presented in Figure 5. Figure 2 indicates that 35% of the habitat services were lost. In sharp contrast, 65% of the habitat services were intact.

We further quantified the extent of habitat service loss across the landscape as follows: low habitat loss from 0% to 20%, moderate habitat loss represented by 20–32%, high habitat loss represented by 32–56% and 56–95% representing severe habitat loss (Figure 3).

Areas affected by habitat services loss are shown in Figure 4. Natural areas and water bodies in formal PAs and privately owned natural areas surrounding PAs had low habitat service loss. Moderate habitat service loss was recorded in areas surrounding cultivation, urbanisation, mining and plantations. Areas adjacent to mining, urban development and cultivation had high habitat service loss and severe habitat service loss was mainly recorded in areas in close proximity to cultivated areas.

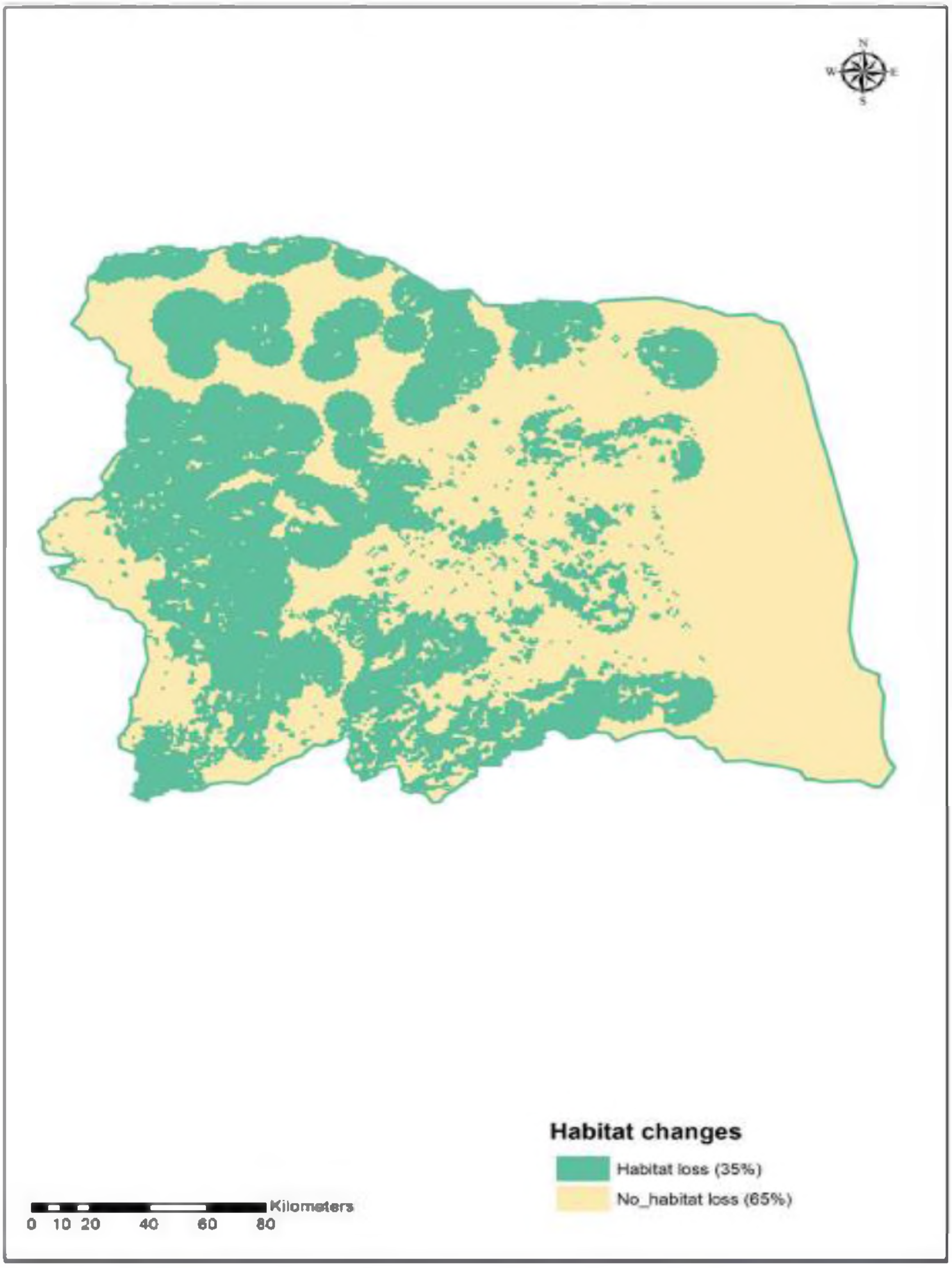

Figure 2. Habitat changes in the Vhembe Biosphere Reserve and the northern parts of Kruger National Park study areas.

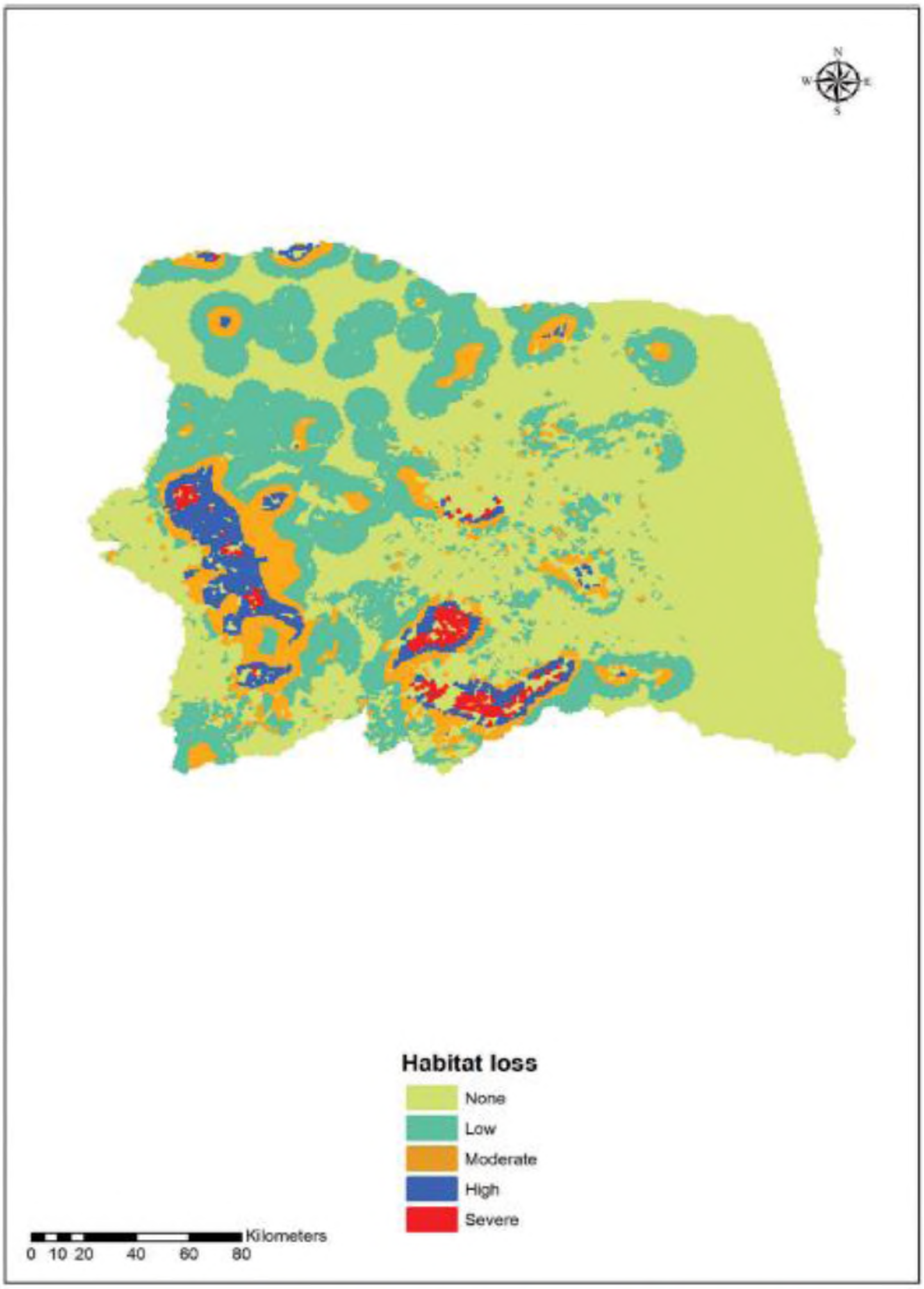

Figure 3. The extent of habitat loss in the Vhembe Biosphere Reserve and the northern parts of Kruger National Park study areas.

The degradation of vegetation types in the study area is illustrated in Figure 5. At least 19 of the 34 vegetation types (i.e., 56%) were degraded.[1]

4. Discussion

4.1. Habitat quality

Most habitats (72%) were in good condition. A habitat in a good state has the capacity to deliver a service of providing suitable living conditions for plants and animal species, and as a supporting service which underpins the delivery of other services such as provisioning, cultural and regulating services (MA 2005). Furthermore, a habitat is considered to be in good quality due to the high-quality resources that maximise species survival such as food and nesting sites among other things (Morrison et al. 2006; Johnson 2007). Habitat quality is also influenced by the proximity of sources of degradation (Tallis et al. 2011). High-quality habitats are associated with intact ecosystems with minimal human influence (Tallis et al.

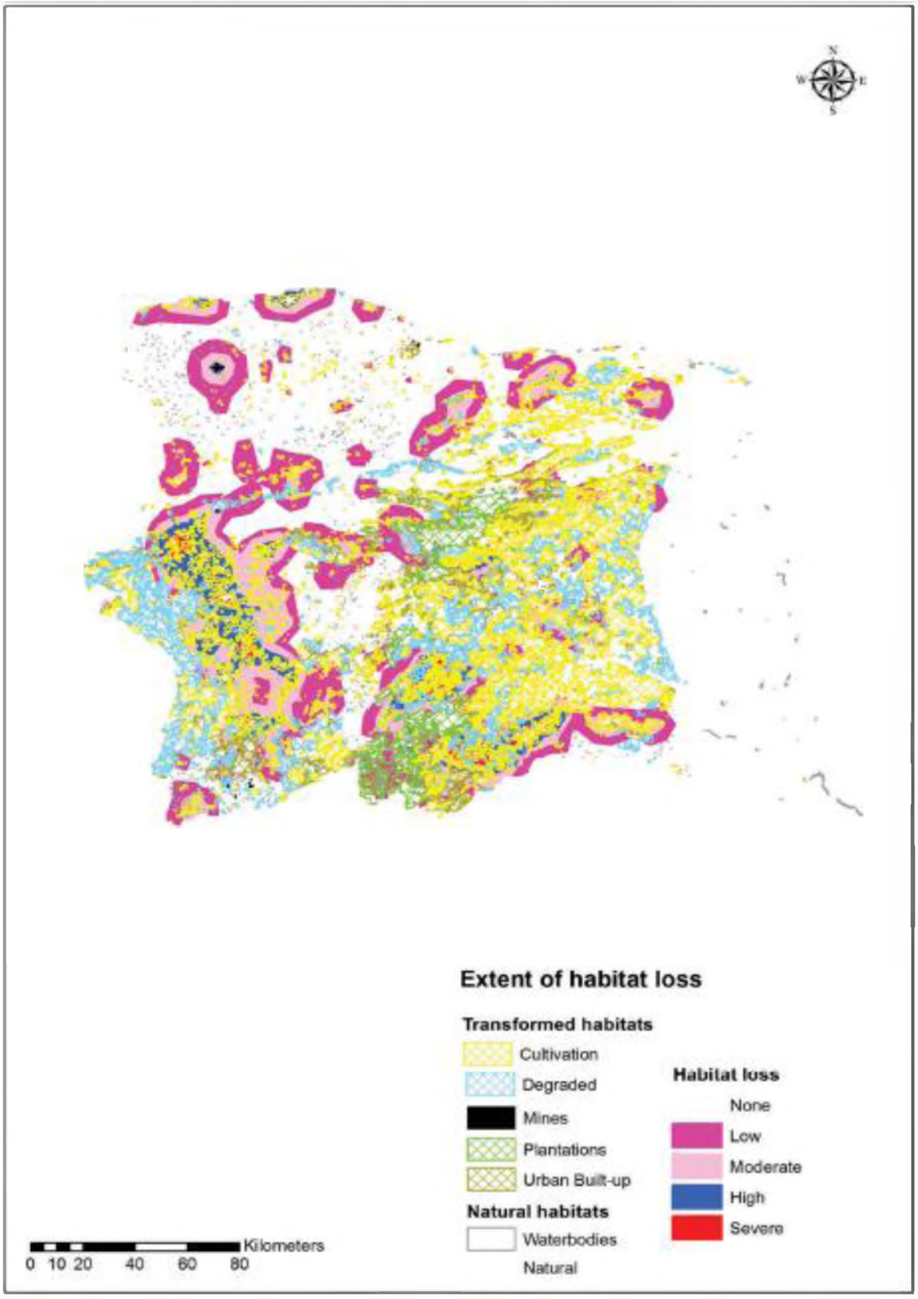

Figure 4. The extent of transformed habitats and natural habitats in the Vhembe Biosphere Reserve and the northern parts of Kruger National Park study areas.

2011). An area dominated by high-quality habitats represents high biodiversity (Johnson 2007). We attributed the dominance of high-quality habitats in PAs to their regulation (NEMPAA 2003), the presence of deterrents and law enforcement, which in privately owned conservation areas were moderately provided (Personal observation[a]). Other researchers have also shown that legal protection of habitats mitigates the impacts of threats on biodiversity (Stolton & Dundley 1999; Tallis et al. 2011).

The presence of high-quality habitats within conservation areas suggested that these areas had the potential to support the delivery of a suite of ES such as cultural (recreation), provisioning (medicinal plants and timber) and regulating services (Dombo et al. 2006; Stolton et al. 2010; WBR 2012). Although the habitats were generally found to be of good quality, they could still be vulnerable to degradation, since human pressure/threats are likely to intensify in future. This normally happens with growing demands

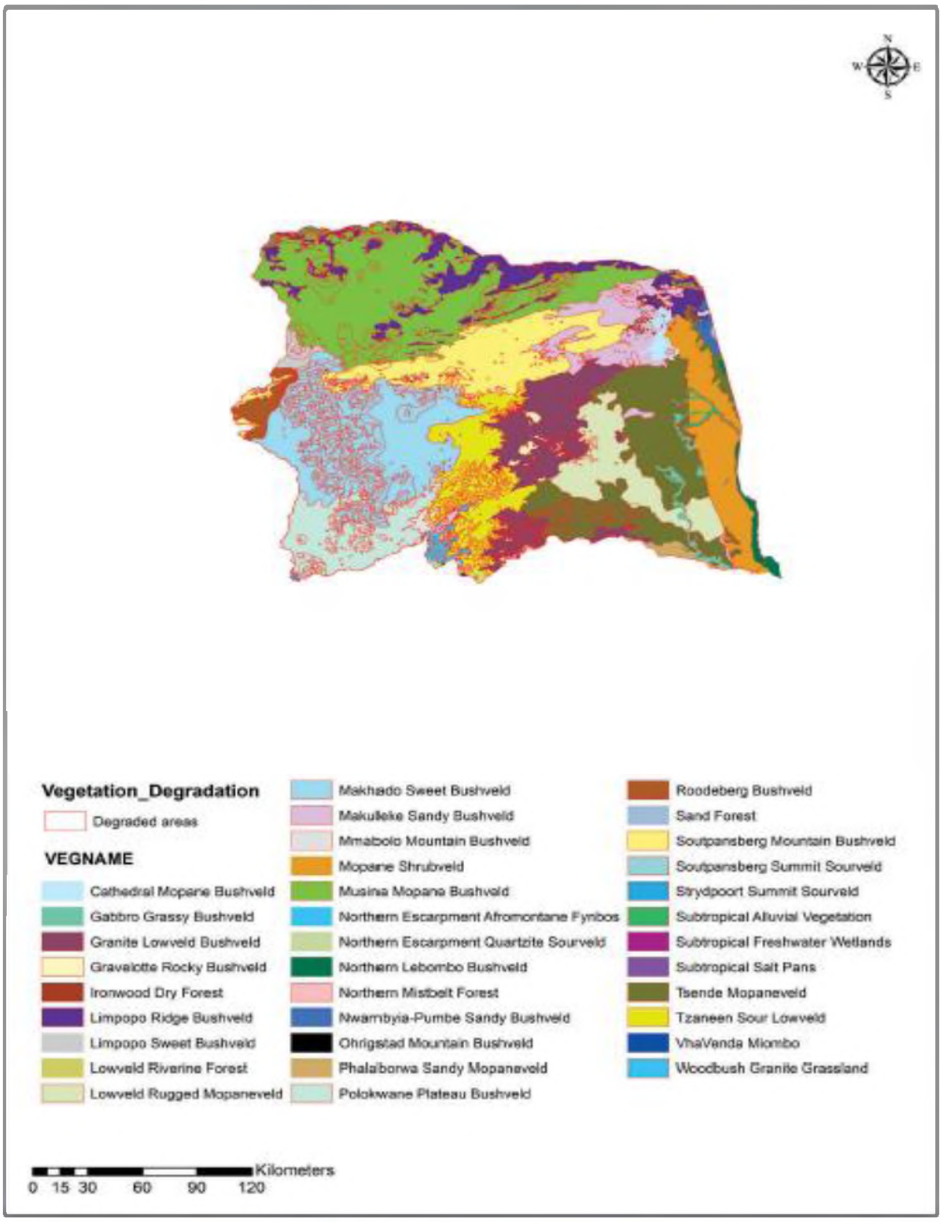

Figure 5. The extent of degradation of vegetation types in the Vhembe Biosphere Reserve and the northern parts of Kruger National Park study areas.

on ES due to growing human populations (Clay et al. 1994; MA 2005). The adverse impacts of agriculture, mining and urban developments on natural ecosystems are thus expected to continue especially in developing countries where poverty and population growth are high (Tilman et al. 2002; MA 2005; NPC 2011).

About 28% of the habitats were of a low quality due to anthropogenic threats. These habitats were in close proximity to mining, plantations, cultivated areas and urban settlements. Low-quality habitat was attributed to habitat destruction due to removal of vegetation which is usually carried out during implementation of different LU activities (Ashton et al. 2001; McKinney 2008; Koh & Gardner 2010). Conversion of natural systems to agriculture was found to reduce some ES (Rouget et al. 2003; Power 2010). However, low-quality habitats in areas designated for agricultural activities were found to be doing well in delivering food-provisioning services such as crops and livestock (Dombo et al. 2006; LDA 2012; WBR 2012). Nevertheless, these low-quality habitats are poor in terms of biodiversity value (Rouget et al. 2003; Tallis et al. 2011). Low habitat quality has been associated with degraded areas (Lindenmayer et al. 2008; Koh & Gardner 2010).

Low habitat quality has furthermore been associated with low biodiversity in general (Bender et al. 2003; Fahrig 2003; Tischendorf et al. 2003), since a habitat in a poor state has limited ability to provide suitable conditions for species and to support the provision of other services needed to support human well-being (MA 2005).

4.2. Habitat loss and degradation

About 35% of the habitats were lost. This resulted in loss of services associated with the provision of suitable living conditions for wildlife and with supporting the delivery of other ES. Cultivation was the greatest cause of habitat loss, followed by urbanisation and plantations, with mining causing the lowest impact. Other researchers have also recorded the contribution of different LUs such as agriculture (Rouget et al. 2003; Venter et al. 2006; McKinney 2008; Polasky et al. 2011), mining (Ashton et al. 2001; Phillips 2001) and urbanisation (Rouget et al. 2003; Venter et al. 2006; McKinney 2008; Uttara et al. 2012) to habitat loss. For example, Rouget et al. (2003) found that 30% of sub-tropical thicket had been transformed due to conversion of land to agriculture leading to significant loss of biodiversity in this global biodiversity hotspot.

Areas with low habitat loss fell within the core areas (represented by PAs) of the BR (Dombo et al. 2006; WBR 2012). Low habitat loss in areas represented by PAs means insignificant loss of habitat services such as living spaces for wildlife and gene pool protection, thus protecting species from decline. Low habitat loss in PAs provides an opportunity for the delivery of recreational, raw materials and a host of regulating services, among others (Stolton et al. 2010). Low habitat loss in natural areas was not surprising since PAs are expected to be effective tools for conserving and protecting biodiversity (IUCN 2004; Stolton 2010; Tallis et al. 2011). Moreover, core areas are strictly protected by legislation and activities in these areas are highly regulated (NEMPAA 2003).

Areas that suffered significant habitat loss were surrounded by human dominated landscapes such as urbanisation, agriculture and mining. These landscapes fall within the transition zone of the BR which caters for different LU systems (Dombo et al. 2006; WBR 2012). It is important to note that, urbanisation, mining and agriculture are spatially disparate LU systems as permitted by the current LU zone management (Dombo et al. 2006; WBR 2012) and are not necessarily degraded areas. However, these LUs are regarded as major threats which lead to habitat service loss and ultimately to biodiversity and other ES loss (Ashton et al. 2001; MA 2005; Uttara et al. 2012; Chaplin-Kramer et al. 2015).

The finding of high habitat loss in areas surrounded by urban areas confirms the conclusions of other workers who found urbanisation to be the second highest driver of habitat loss (Czech et al. 2000; Venter et al. 2006; McKinney 2008; Uttara et al. 2012). Severe habitat loss in areas adjacent to cultivated areas confirms the findings of other studies (Stolton & Dundley 1999; MA 2005; Venter et al. 2006; Power 2010). Agriculture has been found to be the greatest cause of habitat loss in many landscapes (Rouget et al. 2003; Chaplin-Kramer et al. 2015). Habitat service loss is regarded as the main cause of extinction of species (Foley et al. 2005; MA 2005; Lindenmayer et al. 2008; Rockström et al. 2009). Mining has been found to have a negative impact on biodiversity (Ashton et al. 2001; Brewer et al. 2003; MA 2005). South Africa is not exempted from this phenomenon (DWAF 2004; Munnik et al. 2010; van der Burg 2012). Legislation has been put in place to address the negative impacts of mining activities on biodiversity (DEA et al. 2013), although more resources need to be channelled towards implementation of the policies (DEA et al. 2013).

The finding that Makhado Sweet Bushveld was the most degraded vegetation type of the 19 vegetation types found in the study areas (Figure 5), is not surprising, as this vegetation type has been found to be hardly protected (Mucina & Rutherford 2006). Similarly, vegetation types found to have been moderately affected by habitat loss were also at great risk, as they were poorly protected or unprotected (Mucina & Rutherford 2006). The degradation of vegetation under protection might be a result of threats such as pollution, edge effects and habitat fragmentation which are not prevented by the presence of physical/legal or other types of protection (Tallis et al. 2011). Degradation of vegetation has a negative impact on the delivery of ES (MA 2005; Tallis et al. 2011).

Our study could be compared with that of La Notte (2012) with regard to the use of environmental indicators such as habitat sensitivity to threats and the impact of human pressure on habitats, as well as the application of the mapping approach. However, thorough comparison of La Notte (2012) and our findings was difficult due to the following differences. First, La Notte (2012) used the Benefit Transfer (BT) technique to value the services, we used InVEST. Second, it valued services in monetary terms; in our study services were valued in biophysical terms. Lastly, our study assessed and mapped habitats for ES in response to human pressure such as urbanisation, mining and cultivation. La Notte's (2012) study valued and mapped habitat services using three different indicators (ecological value, ecological sensitivity and human pressure).

Our results demonstrated that the InVEST habitat quality model is useful because of the following reasons. First, it has the ability to characterise the sensitivity of habitats types to various threats. Second, it takes into account the different impacts of threats on habitats. And third, it allows estimation of the relative impacts of one threat over another. Guerry et al. (2012) highlighted other advantages of the InVEST tool which included its applicability to marine systems to evaluate different effects of management practices on the delivery of ES. InVEST, however, has some drawbacks and therefore should be applied with caution as it does not provide detailed species occurrence data. It also provides some difficulties for modelling changes in the occurrence of multiple species, their persistence or vulnerability under future conditions.

5. Conclusions

We demonstrated the contribution of anthropogenic threats to habitat loss. Habitat loss often followed a pattern with more degradation found in human-dominated systems than in natural systems such as conservation areas. Although PAs systems are still crucial for preserving and protecting biodiversity, they are vulnerable to threats. Human-induced impacts resulted in loss of habitat service and degradation that negatively affected the delivery of other ES. There were trade-offs between human-induced LUs and biodiversity conservation.

LUs such as urbanisation, agriculture and mining should find ways to accommodate biodiversity conservation. Strategies should be put in place to inform management of vegetation types that are threatened by degradation. Habitat condition assessment is highly recommended to serve as a basis for assessing delivery of ES and for informing LU planning.

Note

1. The affected vegetation types were Granite Lowveld Bushveld, Gravellote Rocky Bushveld, Makhado Sweet Bushveld, Roodeberg Bushveld, Tzaneen Sour Lowveld, Polokwane Plateau Bushveld, Lowveld Rugged Mopane Veld, Tsende Mopane Veld, Mmabolo Mountain Bushveld, Northern Mistbelt Forest, Woodbush Granite Grassland, Soutpansberg Mountain Bushveld, Musina Mopane Bushveld, Soutpansberg Summit Sourveld, Strydpoort Summit Sourveld, Subtropical Alluvial Vegetation, Limpopo Ridge Bushveld, Limpopo Sweet Bushveld and Makuleke Sandy Bushveld. Of these, Makhado Sweet Bushveld was found to be most degraded. Moderate degradation was recorded in Roodeberg Bushveld, Polokwane Plateau Bushveld, Mmabolo Mountain Bushveld, Northern Mistbelt Forest, Soutpansberg Mountain Bushveld, Tzaneen Sour Lowveld, Musina Mopane Bushveld, Woodbush Granite Grassland and Gravellote Rocky Bushveld. Low degradation was recorded in the following vegetation types; Granite Lowveld Bushveld, Lowveld Rugged Mopane Veld, Tsende Mopane Veld, Soutpansberg Mountain Bushveld, Strydpoort Summit Sourveld, Subtropical Alluvial Vegetation, Limpopo Ridge Bushveld, Limpopo Sweet Bushveld and Makuleke Sandy Bushveld. Despite the fact that some of the vegetation types are well protected such as Musina Mopane Bushveld and Limpopo Ridge Bushveld, they are still affected by degradation

Disclosure statement

No potential conflict of interest was reported by the authors.

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CHAPTER 6

ABOVE-GROUND CARBON STORAGE ASSESSMENT IN A SOCIO- ECOLOGICAL SYSTEM: A CASE STUDY FROM SOUTH AFRICA

This chapter is intended for submission to the journal *Ecosystem Services* as Ntshane B.C and Gambiza J.

Abstract

The Millenium Ecosystem Assessment (2005) found that at least 15 ecosystem services were in a poor state; among those were regulating services, which included climate regulating services (i.e. carbon storage and sequestration). One of the major consequences of the degradation of climate regulating services is climate instability. Since climate instability is of global concern, successfully stabilizing it requires global cooperation. In response to this need, countries came together and established the United Nations Framework Convention to Combat Climate Change and the Kyoto protocol. To comply with these commitments successfully, information on among others carbon stocks is required. I applied the Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) to quantify and map carbon stored in an above-ground pool in four land cover types (natural forest, cultivated areas, plantations and degraded areas) in two socio-ecological systems in South Africa. I recorded some variations in terms of carbon storage per land cover type in the two study sites under analysis, Vhembe and Waterberg socio-ecological systems. In Waterberg socio-ecological system, the total above ground (TAG) carbon storage was as follows: natural forest contained 70%, cultivated areas 25%, degraded areas 4% and the lowest stocks (1%) were found in plantation areas. On the other hand, the Vhembe socio-ecological system had TAG carbon storage of 64% in natural forest, 30% in plantations, 5% in degraded areas and 1% in cultivated areas. In terms of carbon storage in vegetation, the savanna biome had the highest storage, followed by grassland, forest and azonal vegetation respectively. The results further suggested that there is no correlation between vegetation types in terms of its protection status and carbon storage. This study recommends wide-ranging assessments of this nature in SA to inform climate change decision-making.

Key words: Climate change; Millenium Ecosystem Assessment; Convention on Climate Change; ecosystem services; Kyoto protocol; InVEST

6.1 INTRODUCTION

The Millenium Ecosystem Services Assessment (MA) (2005) found that at least 15 ecosystem services (ES) were in a poor state, among them regulating services. Following the MA`s (2005) classification of ES, regulating services include regulation for natural disasters and climate regulation (by carbon (C) storage and sequestration). In Southern Africa, on top of regulating services, provisioning services such as water, wild products (food and medicinal resources) and fodder, as well as some of the cultural ES, among others, are being subjected to degradation (Schackleton et al. 2008).

Ecosystems regulate the earth`s climate by adding and removing greenhouse gases (GHG) from the atmosphere (Tallis et al. 2011). Ecosystems collectively store more C than the atmosphere (Lal 2004). By storing the terrestrial carbon, ecosystems keep carbon dioxide (CO_2) out of the atmosphere where it would contribute to climate change (Tallis et al. 2011). A significant amount of C is stored in living organisms and their dead, undecomposed or partially decomposed remains in soil, on the sea floor or in sedimentary rock. Global atmospheric concentrations of GHG, CO_2, methane (CH_4) and nitrous oxide (N_2O) have increased dramatically as a result of human activities (MA 2005; DEAT 2004; IPCC 2007). The increase in CO_2 is mainly due to the use of fossil fuel, while the increase in N_2O is attributed to land use change due to agriculture (IPCC 2007). Tropical deforestation currently accounts for approximately one fifth of the net increase in atmospheric CO_2 (IPCC 2007). The emissions of GHG are predicted to grow in future despite practices of sustainable development (IPCC 2007).

Clearing of forests contribute to C emissions (IPCC 2007). Increasing concentrations of C emissions in the atmosphere contribute to climate change, which affects human well-being through adverse impacts on the availability of fresh water, food production and the distribution and seasonal transmission of vector-borne infectious diseases (MA 2005; IPCC 2007). Climate change is therefore regarded as a threat to sustainable development that could undermine poverty alleviation efforts, with implications for ES (MA 2005). If nothing is done to address the current levels of GHG emissions, climate change could become the greatest environmental problem to hit the 21st century, with some of its impacts highly likely to be irreversible (MA 2005; IPCC 2007).

In response to the challenges posed by climate change, countries came together and established the United Nations Framework to Combat Climate Change (UNFCCC) in 1992 and the Kyoto Protocol in 1997. In response to these global obligations, countries are required to develop climate change response policies that will inform mitigation and adaptation strategies, including C emission reduction, activities regarding C sequestration, C accounting and land use planning (Archard et al. 2004; Naidoo et al. 2008; Law et al. 2015; DEA 2015).

South Africa (SA) is a significant emitter of GHG, ranking among the world's top 15 energy-intensive countries (DEAT 2004). As a signatory country, SA has to comply with the requirements of the UNFCCC and the Kyoto protocol. To implement its climate change response policy successfully, SA has to understand the impact and magnitude of climate change (DEA 2015). In order to inform the required understanding, information on C stored in the ecosystems is required as a baseline and to inform climate change mitigation strategies (DEA 2015). Carbon is stored in four fundamental pools: soil and dead organic matter, below ground and above ground (IPCC 2007; Tallis et al. 2011). Forests, including tree plantations, are major sinks of atmospheric C (IPCC 2007).

Several studies that have been undertaken to estimate and map C stocks in SA focused mainly on soil and vegetation in general (Rouget et al. 2004; Mills et al. 2005; Egoh et al. 2008). This study aimed at assessing C stored in an above-ground pool in SA. The main objectives were (1) to estimate the amount of C stored in land cover and vegetation types (2) to map C stored in land cover and vegetation types; and (3) to assess the relationship between C storage and vegetation type. Understanding C dynamics in different land cover types was also crucial to inform management decisions and climate change mitigation assessment (Birdsey et al. 2006; IPCC 2007; DEA 2015).

6.2 MATERIALS AND METHODS

6.2.1 Study areas

The study areas were located in Limpopo, one of the nine provinces in SA. Limpopo covers five district municipalities: Capricorn, Vhembe, Waterberg, Sekhukhune and Mopane. The criteria for study area selection were as follows: (1) it had to be a district municipality; and (2) it had to contain a biosphere reserve (BR). On the basis of these criteria, within Limpopo Province, two district municipalities, Waterberg and Vhembe, met the requirements. Waterberg is the largest (49 504 km^2) of the five district municipalities in the province and hosts Waterberg Biosphere Reserve (WBR). Vhembe covers 21 349 km^2 and hosts Vhembe Biosphere Reserve (VBR). To make comparisons feasible, the Vhembe area was extended to cover parts of Capricorn and Mopani district municipalities. For the purpose of this analysis, the Waterberg area will be known as the Waterberg socio-ecological system (WSES) and also as Waterberg study area and the Vhembe region and associated areas will be known as the Vhembe socio-ecological system (VSES) and sometimes as Vhembe study area.

Land use/cover that occurred in the study areas included agriculture, forestry plantations and natural forests. Agricultural activities were well advanced and ranged from crops and livestock to poultry (VDMIDP 2012). Agricultural areas covered around180 000 ha and forestry plantations covered less than 1000 ha. In terms of human settlements, the VBR was well developed, with a population of over 1 000 000, whereas the WBR had fewer than 100 000 inhabitants (Dombo et al. 2006; WBR 2012). With regard to the climate, the study areas fell within the tropical dry climate zone with summer rainfall, a dry period of five to eight months and rainfall ranging from 500 mm to 800 mm per annum (FAO 2012).

Vegetation composition in the study areas covered four biomes: grassland, forest, azonal and the main part, dominated by the savannah biome. Natural forests in the study areas were tropical dry, known to be threatened (Blackie et al. 2014), less protected (Miles et al. 2006; Blackie et al. 2014) and less researched forests (Blackie et al. 2014). The savanna component included the bushveld parts, occurring mostly in the Waterberg study area. According to Mucina and Rutherford's (2006) vegetation classification, the main vegetation types occurring in the Waterberg study area in the savanna biome were Central Sandy Bushveld and Waterberg Mountain Bushveld, which dominated the areas around the Waterberg Mountains. Western Sandy Bushveld occurred mainly in the low-lying areas. Also occurring within the Waterberg study area were Limpopo Sweet Bushveld, Makhado Sweet Bushveld, Roodeberg Bushveld and Waterberg-Magalies Summit Sourveld (Mucina and Rutherford 2006).

The main vegetation types in the Vhembe study area are Musina Mopane Bushveld and Limpopo Ridge Bushveld, which fell within the savanna biome and dominated around Musina and the areas along the Limpopo River. Soutpansberg Mountain Bushveld and Soutpansberg Summit Sourveld (part of the savanna biome) were mainly confined to the Soutpansberg mountain region. Vha-Venda Miombo also occured in the Vhembe region. Mopane Basalt Shrubland and Makuleke Sandy Bushveld (falling within the savanna biome) dominated the northern part of the Kruger National Park (KNP). Also occurring only in the northern part of KNP, but mainly falling within the forest biome, was Cathedral Mopane Bushveld, Ironwood Dry Forest and Lowveld Riverine Forest (Mucina and Rutherford 2006).

With regard to geological composition, the study areas form part of the Limpopo River Basin, which consists of the Limpopo mobile belt and the Bushveld Igneous Complex. The southern part of the Limpopo River Basin in the Highveld is characterized by the occurrence of Karoo sediments

(Vryheid Formation), including sandstones, clay stones, shales and coal deposits (FAO 2004). The geological formation in the Waterberg study area consisted of dominantly quartzite sandstones, but also conglomerates, flagstones and shale (WBR 2012).With regard to soil composition, in the far northern parts of the Vhembe area soils are weak and shallow, on hard or weathering rocks. The Soutpansberg and Blouberg regions are dominated by rock with limited soil, shallow soil or weathering rock with clay soil and soil with a high base status in places. The dominant soils forms are Glenrosa, Plinthic catena, Primacutanic and/or Pedocutanic and Red-yellow apedal, following MacVicar et al.'s (1977) soil classification system. In the western portion of the study area soils are leached and sandy, mostly of a diastrophic nature. Because of the hilly and mountainous nature of the terrain, a large portion of the soil is very shallow and rocky (WBR 2012). The dominant soil forms are Mishap and Glenrosa (in rocky areas) and Clovelly and Avalon in flat areas, according to MacVicar et al.'s (1977) soil classification system.

6.2.2 Estimation of carbon storage in land cover/vegetation types

I estimated C stored in the above-ground pool in four land cover types (natural forest, plantations, cultivated areas and degraded areas). I also estimated C stored in different vegetation types in the natural forest land cover following the vegetation classification of Mucina and Rutherford (2006). Like Rouget et al. (2004), I ranked Mucina and Rutherford`s vegetation biomes (forest, savanna, grassland and azonal) as very low, low, medium or high, depending on the amount of C stored. High C storage areas were identified as C hotspots. Like Aaron and Gibbs (2008) and Petrescu et al. (2012), I used the Intergovernmental Panel on Climate Change's (IPCC) Tier-1 default values for above-ground biomass (IPCC 2006) specific to the location of the study sites in terms of continent (in this case Africa) and ecoregion (in this case tropical dry forest), to calculate the above-ground C storage per hectare (ha) in metric tons (Mg) as presented in Table 6.1. Since the IPCC data were reported in dry biomass, total living vegetation biomass was converted to C value using the default C conversion factor of 0.5 (Tallis et al. 2011). Table 6.1 presents the input data used to calculate C storage/ha in different land cover types in the study area.

Table 6.1 Input data used to calculate carbon storage/ha in different land cover types (Adapted from IPCC 2006).

Vegetation type	*Above-ground biomass/ha in metric tons (Mg)*	*Biomass-to-carbon conversion factor*	*Carbon (C) value in metric tons/ha (Mg/ha)*
Natural forest	130	0.5	65
Plantations	60	0.5	30
Cultivation	10	0.5	5
Degraded areas	2	0.5	1

6.2.3 Quantification and mapping of carbon stocks

I applied the Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) C storage and sequestration modelling suite as described in Tallis et al. (2011) to map and quantify the total above ground (TAG) C stored in each of the four selected land cover types. I used C values (MgC/ha) in Table 6.1 together with the South African National Land Cover map (2009), developed by the South African Biodiversity Institute (SANBI 2009) as input data to run InVEST InVEST consists of spatially explicit tools that map and value ES in an integrated way. The InVEST C storage and sequestration model uses data on land cover and C stored in one or more of the four fundamental C pools (above-ground biomass, below-ground biomass, soil and dead organic matter) to estimate the amount of C currently stored in a landscape or the amount of C sequestrated over time. For the purpose of this study, the C biomass was assessed in one pool, above ground. Above-ground biomass constitutes the largest C pool (Buyinza et al. 2014; Liu et al. 2014) in terrestrial ecosystems. The determination of above-ground biomass is very useful in assessing changes in vegetation structure (Buyinza et al. 2014).

6.2.4 Correlation between carbon storage and land cover/vegetation types assessment

The vegetation classification system of Mucina and Rutherford (2006) was used to classify vegetation into biomes and different types (savanna, forests; grassland, azonal, etc). Vegetation was further divided into four categories according to its status: critically endangered, endangered, vulnerable or protected. The hypothesis of the study was that protected vegetation types will have more C stocks than less protected, threatened and vulnerable vegetation types. Similarly, natural land cover types (such as natural forests), will have more C stored than transformed land cover types (cultivated/plantation areas and degraded areas) The amount of C stored in different land cover/vegetation types was determined by overlaying C storage maps on vegetation maps using ArcGIS spatial analyst tools (ESRI 2013).

6.2.5 Running the InVEST carbon storage model

Following Tallis et al. (2011), an InVEST toolbox was first added to the existing Arc map toolbox. The C storage model was selected and an interface was opened. In this interface all required data to run the model were uploaded and authorized. Once all the required inputs had been entered and authorized, the model's running progress log was displayed until the model had been completed successfully. Final results were contained in the output folder of the model, displayed as *tot_C_cur* (total current C stored). This was the sum of all C stored in the C pools included, in this case above ground. An intermediate folder contained data of each C pool independently; in this case it was displayed as *C_above_cur* (current C stored in the above-ground pool).

6.3 RESULTS

6.3.1 Carbon storage and land cover types

Results, as presented in Table 6.2, indicated that the Waterberg study area contained a higher amount of total above ground (TAG) C stored in its hotspot areas (33 200 MgC, representing 70%), compared to the Vhembe study area, where a TAG amount of 26 000 MgC (representing 64%) was stored. The land cover type storing more C in both study areas was natural forest. In the Waterberg study area, C was stored in different land cover types as follows: the highest amount of C (33 200 MgC, representing 70%) was contained in natural areas, followed by cultivated areas with 12 000 MgC (representing 25%) and degraded areas with 2000 MgC (representing 4%). The lowest amount of C, amounting to 400 MgC (representing 1%), was stored in forestry plantations. Carbon storage in the Vhembe socio-ecological system was represented as follows: natural areas contained the highest amount of C stored (26 000 MgC, representing 64%), followed by plantations with 12 000 MgC (representing 30%) and degraded areas with 2000 MgC, representing 5% (Table 6.2). The lowest amount of 400 MgC (representing 1%) was found in cultivated areas. Figures 6.1 and 6.2 show C storage ranges in different land cover types in the study areas ranked as very low, low, medium and high. Table 6.2 presents the percentage representation of C stored in different land cover types in the study areas.

Table 6.2 Percentage representation of carbon stored in different land cover types in the study areas.

Study areas	*Land cover type*	*Carbon (C) stocks/ha in metric tons (Mg)*	*Total above-ground (TAG) C stocks in Mg*	*TAG C (%)*
Waterberg	Natural forest	65	33 200	70
	Cultivated areas	5	12 000	25
	Degraded areas	1	2 000	4
	Plantations	30		
Vhembe				
	Natural forest	65	26 000	64
	Plantations	30	12 000	30
	Cultivated areas	5	400	1
	Degraded areas	1	2 000	5

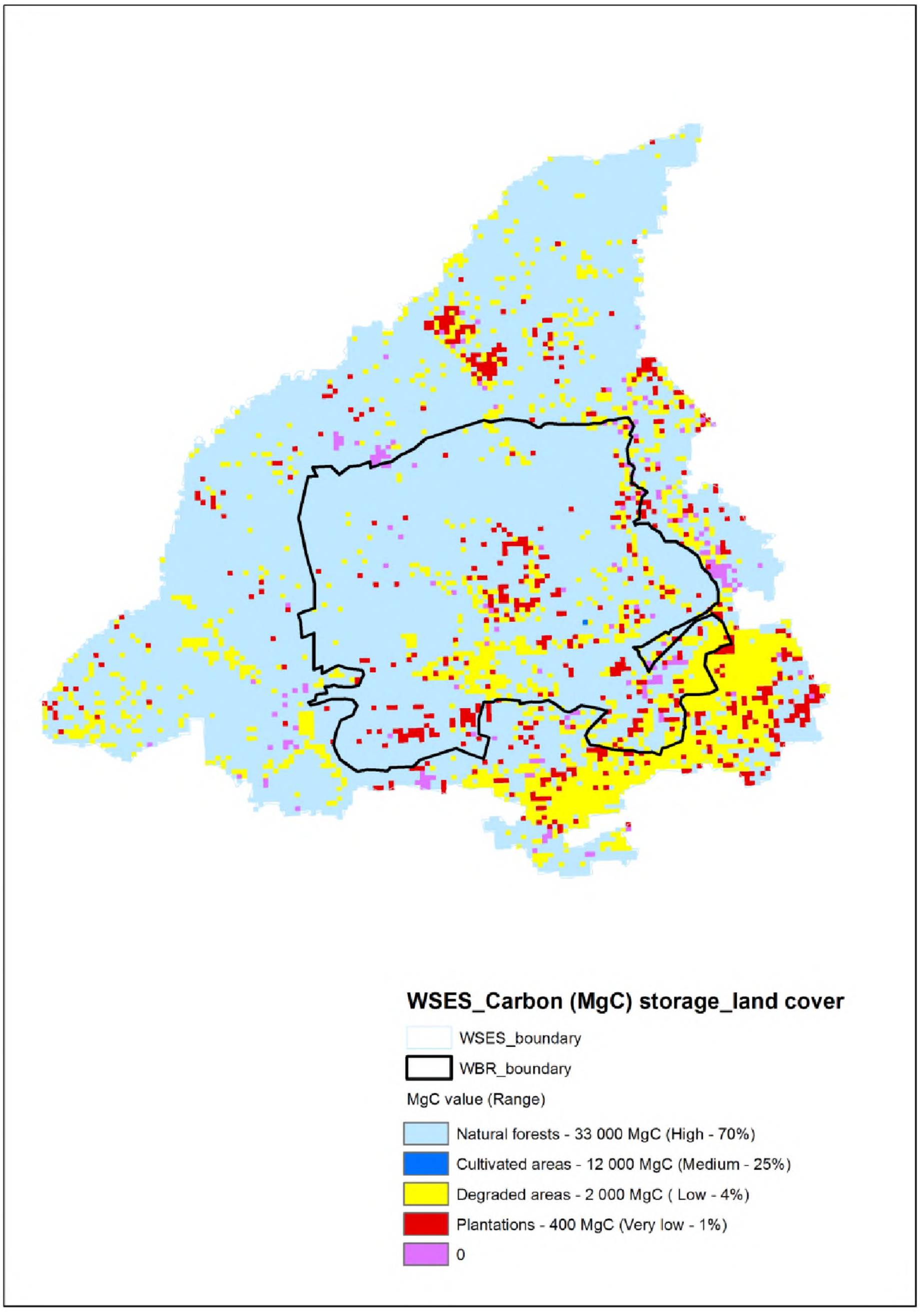

Figure 6.1 An illustration of the TAG C (MgC) storage range in different land cover types (cultivated areas, degraded areas, plantations and natural forest) in the Waterberg socio-ecological system (WSES), including the WBR.

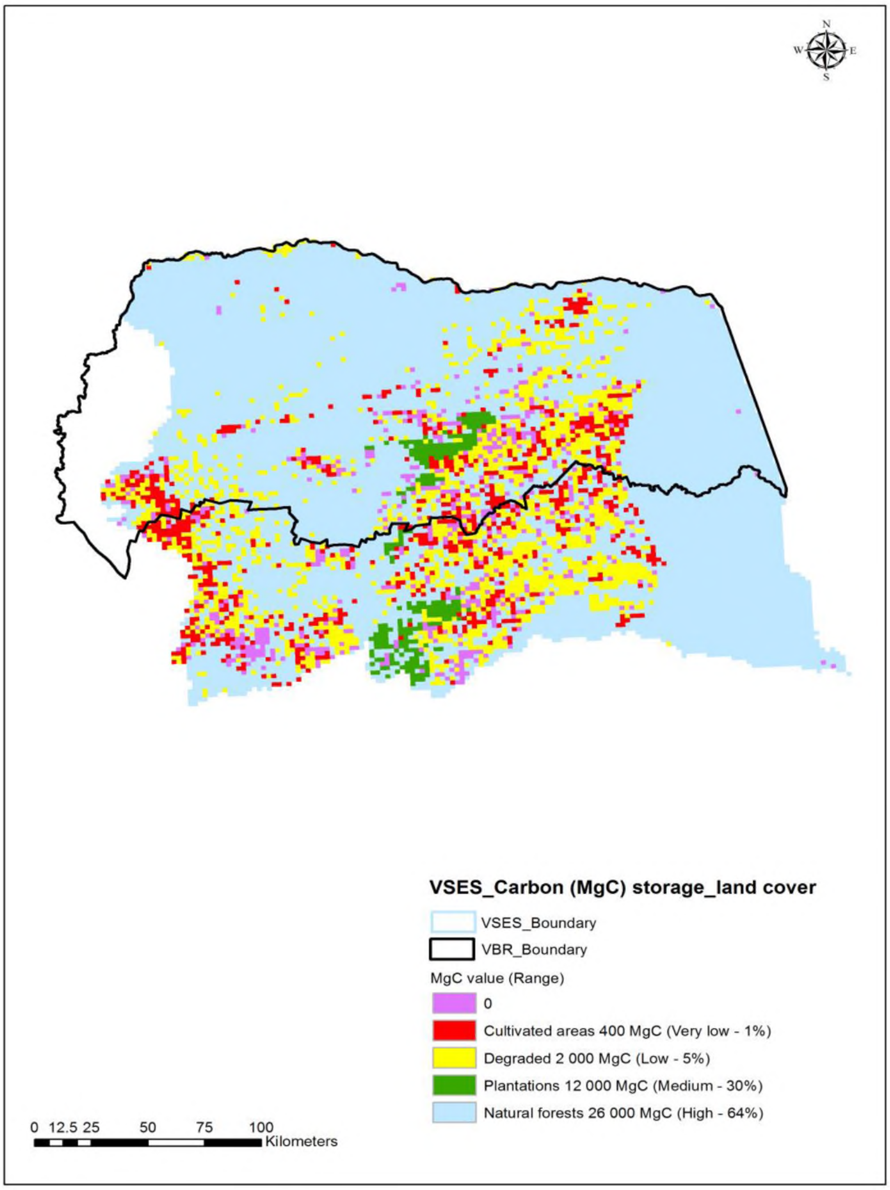

Figure 6.2 An illustration of TAG C (MgC) storage range in different land cover types (cultivated areas, degraded areas, plantations and natural areas) in the Vhembe socio-ecological system (VSES), including the VBR.

6.3.2 Carbon storage and vegetation types

In general, the savanna vegetation biome was found to contain the highest amount of C, representing 70% in the Waterberg study area and 64% in the Vhembe study area. The vegetation types falling within the savanna biome (Dwaalboom Thornveld, Madikwe Dolomite Bushveld, Western Sandy Bushveld, Roodeberg Bushveld) were found to be dominating in the medium to high C storage range (12 000-33 200 MgC) in the Waterberg study area. However, vegetation types such as Strydpoort Summit Sourveld and Mamabolo Mountain Bushveld, also in the savanna biome, were recorded in the low to medium C storage range (400-12 000 MgC). Some of the vegetation types (Makhado Sweet Bushveld (savanna), Limpopo Sweet Bushveld (savanna), Subtropical Alluvial Vegetation (azonal), Waterberg Mountain Bushveld (savanna), Poung Dolomite Mountain Bushveld, Central Sandy Bushveld (savanna) and Polokwane Plateau Bushveld) were represented in all three C storage ranks: low, medium and high C storage ranking areas. Azonal vegetation types were recorded in the medium C storage range, representing only 10% of C storage. Grassland was recorded in the medium-high C storage range, covering at least 20% of C storage in the study area.

In the Vhembe study area, savanna biome vegetation types were found to be dominating in all C storage ranks, representing 64% of C storage. In terms of C storage per vegetation type, included in the lowest ranking (0-2000 MgC) were Mopane Shrubveld (savanna), Soutpansberg Mountain Bushveld (savanna) and Makuleke Sandy Bushveld (savanna); medium-ranked C areas (2 000-12 000 MgC) included Makhado Sweet Bushveld (savanna), Granite Lowveld Bushveld (savanna), Lowveld Rugged Mopane Veld (savanna), Tsende Mopane Veld (savanna) and Tzaneen Sourveld (savanna) and among vegetation with the highest C stored (12 000-26 000 MgC) were Musina Mopane Bushveld (savanna), Polokwane Plateau and Woodbush Granite Grassland. Figures 6.3 and 6.4 illustrate C storage in different vegetation types in the study areas. Forest and azonal vegetation biomes were found to be dominating in the high C storage range. Grassland vegetation types in this study area were recorded in the medium-high C storage range as well.

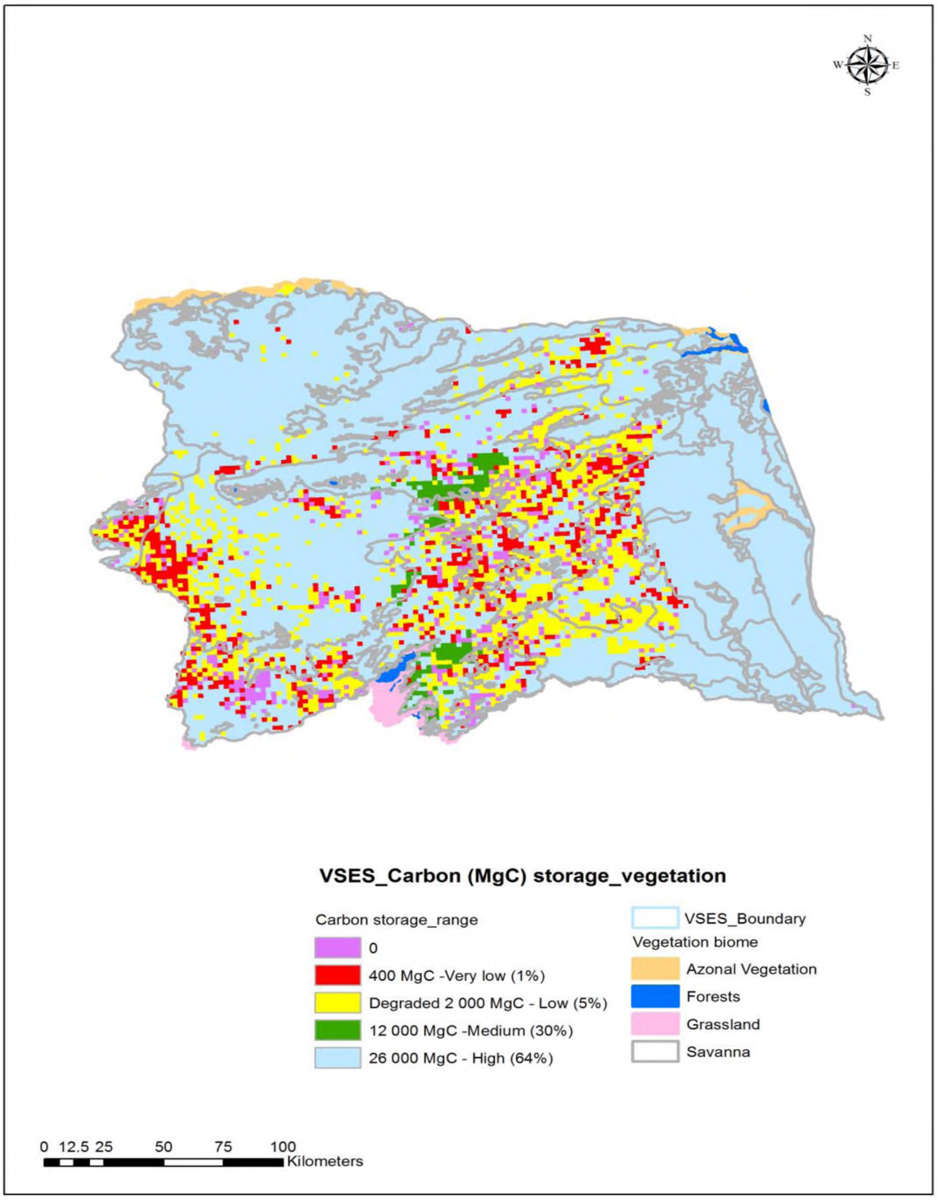

Figure 6.3 An illustration of the TAG C (MgC) storage in different vegetation types in Vhembe socio-ecological system (VSES), ranked low, medium or high in terms of the amount of C stored.

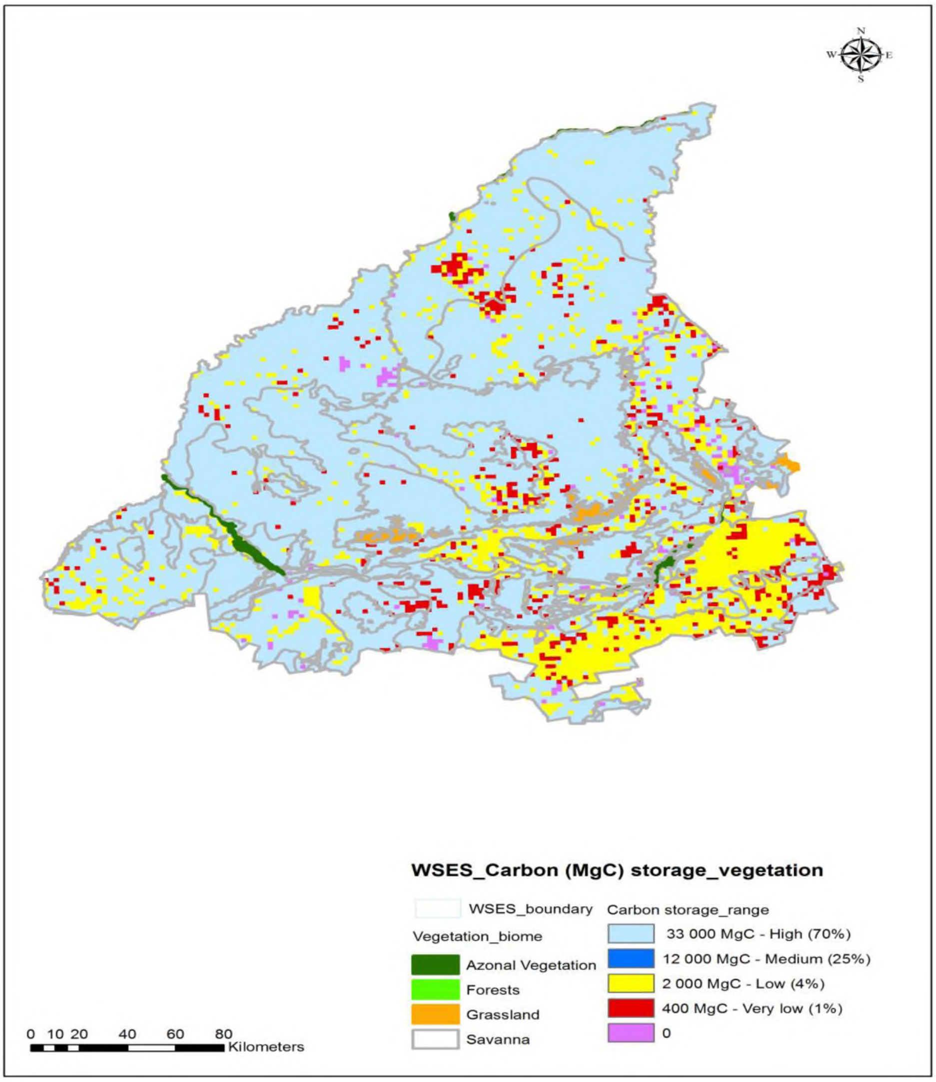

Figure 6.4 An illustration of the TAG C (MgC) storage range in different vegetation types in the Waterberg socio-ecological system (WSES) study area (vegetation types are represented by biomes), ranked low, medium or high in terms of the amount of C stored.

6.4 DISCUSSION

6.4.1 Carbon storage in land cover types

Results indicated that both study areas had high C stocks in natural forest land cover. The finding of high C stocks in natural forests is consistent with other studies (Buyinza et al. 2014; Lucey et al. 2014; Mugagga et al. 2015). Natural forests are associated with high C stocks, as they are less transformed (FAO 2012; Golden Agri-Resource and SMART 2012). High C stocks found in natural forests in the study area could also be associated with the fact that these areas were dominated by protected areas, which are known for their intact nature and have also been found to contain high C stocks (Campbell et al. 2008; IUCN 2010; Fongnzossie et al. 2014). Results also indicated that the Waterberg study area had more C storage hotspots than the Vhembe study area. This could be attributed to the fact that this area was associated with the WBR, which was less developed, with a population of fewer than 100 000 (WBR 2012), and the dominant land uses were game farming and ecotourism, which are associated with conservation (WBR 2012). As expected, the situation in the Vhembe study area was slightly different, as it was highly developed in terms of land use, which included cultivation and livestock farming, as well as well-established human settlements with a population of around 1 500 000 (Dombo et al. 2006; StatsSA 2012). Human populations are known to exert pressure on natural vegetation in the quest to establish settlements and agricultural land (Mugagga et al. 2015).

In terms of other land cover types, other than natural forests, I found some variations. Forest plantations were found to contain more C stocks in the Vhembe study area than cultivated land. This finding was consistent with the study`s hypothesis, which indicated that natural areas will contain more C stocks than transformed areas. The finding of plantation land cover with more C stocks in the Vhembe study area than in cultivated lands was consistent with those of other researchers (Mugagga et al. 2015; Rahman et al. 2015). The finding of more C stocks in plantations than in cultivated areas is attributed to the higher number of trees, compared to few scattered trees usually associated with agricultural/cultivated plots (Mugagga et al. 2015). Consistent with these observations, plantation areas are the second most extensive form of land cover, with more areas covered in hectares in the Vhembe study area (SANBI 2009). However, the finding of less C storage in cultivated areas was not surprising, as this type of land use has been associated with vegetation and habitat destruction (Ashton et al. 2001; McKinney 2008; Koh and Gardner 2010). A decline in C stocks has been associated with a decline in vegetation density (Dewi et al. 2009; Solichin et al. 2011; Golden Agri-Resources and SMART 2012). Agricultural areas have also generally been associated with lower C stocks (IPCC 2006; Lucey et al. 2014), and their activities have been associated with a reduction in certain ES (Power 2010; Rouget et al. 2003). Clearing of forests for agricultural purposes results in stored C in vegetation being released into the atmosphere (Gibbs et al. 2007; IPCC 2007; Buyinza et al. 2014).

A slightly different observation was made in the Waterberg study area, where cultivated areas were found to contain more C stocks than forest plantations. This observation was expected and attributed to the high intensity of agricultural land use in these study areas. Also attributed to lower C stocks is persistent clearing/logging, as it reduces stored C (IPCC 2007; Tallis et al. 2011). In this case it also so happened that in the Waterberg study area, the few remain of forest plantations were scattered and cut every second or third year through the Expanded Public Works Programme, thus releasing more C into the atmosphere. I also support the observations made by Mugagga et al. (2015), that the only time when agriculture could have more C stocks than forest plantations, as in this case, is when the forest plantation is small. Together, the few remaining scattered plantations only covered 760 ha (SANBI 2009).

The finding of degraded areas in the low C storage range is associated with the clearing of natural forests to create human-managed systems (MA 2005; IPCC 2007), thus releasing more C into the atmosphere (Gibbs et al. 2007; IPCC 2007). My finding is consistent with those of Brakas and Aune (2011) and Buyinza et al. (2015), who found degraded land cover types to have lower C stocks as well. Overall, these findings support the study`s hypothesis that transformed /degraded land cover will have less C stored than natural land cover.

The study also identified limitations with regard to the potential future trend in C storage below ground, in litter and in soils, since it only focused on estimated C stored in the above-ground pool. This means that it remains unknown how much C is stored below ground, in litter and soils, which limits the study with regard to the potential future trend in C storage in the excluded pools. However, it may be useful in providing a basis for establishing the future trend in C storage in the above-ground pool in the study areas. The results of this study could also be used for extrapolation to other similar ecosystems

6.4.2 Carbon storage and vegetation types

Generally, the savanna biome was found to be dominant in all three C storage ranges (low, medium and high). This finding could be associated with the fact that this vegetation biome was dominant in the Waterberg study area, covering 53%, and second dominant in the Vhembe study area, covering 35% (Mucina and Rutherford 2006). This study also indicated that areas covered with savanna vegetation contained the highest TAG C stocks of up to 33 200 Mg (representing 70% of C storage) in the Waterberg study area, and 26 000 Mg (representing 65%) in the Vhembe study area. Scolforo et al. (2015) also observed high C storage in the savanna biome, compared to other vegetation biomes (semi-arid woodlands and Atlantic forest). The results of the study are also consistent with that of Egoh et al. (2008), who found the same C storage range dominated by savanna vegetation types. Moreover, this study`s findings concur with those of Brakas and Aune (2011) and Buyinza et al. (2014) who reported low above-ground stocks on grassland. I attribute the current observations to firstly, the size of the area covered with grassland, which is 28% in the Waterberg study area and 8% in Vhembe study area, and secondly land use change, as most of the natural woodland vegetation has been cleared to make way for agriculture (De Klerk 2003; WBR 2012; Dombo et al. 2006). Change in land use from natural forest to grassland and agriculture was found to reduce the above-ground biomass, thus affecting C storage (Mendoza-Ponce and Galicia 2010). Carbon storage in the azonal vegetation biome covered around 12% in the Waterberg study area and 22% in the Vhembe study area, mainly in the medium to high C storage range. However, I lacked detailed previous data to compare my findings.

The forest vegetation biome was found to have the least C storage of around 7% in Waterberg study area. The finding of less C storage in the forest vegetation biome of the Waterberg study area is in contradiction with that of Rouget et al. (2004) and Buyinza et al. (2014), who found high C stocks in forest vegetation. I attribute the finding of low C storage in the forest biome mainly to the size of the area covered, which was less than 10% in the Waterberg study area. However, a significant difference was found in the Vhembe study area, where the forest vegetation biome stored more than 50% of C. High C storage in the forest biome compared to other biomes was also found elsewhere (Rouget et al 2004; Brakas and Aune 2011). I attribute the current finding of high C storage in the Vhembe study area to the size covered by the forest biome, which was more than half of the study area under analysis.

With regard to individual vegetation types, I found significant variation. The low to medium C storage recorded in Strydpoort Summit Sourveld and Mamabolo Mountain Bushveld vegetation types could be attributed to the fact that they were found to be poorly to moderately protected (Mucina and Rutherford 2006). Similarly, the finding of Limpopo Sweet Bushveld, Makhado Sweet Bushveld, Waterberg Mountain Bushveld, Central Sandy Bushveld, Polokwane Plateau Bushveld and Poung Dolomite Mountain Bushveld vegetation types with low C storage in the study area was not surprising, as they were poorly protected (Mucina and Rutherford 2006). The finding of Dwaalboom Thornveld, Roodeberg Bushveld and Western Sandy Bushveld vegetation types in the medium to high C storage range, despite being poorly protected, could be attributed to the fact that they were found to be less threatened (Mucina and Rutherford 2006). Subtropical alluvial vegetation being represented in the medium to high C storage rank could be associated with the fact that this vegetation type was found to be well protected and less threatened (Mucina and Rutherford 2006.

The finding of Musina Mopane Bushveld with high C storage in the Vhembe study area indicated that this vegetation type had good C storage potential, despite the fact that it was found to be poorly conserved (Mucina and Rutherford 2006). However, the finding of high C stored in Musina Mopane Bushveld and Polokwane Plateau and Woodbush Granite Grassland vegetation types in the Vhembe study area was not expected, as they were found to be poorly protected or not protected at all (Mucina and Rutherford 2006). The same is true for the finding of low C stored in Mopane Shrubveld and Makuleke Sandy Bushveld in the same study area, as both these vegetation types were well protected (Mucina and Rutherford 2006). However, the finding of low C stored in Soutpansberg Mountain Bushveld, again in the Vhembe study area, was expected, as this vegetation type was found to be poorly protected (Mucina and Rutherford 2006). The study findings above suggest that there is no correlation between C storage and vegetation types, as hypothesised.

6.5 CONCLUSIONS

The study managed to (1) quantify C stored in land cover and vegetation types in the study areas; (2) map the spatial distribution of C storage in the study area; (3) demonstrate that the type of land use has an effect on C storage in the ecosystems; and (4) indicate that there is no correlation between C storage in vegetation types and their protection/conservation status; vegetation types that fell within protected areas did not contain high C stocks as expected and vice versa. Given the importance of social-ecological systems such as BRs in the delivery of vital ES such as C storage, and the fact that natural forest cover is continuously being degraded through various human-induced activities, it is highly recommended that (1) a wide range of assessments like this one be conducted so that they will form the basis for decision-making on land use planning and climate change mitigation and (2) strategies that focus on the preservation of whatever C is currently stored are developed, to decrease further degradation.

Although some strides have been made in raising awareness about the impact of climate change, more still needs to be done to deal with the persistent problems caused by this phenomenon. It is for this reason that countries, including SA, are required to put more effort into their climate change focus strategies in order to meet their international obligations. With so much C stored in this area, it is clear that SA could be contributing more from the remaining ecoregions; all that is required is to prevent the acceleration of anthropocentric climate change through the implementation of sustainable climate change mitigation and adaptation strategies.

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CHAPTER 7

ECONOMIC VALUATION OF PROVISIONING SERVICES IN TWO BIOSPHERE RESERVES IN SOUTH AFRICA

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Abstract

The importance of biosphere reserves (BRs) cannot be underrated as an important source of ecosystem services (ES) that contribute to human well-being. Among these ES are timber and firewood. Firewood remains a primary source of energy for heating and cooking for many households around the world, including South Africa, and timber is an important source of fuel and infrastructural material. The production of planted forests forms a major part of the South African economy, therefore determining their economic contribution is very important. I applied the Integrated Valuation of Ecosystem Services and Trade-offs tool, to determine the net present value (NPV) of two provisioning ES (timber and firewood) in a BR context, focusing on planted forests. Taking into consideration various input factors, at a 12% discount rate, the NPV for timber production accounted for R23 317/ha in VBR and R57 304/ha in Waterberg biosphere reserve (WBR). However, at lower discount rates (4 and 7%), the NPVs for timber were negative in Vhembe biosphere reserve (VBR) and positive in WBR. With regard to firewood production, the NPVs were negative against all three discount rates in both study areas. The results suggest that profit generation in terms of firewood production in both study areas is unsustainable; however, there is good investment potential in timber production in the VBR study area.

Key words: Ecosystem services; economic valuation; total net present value, biosphere reserve, forest plantations, provisioning.

7.1 INTRODUCTION

Biosphere reserves (BRs) are socio-ecological systems that consist of multiple subsystems of natural and man-made origins (Ostrom 2009; Palomo et al. 2011), such as forest ecosystems of both plantation and indigenous nature. Forest ecosystems cover over 4 billion hectares (ha) globally (FAO 2010), comprising around 95% of the indigenous component and around 5% of plantations and representing 31% of the world's surface area (FAO 2010). Of this, 17%, representing 650 million ha, can be found in Africa (FAO 2004). In the South African context, forest covers over 40 million ha, of which the indigenous component makes up 0.4% of the land surface area (DAFF 2011a), covering 492 700 ha, while plantations cover approximately 1.4% of the surface area, representing 1.3 million ha of the country's total land surface area (Grundy and Wynberg 2001; DAFF 2011a).

Forest is an important land cover component globally and its enormous contributions to human wellbeing cannot be overstated. The importance of forests is pronounced as the source of various ecosystem services (ES) that contribute to human wellbeing ecologically, socially and economically (Eftec 2010; DAFF 2011a; FAO 2012; Aggrawal et al. 2013). Some of the important contributions made by forests include performing various regulating functions such as mitigating natural disasters and phenomena, e.g. floods and climate change. Forests are also responsible for the production of consumptive products such as browsing material for livestock and game (Aggrawal et al. 2013; FAO 2012), fuel wood and raw material such as timber.

Firewood remains an important contributor to satisfying energy requirements throughout the world (FAO 2010). Firewood satisfies at least 27% of total primary energy requirements in Africa (FAO 2014) and about 90% of South African rural households use firewood for various purposes, including heating and cooking (Shackleton et al. 2007; Chirwa et al. 2010). About 8 billion of the world`s population depend on forests for their shelter requirements (FAO 2014). In South Africa (SA), households' collection of timber seems to be on a small scale; more focus is placed on retail and exports (DAFF 2011b). Notwithstanding the need for firewood and timber to meet various households requirements throughout the world (FAO 2014), meeting these demands comes with some trade-offs. On top of other anthropogenic pressures exerted on natural forest ecosystems, i.e. desertification, habitat loss and degradation, as well as land use decisions that tend to be made in economic terms (Seidl et al. 2007; Daily et al. 2009, Kovacs et al. 2013), the demand for timber and firewood contributes to a further decline in the natural forest cover and climate change (MA 2005; IPCC 2007). In fact, natural forest cover has declined tremendously and it is now ranked among the most threatened land covers in the world (MA 2005).

Given the magnitude and dynamics of anthropogenic challenges to natural forest ecosystems, societies are forced to employ various strategies to address them. In SA, the much-needed solution to supplement the social, ecological and economic value chain of the declining natural forest cover could be found through forest plantations. This includes mitigating the risks posed by the climate change phenomenon and meeting the demand for timber and firewood, among others. In the 2010/11 financial year, about 233 069 tons of firewood were produced from planted forests in SA, of which 26 292 tons were harvested in Limpopo Province. Planted forests also yielded 4 611 723 m^3 for sawlogs, poles and droppers, as well as 1 09 1 094 tons of mining timber and pulpwood (DAFF 2011b). Given the fact that planted forests cover less than 2% of SA (DAFF 2011a), more forest plantations can be added to the system through the afforestation process, thus providing the much sought-after mitigation to climate change and shrinking forest cover (FAO 2010; DAFF 2011a). However, species suitable for afforestation must be selected with care, as exotic species (*Pinus and Eucalyptus spp)* are known to consume more water compared to indigenous species such as *Berchemia zeyheri*, *Celtis Africana* and *Ptaeroxylon obliquum,* among others (Gush et al. 2011).

Knowledge of the economic value provided by forest ecosystems is beneficial when making tough land use decisions concerning these systems, while assisting in stimulating appreciation of the ES they provide (Seidl et al. 2007; Nelson et al. 2009; Kovacs et al. 2013). Some of the well-known valuation strategies include taking into consideration the economic, social and ecological contributions made by ecosystems (TEEB 2010; Haines-Young and Potschin 2009; Tallis et al. 2011; Gómez-Baggethun et al. 2014).

Economic valuation approaches attempt to determine the value of goods and services in monetary terms (Haines-Young and Potschin 2009; TEEB 2010; Gómez-Baggethun et al. 2014). Economic valuation approaches are divided into three types: the direct market, revealed preference and stated preference approaches (Haines-Young and Potschin 2009; TEEB 2010; Gómez-Baggethun et al. 2014). Direct market approaches are used to determine the values of those ES that can be involved in market transactions. These approaches are further divided into three main approaches: the market price, cost-based and production function approach. The market price-based approach is applicable to those ES that are often sold in markets (Haines-Young and Potschin 2009; TEEB 2010; Gómez-Baggethun et al. 2014), including most of the provisioning ES, e.g. timber and crops. The cost-based approach is related to the cost estimated for the replacement of ES artificially and is further divided into replacement and mitigation/restoration cost methods (Haines-Young and Potschin; Eftec 2010); the restoration cost method refers to costs estimated for the restoration of lost/damaged ES. The production-function approach is further divided into two types: production-function and factor income approaches, which are used to estimate how much a particular ES contributes to the delivery of another ES that is traded in the existing market, e.g. how soil fertility improves timber production and therefore the income of the landowner (Eftec 2010).

The economic value of forests can be measured through the financial contribution of the harvested products to the regional economy (Wu et al. 2007; Eftec 2010; Kovacs et al. 2013). Various studies have conducted valuation of ES provided by forest ecosystems (Wu et al. 2007; Nelson et al. 2009; Eftec 2010; Kovacs et al. 2013), but the focus on the determination of the net present value (NPV) is limited. In SA, determining the economic contribution of planted forests is very important, as they play a crucial role by contributing to the economy, contributing around 1.2% to GDP, amounting to an estimated R12 billion and providing 170 000 jobs. We conducted an economic valuation of two important ES provided by planted forests, timber and firewood, in a BR context using the Integrated Valuation of Ecosystem Services (InVEST) modelling and valuation tools. In order to achieve the main aims of the study, the following objectives had to be addressed: (1) to determine the NPV of timber and firewood production in the study areas, and (2) to quantify the volume of timber and firewood biomass produced in the study areas.

7.2 MATERIALS AND METHODS

7.2.1 Study area

The study areas were located in Limpopo Province of SA in the Vhembe and Waterberg district municipalities. Both study areas were situated in socio-ecological systems called BRs, which through their zonation structure allowed different ecosystems of both natural and unnatural origin to co-exist (UNESCO 2010). UNESCO`s Man and Biosphere Program BR concept in South Africa made its mark with the establishment of the first BR in 1998: Kogelberg, situated in the Western Cape Province. Currently there are six BRs in South Africa, three of which are situated in Limpopo Province: Vhembe, Waterberg and Kruger to Canyon. The focus of the study was Vhembe (VBR) and Waterberg (WBR).

In the VBR and WBR, diverse land use took place in both natural and unnatural ecosystems. Most of the indigenous forest areas left were found in protected areas (PAs), including the famous gallery forest of the Mapungubwe National Park in VBR and Apiesrivierspoort forest in Marakele National Park in the WBR. Most indigenous forests found outside this type of protection are under threat of degradation (PAK 2008). One of the well-known indigenous forest areas outside PAs is Thathe-Vonde, which is part of the Komatiland Forests (KLF) in the VBR. The indigenous forest components mentioned here exist for conservation purposes only; no commercial harvesting takes place. If harvesting occurs at all, it is carried out illegally for subsistence purposes. This study excluded the analysis of indigenous forests` production of timber and firewood on purpose, as the production of these commodities in this context does not form part of their management objectives and neither timber nor firewood production for commercial purposes takes place within the indigenous component. In WBR, since there was no known commercial plantation in existence, and planted forests as land use have been converted to other land uses, the study focuses on the remaining isolated pockets of plantations.

7.2.2 Valuation approach used in this study

I used the InVEST approach (Tallis et al. 2011) to determine the economic value of timber and firewood production in the study areas. InVEST is a spatially explicit modelling tool that consists of a suite of models that map and value ecosystem goods and services provided by nature (Daily et al. 2009; Tallis et al. 2011). Among these modelling suites is a timber production model.

The InVEST timber production model estimates the production value of natural forests and forestry plantations. This model analyses the amount and volume of legally harvested timber from natural forests and managed plantations based on the harvest level and cycle. The model's output maps the NPV of forest harvests over some user-defined time interval. If the timber parcel map is associated with the current land use/land cover (LU/LC) map the model calculates, for each timber parcel, the NPV of harvests that occurred between the current year and some user-defined date. The total net present value (TNPV) includes the revenue that will be generated from selling all timber/firewood harvested from the current year to the number of years that the plantation will be valued (T) after the current year, less harvest and management costs incurred during this period. Finally, all monetary values are discounted back to the current year's present value, assuming that harvest practices and prices are static over the time interval. The valuation model estimates the economic value of timber based on the market price, harvest and management costs and a discount rate and calculates its economic value. Since firewood production in this analysis is an output of timber plantations, the InVEST timber model applied here will be applied to firewood production as well as the firewood production from timber plantations under analysis.

Data tools needed to run the model successfully include a GIS vector dataset, projected in meters, with a unique identifier that indicates the different timber parcels on the landscape (Tallis et al. 2011). The model also requires a separate data table about the timber/firewood parcels on the landscape that can be joined to the polygon dataset in #1. Columns contain an attribute for each parcel. Table 7.1 presents InVEST timber production data requirements (Tallis et al. 2011).

Table 7.1 InVEST timber/firewood production model data requirements

Attribute	Description	Calculation methodology
Timber_parcel	Demarcated timber compartment per age class	Timber parcels were numbered 1 to 8 in VBR and 1 in WBR
Parcel_ID	Same as timber/firewood parcel ID in #1. IDs must match the parcel IDs used in the polygon map.	Determined by the model
Parcel_area	The area of the timber/firewood parcel in hectares	Extracted from the plantation map`s attribute table
Percentage of harvest	The proportion of the timber/firewood parcel area that is harvested each harvest period; units are integer percentage.	Parcel area/rotation period, obtained from the plantation management
Harvesting_mass	The mass of wood harvested per hectare in each harvest period (in metric tons (Mg) for *Eucalyptus spp.* and cubic meters for pinus species.	Obtained from the plantation management
Frequency of harvest	The frequency of harvest periods, in years, for each parcel	Harvesting takes place every year, =1
Price (R)	The marketplace value of the wood harvested from the parcel	Obtained from the plantation management
Maintenance_cost (R)	The annualized cost ha^{-1} of maintaining the timber/firewood parcel	
Harvesting_cost (R)	The cost incurred per ha when harvesting.	
T	The number of years from (current year (yr_cur) or future year (yr_fut) that parcel harvests will be valued. If the parcel is in an even age rotation managed plantation, T can be any number, although a large T is not recommended. If the harvest is expected to be an immediate one-time clear cut T = 1.	The parcels were rotation managed, 30 years for *Pinus spp.* and 12 years for *Eucalyptus spp.*
Immediate_harvest	This attribute answers whether a harvest occurs immediately – whether a harvest occurs in yr_cur, or whether the user is evaluating a forest parcel associated with a future LU/LC scenario occurring in yr_fut. Answer yes (entered as YES or Y) or no (entered as NO or N) to whether a harvest should be calculated for yr_cur or yr_fut. If yes, then the NPV of harvest in the parcel includes a harvest in yr_cur.	NPV includes harvest in yr_cur (yes applied for all timber parcels)

Biomass Expansion Factor (BCEF)	An expansion factor that translates the mass of harvested wood into volume of harvested wood. The expansion factor is measured in Mg of dry wood per m³ of wood. The expansion factor is a function of stand type and stand age (this factor is known as the biomass expansion factor in the literature). If data on this expansion factor are not available, one can use the BCEFR row in table 4.5 of IPCC (2006). Otherwise, this expansion factor can be set equal to 1 for each parcel.	Set equal to 1 for each parcel as recommended by the model.
Market Discount Rate	This is optional and only required for valuation. This number is not supplied in a table, but instead is input directly through a tool interface. The tool's default value is 7% per year, and the other one is 3%. The rate will, however, differ and depend on the country and landscape being evaluated.	Chosen discount rate was 12% calculated based on weighted average cost of capital (WACC) using South African rates (prime, government bond, tax, interest rate and CPIX among others), as well as the recommended rates of 4% and 7% for environmental projects

7.2.3 Information sourcing

The first stage of data collection to meet the requirements of the model, as indicated in Table 7.1, was through stakeholder engagement. This process was conducted by interviewing stakeholders who owned forest plantations between period 2012 and 2013, with the aim of understanding the extent, value and benefits of the forest ecosystems found in the study areas. In VBR, 22 stakeholders who were managing forest plantations over 200 ha and willing to participate in the survey were interviewed. The total population of stakeholders with forest plantations according to the information received from the Department of Agriculture, Forestry and Fisheries was around 200. At least eight stakeholders in VBR were accessible for face-to-face interviews and 14 were interviewed telephonically. The selection targeted mainly those that were in the forestry business, managed at least 200 ha of forestry plantation and were accessible for the interviews. In WBR, 10 stakeholders, situated in the proximity of the available forest plantation patches, were contacted to establish an understanding regarding the use of these plantations. Four stakeholders were interviewed face to face and six were interviewed telephonically. The reason for the lower number of stakeholders involved in the WBR compared to the VBR was mainly that only a few plantation patches were left, generally in isolated places, and most were outside stakeholders` properties.

The WBR and VBR forestry plantation datasets used were extracted from the SA National Land Cover dataset (SANBI 2009). Supplementary information pertaining to timber parcels, such as size in hectares (ha), harvesting mass, percentage of harvest, frequency of harvest and selling price (market value) of harvested wood was acquired through engagement with the landowners. Additional information pertaining to maintenance and harvesting costs was obtained from Forestry Valuations (2012). Information pertaining to firewood production in VBR was extracted from the report by Venter (2009) and in WBR it was obtained from the EPWP project manager who was involved with the cutting/clearing of the plantations, as well as some of the stakeholders who were harvesting firewood from time to time in some of the plantations.

7.2.4 Data collected

7.2.4.1 State of timber production in the study areas

The VBR study area had more than 200 timber plantations, most of which were very small. The study focus was KLF. The KLF plantation was selected, as it is the biggest forest plantation in the VBR and operates commercially. For the purpose of this study, only commercial timber plantation production in five parcels was analyzed. Of the five, one was managed for *Eucalyptus spp.* only; the other four produced a mixture of *Pinus spp.* and *Eucalyptus spp*. *Pinus spp.* are managed for up to 30 years, while *Eucalyptus spp.* are harvested every 12 years in all the timber parcels. The five main timber plantations were further divided into eight parcels, separating the two dominating species of *Eucalyptus spp.* and *Pinus spp.* The first timber parcel covered 5 766 ha, comprising 5 245 ha of *Pinus spp.* and 521 ha of *Eucalyptus spp.* The second timber parcel covered 222 ha and was dominated by *Eucalyptus spp.* The third timber parcel covered 613 ha and was managed for both *Pinus spp.* (425 ha) and *Eucalyptus spp.* (188 ha).The fourth timber parcel covered 776.75 ha, with 325 ha covered by *Eucalyptus spp.* and 441 ha covered by *Pinus spp.* The last timber parcel covered 4 017 ha and was dominated by *Eucalyptus spp.*

Harvesting involved at least a third of the timber parcels, (3% f*or Pinus spp.* and 8% for *Eucalyptus spp.*) once per annum. Given the fact that the plantation under analysis was operating commercially, it was easy to obtain the market value of the harvested timber, and the information received reveals that *Pinus spp.* was sold at R450/Mg and *Eucalyptus spp.* at R400/Mg. It was also revealed through engagement with the plantation management that the volume of harvested wood amounted to 380 Mg/ha for *Pinus spp.* and 200 Mg/ha for *Eucalyptus spp.* We could not obtain a breakdown of the harvesting and maintenance cost from the plantation management, therefore the information on this was obtained from the free access Forestry Valuations (2012) website.

In WBR, no timber plantations were available that were managed for commercial purposes. Only small patches of abandoned plantations were left. The remaining patches consisted only of

Eucalyptus spp. species; there was no *Pinus spp.* The total forest plantation patches covered an area of 760 ha, comprising various small isolated patches. Because timber production in WBR occurred on a small scale, mainly for domestic purposes, the whole plantation left in WBR was treated as a single parcel covering 760 ha, of which 10% was harvested every year, mainly for domestic use, but for the purpose of this study we used 8% as the proportion of harvest to be consistent with the value applied in the VBR study area.

No maintenance cost was incurred to keep up production, since this production mainly involved a collection of abandoned old plantations, most of which the landowners wanted to see eradicated, to the extent of commissioning Government`s Extended Public Works Program (EPWP) to deal with it. However, costs were incurred during harvesting, since this was carried out using various machines such as chainsaws, which needed consumables to operate. The focus was therefore on the EPWP operations. It cost the EPWP around R350 per person per day (according to the information provided by the EPWP project manager), taking into consideration wages, transport, machinery and consumables, to carry out an operation, with a team of 10 people taking a day to clear 1 ha. However, for the sake of consistency, we decided to apply the same values applied in VBR for harvesting cost. Table 7.2 contains input data sourced for the purpose of the analysis of WBR and VBR timber production.

Table 7.2 VBR and WBR`s inputs to timber production

VBR`s inputs to timber production										
Parcel_ ID	*Parcel area (ha)*	*% of harvest*	*Freq_harv (in years)*	*Harvest_ Mass (Mg/ha)*	*Market value (in rands) of harvested wood (Mg)*	*Maint _cost (R/ha)*	*Harv_cost (R/ha)*	*Years parcel will be valued (T)*	*Immed_harv (Yes/No)*	*Biomass expansion factor (BCEF)*
1	5245	3	1	380	450	2460	2849	30	Yes	1
2	521	8	1	200	400	2950	3167	12	Yes	1
3	222	8	1	200	400	2950	3167	12	Yes	1
4	425	3	1	380	450	2460	2849	30	Yes	1
5	188	8	1	200	400	2950	3167	12	Yes	1
6	325	8	1	200	400	2950	3167	12	Yes	1
7	441	3	1	380	450	2460	2849	30	Yes	1
8	4017	8	1	200	400	2950	3167	12	Yes	1
WBR`s inputs to timber production										
1	760	8	1	200	400	0	3167	60	Yes	1

7.2.4.2 State of firewood production in the study areas

The production of firewood in VBR happened during timber processing, where timber products that did not meet the requirements of a standard market product were regarded as waste and used as firewood. This happened in two of the five timber plantations under analysis in the VBR. Although two timber plantations were involved, only the one close to the communities was used in this analysis. The output generated through this process amounted to an average of 20 tons per ha (Venter 2009) and was collected by the local communities who later resold it in their villages. Firewood cost around R80 a ton (Forestry Valuations 2012).

The production of firewood in WBR was slightly different from that in the VBR. It occurred on isolated patches of timber left after land use change. Although the plantation patches together amounted to more than 760 ha, this analysis only involves 10% of the one that formed part of the EPWP alien clearing program along the main core area, as indicated for timber production in this BR as well. Again for the sake of consistency, an 8% proportion of the harvest was used. The following outputs were also the same as those used for timber production in the WBR: percentage (proportion) of harvest, frequency of harvest and harvesting mass. No maintenance costs were associated with firewood production in WBR. Harvesting costs amounted to R3 000/ha; however, as we did for timber production, for the sake of consistency, we applied the Forestry Valuations (2012) value for harvesting costs, which amounted to R3167/ha. Firewood cost around R10 for 8 kg bag. We used the minimum price of R80/ton for firewood to be consistent with the other study area. Table 7.3 contains input data sourced for the purpose of the analysis of firewood production in the WBR and VBR study areas.

Table 7.3 WBR and VBR`s input to firewood production

Inputs to firewood production										
Parcel_ ID	*Parcel area (ha)*	*% of harvest*	*Freq_harv (in years)*	*Harvest_ Mass (Mg/ha)*	*Market value (in rands) of harvested wood (Mg)*	*Maint _cost (ha)*	*Harv_cost (ha)*	*Years parcel will be valued (T)*	*Immed_harv (Yes/No)*	*Biomass expansion factor (BCEF)*
VBR Firewood	4017	8	1	20	80	0	3167	12	Yes	1
WBR Firewood	760	8	1	20	80	0	3167	60	Yes	1

7.2.5 Calculation of the required input data

The formulae used to calculate the required input were taken from Forestry Valuations (2012). The percentage of harvest is calculated through the following formula: Parcel area (A)/rotation period (C) and then the value is converted into a percentage of B, as displayed in Table 7.4.

Table 7.4 Calculation of plantation proportion of harvest

A	B	C	D
Parcel _ID	*Parcel_area*	*Rotation period/number of years that parcel will be valued (T)*	*Percentage of harvest*
1	5 245	30	5245/30 =175 175 is equal 8.34% of the parcel area (B).
2	521	12	521/12 =43 (8.25%)
3	222	12	222/12 =19 (8.56%)
4	425	30	425/30 =14 (8.30%)
5	188	12	188/12 =16 (8.51%)
6	325	12	325/12 =27 (8.30%)
7	441	30	441/30 =15 (3.40%)
8	4017	12	4017/12 =335 (8.33%)

The formula for calculating harvesting cost was as follows: R/ton x MAI x T

(B x C x D), (see Table 7.5). MAI means mean annual **i**ncrement and R stands for rand.

Table 7.5 Calculation of plantation harvesting costs

A	B	C	D	E	F
Parcel_area (ha)	*Rand per ton (R/ton) Standard forest cost equals 90 for Pinus spp. and 190 for Eucalyptus spp.*	*R/ton/ha/T (MAI)*	*Rotation period (T)*	*Total harvesting costs (ha)*	*Harvesting cost/ha (E/12)*
5 245	90	12.66	30	34 182	2849
521	190	16.67	12	38 000	3167
222	190	16.67	12	38 000	3167
425	90	12.66	30	34 182	2849
188	190	16.67	12	38 000	3167
325	190	16.67	12	38 000	3167
441	90	12.66	30	34 182	2849
4 017	190	16.67	12	38 000	3167

Maintenance cost is calculated as follows: Total rand per ha (R/ha (E) x parcel area (A). Rand per hectare is the sum of annualized R/ha (B), fire protection R/ha (B) and overheads R/ha (D), all of which are standard forest costs from Forestry Valuations (2012) (refer to Table 7.6).

Table 7.6 Calculation of plantation maintenance costs

A	B	C	D	E	F
Parcel_area (ha)	*Annualized R/ha (Standard forest cost)*	*Fire protection R/ha (Standard forest cost)*	*Overheads R/ha (Standard forest cost)*	*Total R/ha =Sum (B:D)*	*Total costs (maintenance) =(E x A)*
5 245	485	750	1200	2 435	12 770 650
521	967	750	1200	2 917	1 519 992
222	967	750	1200	2 917	646 333
425	485	750	1200	2 435	1 034 437
188	967	750	1200	2 917	548 333
325	967	750	1200	2 917	948 792
441	485	750	1200	2 435	1 074 273
4 017	967	750	1200	2 435	11 716 367

NPV is a common and useful cash flow measure for short-term investments (Cubbage et al. 2013). There is a wide range of methods that can be used to calculate the discount rate; among these is the Weighted Average Cost of Capital. The Weighted Average Cost of Capital (WACC) is a blend of the cost of equity and the cost of debt (Forestry Valuations 2012); see table 8.9. In this study, NPV was calculated using discount rates of 4%, 7% and 12%. The discount rate of 7% is the InVEST default value recommended for environmental projects (Tallis et al. 2011) and 4% is the recommended discount rate for timber valuation in SA (Forestry Valuations 2012). A discount rate of 12% was the nearest value to 11.80 % calculated based on WACC (see table 7.7.), and discount rates above 10% are recommended for developing countries (Khatun 2010). The NPV has been used as indicator for assessing economic returns for plantations (Keča et al. 2012; Wang et al. 2014).

Table 7.7 Calculation of WACC

Calculation of WACC			
WACC = Kd x d% + Ke x e%			
Where:			
Kd	After tax rate of return on debt capital	**d%**	Debt capital as % debt + equity
Ke	Rate of return on equity	**e%**	Ordinary share capital as % of debt + equity
Cost of Equity			
Expected return on equity = R_f + β x Market Risk Premium + Small Share Premium + Specific Company Risk Factor			
R_f	8.33%	*Government bond as at 30 September 2014 (South Africa)*	
β	1.00	Beta, the correlation between the company and the market, < 1 worst, 1 = same, > 1 better	
Market Risk Premium	6.0%	*Long term*	
Small Share Premium	4.0%	*Subjective, debatable*	
Company Risk Factor	2.0%	*Subjective, debatable*	
Cost of equity	**20.33%**		
Cost of debt			
Prime rate	9.25%	*South Africa prime rate as at 30 September 2014*	
Company	1.00%	*Premium*	
Interest rate	10.25%		

Tax rate		28.0%					
Cost of debt		**7.4%**					
WACC				**Conversion from nominal to real rate**			
Debt: equity ratio				Real rate WACC = (1 + nominal WACC)/(1 + Inflation rate) -1			
d%		40%		Long-term CPIX		**3.0%**	
e%		60%		**Real WACC =**		**11.80%**	
WACC =		**15.2%**					

7.2.6 Process followed to run the InVEST timber model

The following is the process followed in this study to run the InVEST timber production model, as described by Tallis et al. (2011):

Step 1- Creation of workspace

First the InVEST timber files were unzipped to the computer's C drive, followed by the creation of a workspace on the computer hard drive and a folder under the workspace where all output files were saved.

Step 2 - Running the model

After all the processes of Step one had been completed, an arc map document was opened, and then an InVEST toolbox (located in the C-drive) was added. Double-clicking on the timber InVEST toolbox brought about an interface, which required the filling in of values on all required prompts, followed by authorization.

Step 3 - Progress dialogue

Upon completion of all processes required under Step 2, a progress dialogue indicated the script running progress (including whether the model had run successfully or failed to run). Upon successful completion of the model, new folders (containing results) appeared in the workspace, called intermediate and output, containing several raster grids.

7.2.7 Interpretation of the InVEST model results

The results were found in intermediate and output folders, as indicated in Step 3 of the process of running the model above. These folders contained timber/firewood shp. files, among others. In the timber/firewood shp. file attribute table, there were three columns. The first column gave each timber/firewood parcel's TNPV. This was the TNPV of timber production in terms of the user-defined currency. The TNPV included the revenue that would be generated from selling all timber/firewood harvested from yr_cur to T years after the current year less harvest and management costs incurred during this period. Finally, all monetary values were discounted back to the current year's present value. Negative values indicate that costs (management and harvest) are greater than income (price times harvest levels). The second column was the TBiomass column, which gave the total biomass (in Mg) of harvested timber parcel. Biomass harvested from each parcel was measured in metric tonne per hectare. The third column was the TVolume column, which gave the total volume (m^3) of harvested wood removed from each timber parcel (Tallis et al. 2011).

7.3. RESULTS

7.3.1 Economic value of timber production in the study areas

The results for timber production in VBR are summarized as follows: at 4% discount rate, the NPV was -R3216/ha for *Pinus spp.* and -R3403 for *Eucalyptus spp.*, at 7% discount rate, TNPV was -R2645 for *Pinus spp.* and -R3107 for *Eucalyptus spp.* and at 12% discount rate the NPV for *Pinus spp.* was R23 317/ha and for *Eucalyptus spp.* it was R22 177/ha. Biomass production was R342/ha for *Pinus spp.* and R192/ha for *Eucalyptus spp.*

The results for timber production in WBR are summarized as follows: at 4% discount rate, the NPV for timber production in WBR was R144 621/ha, at 7% discount rate, NPV was R92 334/ha, and at 12% discount rate the NPV was 57 304/ha and for biomass production it was R1200/ha. The NPV values for timber production in VBR at 12% discount rate (D/R) and for WBR at 12%, 7% and 4% discount rates are displayed in Table 7.8 below.

Table 7.8 The economic values of timber production in VBR and WBR at different discount rates (D/R)

Parcel_ID	*Parcel_ha*	*TNPV in rands*	*NPV/ha in rands*	*TBiomass*	*Biomass /ha*	*D/R*
Economic value timber production in VBR at 12% D/R						
1	5245	12 229 766	23 317	1 793 790	342	
2	521	11 554 387	22 177	100 032	192	
3	222	4 923 366	22 177	42 624	192	
4	425	9 909 779	23 317	145 350	342	12%
5	188	4 169 337	22 177	36 096	192	
6	325	7 207 630	22 177	62 400	192	
7	441	10 282 799	23 317	150 822	342	
8	4017	89 086 318	22 177	771 264	192	
Economic value timber production in WBR at 12, 7 and 4% D/R						

1		435 515 92	57 304			12%
	760	701 741 12	92 334	729 600	960	7%
		109 911 798	144 621			4%

7.3.2 Economic value of firewood production in the study areas

The NPVs of firewood production in the VBR study area were as follows: At 4% discount rate, it was -R1 223/ha, at 7% discount rate -R1 065/ha and at 12% discount rate -R869/ha. There was no change with regard to biomass production; regardless of the change in discount rate, it was 192/ha at all three discount rates.

In WBR study area, the production of firewood with regard to NPVs was as follows: -R2 949/ha at 4% discount rate, - R1 883/ha at 7% discount rate and -R1 168/ha at 12% discount rate. As in the VBR study area, the volume of the biomass produced did not change with the change in discount rate; it was R960/ha for all three discount rates (4%, 7% and 12%). The NPV and biomass volume for WBR and VBR firewood production are displayed in Table 7.9 below.

Table 7.9 The economic values of firewood production in VBR and WBR study areas

Economic value firewood production in VBR and WBR						
Parcel_ID	*Parcel_ha*	*Discount rate*	*TNPV in rands*	*NPV/ha in in rands*	*TBiomass (Mg)*	*Biomass/ha*
		12%	-34 936 25	-869		
VBR		7%	-42 796 87	-1 065	771 264	192
Firewood	4 017	4%	-49 150 94	-1 223		
WBR	760	12%	-88 823 0	-1 168/ha		
Firewood		7%	-14 311 93	-1 883/ha	729 600	960
		4%	-22 416 38	-2 949/ha		

7.4 DISCUSSION

7.4.1 Economic value of timber production in the study areas

Our results indicate consistency with regard to biomass production, as the values remain the same for all timber parcels in both study areas, regardless of the difference in discount rate. As expected, there seems to be a correlation between the size of the timber parcel and the total biomass produced in metric tons: the bigger the timber parcel, the more the volume of biomass produced in tons. The same observation was made by Finn et al. (2011). However, regardless of the difference in total biomass, biomass/ha was the same for all *Eucalyptus spp.* timber parcels (192/ha) and all *Pinus spp.* timber parcels (342/ha).

A slightly different observation was made on timber performance with regard to the NPV. In VBR, all timber parcels generated negative NPV on discount rates of 4% and 7%. Negative NPV associated with the use of a 7% discount rate was also observed elsewhere (Hill 2004). However, our results contradict those of Šálek and Sloup (2012), who obtained positive values of NPV regardless of the use of a 4% or 5% discount rate in a study conducted in Vietnam. We associate this contradiction with prices and maintenance costs, which are obviously different from country to country. Negative NPVs are mainly associated with high maintenance and harvesting costs and low profits (Finn et al 2011; Tallis et al. 2011). However, discount rates of 4% and 7% were expected to contribute to positive NPVs, as rates between 3% and 7% are highly recommended for discounting environmental projects (Tallis et al. 2011).

At 12% discount rate, timber plantations in VBR produced positive NPV. Positive NPVs were also observed for WBR timber production against all three discount rates (4%, 7% and 12%). Other researchers also found positive NPV for plantations at 12% discount rate (Lopez et al. 2009; Khatun 2010; Sumarga et al. 2015). Positive NPV in VBR is associated with higher profits and low management costs. Although the difference in currency seemed to have made a slight difference, there is some correlation in these results and those of Lopez et al. (2009), where the maximum NPV was $2 238/ha at 12% discount rate. This value is in the same range as the NPVs obtained in the VBR study area, namely R22 177/ha for *Eucalyptus spp.* production and R23 317/ha for *Pinus spp.*, given the exchange rate of the US dollar against the SA rand, which was around R11 at the time the study was conducted. However, our observation of positive NPV against 12% discount rate contradicts the findings of Keča et al. (2012), where the NPV for timber production was negative against 12% discount rate.

The positive NPVs produced here suggest that the income could be higher than the costs (Tallis et al. 2011). However, the WBR timber production was expected to yield no profit in the current study, since timber parcels are not used for commercial purposes, but mainly for household needs on an ad hoc and private case basis and whatever isolated patches are still available, the landowners want to see eradicated (*Ntshane B.C, Personal observation)*, as they are seen as part of invasive alien vegetation that consumes a lot of water (DAFF 2011b). Another factor that contributed to the difference between the VBR and WBR NPVs is the difference in management costs, which was higher in the VBR, as it included both harvesting and maintenance costs; for the WBR it was only harvesting costs that were incurred, as there was no need to maintain plantations that were being chopped down as they were no longer wanted.

7.4.2 Economic value of firewood production in the study areas

The NPV of firewood production in WBR was -R2 949/ha at 4% discount rate, -R1 883/ha at 7% discount rate and R-1 168/ha at 12% discount rate. These values reflect that firewood production was not yielding any profit in this BR. Negative NPVs against all three discount rates indicated here mean that management costs were more than the income. This could be attributed to the fact that the income supposed to be generated/ha was low if compared to costs incurred for harvesting. Taking into consideration the market value of firewood, which was R80/ton, from the 20 tons generated/ha the total income amounted to R1 600, while the harvesting cost was R3 167/ha. Lack of profit in this regard could also be attributed to the fact that profit generation is not a primary objective for firewood production in this BR; production is aimed at getting rid of the abundant timber parcels.

Firewood production in VBR reflects NPV of -R1 223/ha at 4% discount rate, -R1 065/ha at 7% discount rate and –R869/ha at 12% discount rate. Again, negative values, according to Tallis et al. (2011), indicate that the management costs are higher than the profit generated. The results reflect negative NPV regardless of the discount rate used. As in WBR, we attribute this to the higher management cost applied (to cover harvesting). Under normal circumstances, if the plantation was meant for firewood production, at the current market value and associated costs involved, which are supposed to include maintenance costs on top of the harvesting costs, the plantation would make double the loss. It should be noted that maintenance costs were excluded here to avoid double counting; since the primary objective of the parcel involved is timber and firewood production is a secondary objective.

Data generated on the valuation of timber and firewood production in the study areas will be valuable in providing baseline information in terms of cost implications and profits associated with undertaking new afforestation programs and sustainable forest management. Data produced through valuation is very valuable, as it provides mean values per ha, needed to advocate the importance of both natural and unnatural ecosystems, especially those that rely heavily on other ES as inputs to produce their outputs. In the absence of information and associated evidence, it may happen that some ecosystems are compromised, making way for others that are known to be high economic injectors.

7.5 CONCLUSIONS

Our results suggest unsustainable production in plantations whose primary objective is firewood production with the purpose of making profit. However, there is some kind of sustainability in firewood production as a secondary objective, as profit will be made with the realization of the primary objective, e.g. timber production, as in the case of VBR. This also provides opportunities to meet firewood needs without compromising biodiversity in the natural forest ecosystems. Our results indicate that there is potential for good investment in timber production in the VBR study area, given the good profits observed in terms of the NPV at 12% discount rate.

Given the importance of forest ecosystems in the delivery of vital ES, contributing to the national economy and the fact that natural forest cover is continuously being degraded through various human-induced activities, it is crucial for afforestation programs to be considered. More skills and advancement of the knowledge system are also needed to understand how to best optimize timber yield, while employing the most acceptable, efficient and water-saving methods to establish forest plantations.

There is a good opportunity to conduct successful afforestation programs by focusing on indigenous forest species that use water efficiently, such as *Berchemia zeyheri*, *Celtis Africana* and *Ptaeroxylon obliquum,* among others, in new plantations, since they consume less water compared to forest plantations of *Eucalyptus spp.* and *Pinus spp.* Embarking on afforestation programs that focus on indigenous species will not only pay off in terms of financial profits, but will also be appreciated as a positive step towards addressing the global crisis of degrading and shrinking forest cover, while on the other hand increasing the storage of carbon in ecosystems, which is required to stabilize and regulate natural phenomena and prevent disasters such as climate change and floods.

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CHAPTER 8

SYNTHESIS AND CONCLUSIONS

8.1 INTRODUCTION

There is compelling evidence that most ES are in a poor state, taken for granted and not valued and because of this, ES are mostly omitted from decision-making processes. According to Martinez-Harms et al. (2015), a decision is made when an action is implemented, be it through policies, plans, institutional arrangement or without reference to anything. Literature further suggests that valuation is a mechanism that can be used to encourage appreciation of natural assets and incorporate them into decision-making.

This chapter thus provides the synthesis and implications of the overall findings of the study on the valuation and mapping of ES in two BRs in SA. In response to the key objectives, it provides for greater understanding of ES and the importance of valuation and mapping of ES, as well as insight into the state of mapping and valuation of ES in SA. Chapters 2, 3, 4, 5, 6 and 7 addressed the four main objectives in order to achieve the main aim: 1) to assess and evaluate the status of mapping and valuation of ES in SA, (2) to identify and quantify ES and their indicators in the study areas, (3) to investigate and analyse the impact of land use/cover (LU/LC) change to ES in the study areas and (4) to conduct valuation of selected ES in the study areas. As outlined below, the study also attempted to address some of the key elements required to integrate ES successfully and effectively in decision making (MA 2005; Daily et al. 2009) as indicated in chapter 1 of this document.

8.2 SYNTHESIS OF THE MAJOR FINDINGS

8.2.1 Understanding of the interlinked production of services and trade-offs

Many of the ES are interlinked (TEEB 2010), e.g. the three major categories of ES following the MA (2005) classification all depend on supporting services for their production through processes such as primary production, formation of soil nutrients, water cycling and photosynthesis, which involve the same biological processes (MA 2005). Most of the ES also have interlinked roles; e.g. water is both a provisioning and a supporting service (MA 2005), since all life forms, whether of plant or animal origin, require water to survive. It is very important to understand production functions in order to understand how services are produced or how changes in these functions will affect ES produced (TEEB 2010), as well as the role of biodiversity in delivering supporting/production services (MA 2005; TEEB 2010).

It is also very important to understand interconnectivity, as it might increase the likelihood of double counting of ES (MA 2005; TEEB 2010). Also important to note is that these interlinkages do not always result in synergies; there are trade-offs as well (Nelson et al. 2009). The study managed to demonstrate this understanding in chapter 3, through LU change scenarios, as well as in chapter 4 where ES that occur in the study area were identified and mapped. In chapter 5 the researcher demonstrated how ES may affect one another, as a result of interdependence, e.g. when provisioning ES such as agricultural activities are intensified, they might have an impact on water (agricultural activities are associated with high consumption of water) or primary production (because of vegetation clearing).

8.2.2 Stakeholders engagement in decision making process

Stakeholders engagement process forms one of the central issues of this study, which includes understanding of the decision making process of individual stakeholders and transparency as demonstrated in chapters 3, 4 and 7. A famous slogan of Latin origin, "Nothing about Us without Us", supports the idea that decisions should be effected in consultation with the affected individuals, not without them (Charlton 2000). Generally, stakeholder engagement is regarded as one of the most crucial elements of decision-making (MA 2005, Daily et al. 2009; Young et al. 2013). While it is important to include stakeholders in decision-making, they must also be given an opportunity and platform to be personally involved in various decision-making processes. The essence of this study was to promote the integration of ES into decision-making through different stakeholder engagement processes, valuation and mapping. Chapter 3 dealt with stakeholder engagement through scenario planning, chapter 4 dealt with mapping and identification of ES (through stakeholder engagement), and chapter 7 dealt with the valuation of two provisioning ES (timber and firewood).

8.2.3 Focus on other ES beyond provisioning services and understanding that not all ES are valued

Literature evidence suggests that provisioning ES have long been given some kind of recognition, including valuation (Portman 2013; Martinez-Harms et al. 2015). The understanding of other ES, such as regulating and cultural ES, had started to emerge and had advanced significantly by the time the MA (2005) was done. Although understanding of these types of services generally is starting to develop, there is still a gap in the value domain, which is aggravated by the difficulties associated with capturing values of these types of services, as most of them are not traded in markets, which contributes to their degradation and undervaluing, as well as society's failure to appreciate their worth.

In this study, attempts have been made to focus on other services beyond provisioning in order to reflect their worth. This was done by (1) reviewing valuation and mapping of ES studies in chapter 2 and 4, (2) understanding the type of ES and their indicators that occur in the study areas, covered by chapter 4, (3) giving special attention to supporting ES such as biodiversity, covered by chapter 5, which mainly focuses on habitat condition assessment, and (4) focusing on regulating services by assessing and quantifying carbon storage in the study area, covered by chapter 6.

It is well known that the aim of conservation has been to safeguard biodiversity, which underpins most of the supporting ES. Biodiversity conservation strategies, though, have to a certain extent been associated with a hands-off and human exclusive approach (McLaughlin 2011; Pullin et al. 2011), which has been met with mixed feelings and resentment, to the detriment of conservation efforts (Beltrán 2000; Ayivor et al. 2013). Perhaps the emphasis was rather on benefit for future generations (focused on the existence value), and promoting the uses of other ES (i.e. cultural and regulating) than on provisioning. The new buzzword, "ecosystem services", which is linked with benefits to human well-being, is proving to be acceptable as a better alternative to the traditional biodiversity concept, providing an opportunity to assist the achievement of biodiversity conservation goals (MA 2005, TEEB 2010). More strategies and mechanisms are still needed though, to fully unleash the potential of ES to enhance biodiversity conservation goals.

This study further demonstrated an understanding that not all ES are valued in chapter 5, where biodiversity conservation, whose values can mainly be expressed in biophysical, terms (Daily et al. 2009), was modelled.

8.2.4 Use of the best available information

In the rapidly changing context of decision-making pertaining to natural assets, the challenge lies in making effective use of information and relevant tools to keep abreast with these changes. Relevant tools that can aid the successful integration of ES to decision making include quantification/mapping and valuation. The relevancy of the study with this element is outlined in chapters 4 where mapping of ES was conducted as well as chapters 5 and 7 that dealt with valuation of ES.

8.2.5 Integration of research into institutional design and policy implementation

Although the importance of integrating the science of ES into decision-making, such as policy-making, has been strongly emphasised and reinforced through international obligations, among others the Intergovernmental Platform of Biodiversity and Ecosystem Services and the Convention on Biological Diversity, it remains a challenge. To integrate science and policy successfully is problematic (Godfrey et al. 2010), therefore various procedures and institutional arrangements have to be made available to achieve this (Heinrich 2007; Godfrey et al. 2010). Being faced with ES in the decision-making integration gap and science-policy interface gap indicates a dire need for robust strategies to achieve the much needed integration of research into institutional design and policy implementation.

One of the fundamental issues regarding ES assessment is an understanding of the socio-ecological context (Martinez-Harms et al. 2015). In this study, ES assessment was conducted mainly in a BR. Because they are socio-ecological systems, meant to promote sustainable development, while conserving biological diversity and promoting sustainable resource use, BRs have to conform to relevant institutional requirement designs and policies. BRs` main principles of sustainable development thus make it easy to apply the CBD`s three main objectives: (1) the conservation of biological diversity, (2) the sustainable use of its genetic resources and (3) the fair and equitable sharing of benefits. Mechanisms such as valuation can be used to generate information that can assist in designs and policy implementation in socio-ecological institutions such as BRs. Valuation has been applied in chapter 5, 6 and 7, the results of which provide valuable information that can contribute to institutional designs and policy implementation related to socio-ecological systems, BRs in this case.

8.2.6 Evidence based, performance monitoring, evaluation and accountability

According to Heinrich (2007), the aim of both performance management and evidence-based policy is to improve effectiveness by basing decision-making on scientific evidence. However, in order to achieve this, there must be an understanding of how to distinguish evidence from non-evidence, how to communicate such evidence, and how to judge quality and reliability. Lastly, there must also be a balance between information processes for decision-making and accountability (Heinrich 2007).

Accountability, monitoring and evaluation, are also very important aspects in influencing decision-making, such as whether to improve or discontinue the intervention, strategy or policy (UNICEF

2003). The main purpose of evaluation is to determine the significance of a policy, strategy or intervention (UNICEF 2003). In order for the evaluation process to be objective, among others it needs to reconcile the perspectives of different stakeholders (UNICEF 2003). An evaluation report, on the other hand, should include findings and evidence, conclusions, recommendations and lessons learnt (UNICEF 2003).

Chapters 5, 6 and 7 dealt mainly with valuation of selected ES in the BRs, with chapters 5 and 6 focusing on the biophysical component and chapter 7 focusing on the economic component. In chapter 5 modelling results of the habitat condition assessment provided valuation evidence required to make informed decisions on issues such as carrying capacity, introduction and removal of game, threats to biodiversity and ways to deal with these. Chapter 6 dealt with the assessment of carbon storage and quantification of its values, thus providing information required to deal with the climate change phenomenon. Chapter 7 addresses the integration of ES into the national and regional economy, as the main activities focus on the contribution that ES make to the economy both directly through timber sales and indirectly through making provision for an alternative cost-effective energy source (fuel wood), thus contributing to poverty alleviation. This information presents an opportunity to integrate ES into decision-making, as it provides the basis for informed decisions to improve governance and effectiveness related to biodiversity conservation and economic development.

8.2.7 Contribution of the study to the field of ES

All eight chapters attempted to highlight the importance of integrating ES in decision-making for conservation and LU planning through the application of different tools, i.e. value mapping, modelling and quantification. The study also highlights new insights into the existing theories on ES, which in this case are socio-ecological systems and sustainability science. Figure 8.1 provides for the adjusted conceptual framework (MA 2005), denoting areas where the current study is providing new knowledge on the existing theories of ES, in this case socio-ecological systems and sustainability science, as indicated in chapter 1.

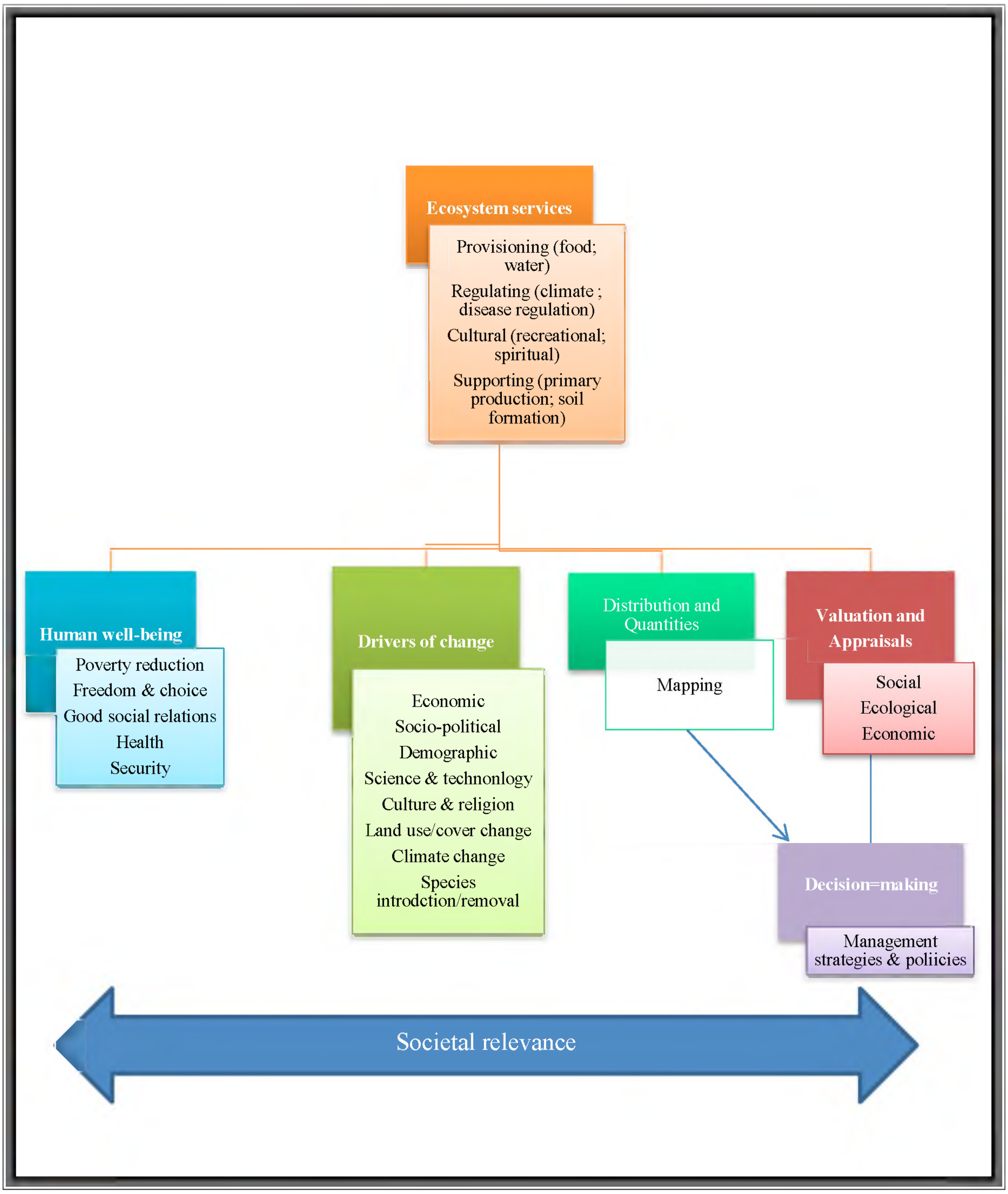

Figure 8.1 Conceptual framework (adapted from MA 2005) highlighting areas (red, green and purple) where the study is contributing new knowledge to the existing theories.

In conclusion, a four-step integrated approach that can aid the successful incorporation of ES into decision-making is proposed: (1) maintain a balance between the social, economic and ecological aspects when making decisions on ES, (2) strive for an evidence-based approach to decision-making (use quantities and values), (3) apply integrated approaches (methods and techniques) to quantification and valuation, and (4) communicate all steps along the way.

8.3 FUTURE RESEARCH QUESTIONS

This study identified a few areas that need research in the field of ES valuation to continue where this study left off. The following questions are relevant in this regard.

- To what extent do PAs contribute to the national economy and poverty alleviation?
- What is the economic value of PAs compared to other land use, such as mining and agriculture?
- What is the value (ecological, social, and economic) of ES generated by PAs?
- What is the value (ecological, social, and economic) of ES generated by BRs?
- What are the quantities of ES generated by PAs?
- What are the quantities of ES generated by BRs?

8.4 CONCLUDING REMARKS

It has become clear that in order to maintain a balance between biodiversity conservation and the mainstreaming of economic benefits, responding to challenges facing socio-ecological systems such as BRs now requires new approaches and tools. The management of PAs, including BRs, needs to realise the important role various tools, such as valuation and mapping of ES, can play in building a body of evidence to advocate the case of these natural assets in economic-orientated periods. Decision-makers must take a holistic approach (considering economic, social and ecological aspects) and take into account the associated trade-offs when making LU decisions regarding natural systems. To keep up with the changing context for managing PAs and socio-ecological systems, there must be a paradigm shift in management approaches and attitudes.

There is growing appreciation of the concept of ES among policy makers and governments as a means to unlock new opportunities for economic development, to safeguard natural assets and to influence decision-making through its valuation. There is a strong need for countries to prioritise valuation of ES in PAs, as they represent auditable systems in achieving the CBD`s objectives of integrating ES into national accounting and economies. Moreover, countries should embrace the BR model, as it represents a holistic approach that integrates the social, ecological and economic aspects to attain sustainable development goals. To date, ES has been a whirlwind subject of science, which strives to address current challenges and trends, including the science-policy interface, to inform decision-making. In order to bridge the gap between science and policy, there must be an interface and monitoring mechanism to ensure that policies are informed by evidence, while policies on the other hand strive to support decision-making.

Amidst increased understatement of the fact that valuation is a means of incorporating natural assets into decision-making, practitioners must be competent enough to apply this approach to satisfy this need, and it must be ensured that approaches in this regard integrate social, ecological and economic needs/requirements to ensure sustainability. In order to enhance the contribution of valuation to decision-making, it is important to understand different areas where its application can be more meaningful and valuable. Understanding and selecting appropriate methods that can be employed in this regard are crucial requirements. To make valuation work in decision-making, careful consideration is also necessary during analysis and interpretation processes to ensure that it is applied in a simplistic and practical manner. Although valuation has broken new ground and the stage has been set for it to be turned into a useful tool for decision-making, it must be noted that it is only a means to an end, not the end itself.

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