

**RISK, RESILIENCE AND SOCIAL-ECOLOGICAL SYSTEMS
IN NATURAL RESOURCE-BASED DEVELOPMENT
IN SOUTH AFRICA**

by

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PREFACE

The experimental work described in this thesis was carried out in the School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal, Pietermaritzburg, under the supervision of Dr. Donovan C. Kotze and Prof. Nevil W. Quinn.

These studies represent original work by the author and have not otherwise been submitted in any form for any degree or diploma to any tertiary institution. Where use has been made of work of others it is duly acknowledged in the text.

ABSTRACT

Ecosystem services, which are dependent on ecological and socio-economic variables, can be viewed as having the potential to help alleviate poverty in rural South Africa. These variables do not act in isolation, but rather form a complex adaptive social-ecological system (SES) whereby the ecological and socio-economic aspects interact with each other at multiple spatial and temporal scales.

Although ecosystem services frameworks have been developed which balance resource conservation and use according to how society values consumptive and non-consumptive ecosystem services, projects that have successfully achieved both conservation and economic objectives are relatively rare. Part of the reason for this has been attributed to the hiatus between theory and practice, where there is a dearth in decision support systems for guiding the use of ecosystem services as a means of poverty alleviation.

Compounding the complexity of SESs in South Africa is the broad socio-political context (e.g. an immature democracy, new policies, new institutions, old legacies, new tenure arrangements, disease and poverty). Development in South Africa is evolving at a rapid rate, and with the potential for detrimental ecological and socio-economic impacts throughout the country if not controlled.

The aim of this research is to integrate SES theory into natural resource management practice, so that the concepts of resilience, risk and ecosystem services assessment can be applied effectively in the understanding of natural resource-based enterprises. To achieve this aim, four contexts representing successive development of SES theory are examined, the objectives of which are as follows: i) Integrate ecosystems services evaluation and SES theory to derive a conceptual framework to identify and assess opportunities for natural resource-based economic empowerment at two estuary study sites in the Eastern Cape, South Africa; ii) Apply and adapt the resulting SES conceptual framework to enhance understanding of the resilience of a SES supporting a wetland-based craft enterprise in KwaZulu-Natal, South Africa; iii) Apply and adapt the resulting SES conceptual framework to an EIA setting to evaluate whether such a framework would constitute a useful tool in EIA practice; and iv) Apply and adapt the resulting SES conceptual framework to build understanding of key issues linked to the pellet bioenergy sector in South Africa.

This study produced four papers each of which addresses one of the four objectives. For Objective 1, a conceptual ecosystem services framework, with a practical toolkit comprising an ecosystem services inventory and risk assessment, was developed. This work was based on estuarine ecosystem services as it was commissioned as part of the Eastern Cape Estuaries Management Programme. This toolkit was tested at two estuaries in the Eastern Cape (Umngazi and Tyolomnqa), South Africa. For Objective 2, the conceptual framework and associated toolkit developed in Paper 1 was applied and adapted to investigate the threats and opportunities associated with the commercialisation of a natural product-based enterprise (NRBE) located at Mbongolwane, 30km inland of Eshowe, KwaZulu-Natal, South Africa. For Objective 3, the conceptual framework was adapted to develop a systematic framework for EIA practice, which supports and promotes public participation, and which encourages the description, understanding and investigation of the impacts of a proposed development on a receiving SES, in an integrated manner. The framework was applied to two developments: i) a community-based accommodation

enterprise at Umngazi estuary; and ii) a proposed wine estate located in the KwaZulu-Natal Midlands. For Objective 4, the resulting conceptual framework was applied and adapted to the woody-biomass industry in South Africa. This industry pelletises wood waste for use as an alternative fuel to coal and gas, and is highly developed throughout the US and Europe. However all four woody-biomass plants which were established in South Africa closed within five years of having been commissioned. The toolkit developed to address objective 4 highlights the threats to establishing and operating a resilient resource-based enterprise which has the potential to contribute to poverty alleviation at a national scale, though job creation and power provision.

This thesis is centred on the Anderies et al. (2004) framework for studying the robustness of SESs, and incorporates elements of the Ostrom (2007, 2009) and McGinnis and Ostrom (2014) framework for identifying the social-ecological variables that affect the resilience of a SES. The methods utilised in this study comprise literature reviews, initial development of conceptual frameworks and toolkits using the reviewed literature, the testing of these using stakeholder engagement for a variety of different scenarios, and finally their assessment using published literature and lessons learned through application.

Social-ecological system theory was applied in this study to: i) identify potential resilient NRBEs (Paper 1); ii) assess the resilience of selected NRBEs with the view of providing strategies (mitigation measures) to increase the resilience of these enterprises (Papers 1, 2 and 4); iii) assess the resilience of natural resource-based enterprises which have previously been established, and failed (Papers 2 and 4); iv) assess the resilience of proposed natural resource-based enterprises which have not been previously established (Papers 3 and 1); v) assess the resilience of natural resource-based enterprises which are based on ecosystem services (i.e. which do not need to be altered prior to utilisation, are not physically infinite and are unquantifiable) (Papers 1 and 3); and vi) assess the resilience of natural resource-based enterprises which are based on a production process where an ecosystem 'good' is an input, which is processed to form an output which is sold for revenue (Papers 2 and 4).

In summary, previous SES conceptual frameworks proved more applicable when used to identify potential natural resource-based enterprises, to assess a proposed enterprise which has yet to be established, and for an enterprise which is based on ecosystem services which do not need to be altered in order to be utilised. The theory proved to be less applicable for assessing an enterprise which has previously been established, and for an enterprise which processes an ecosystem good through a production process. As previous SES theory has focused on analysing the robustness or sustainability of SESs, and is not centred on enterprise dynamics, such as internal business interactions or a production process (as these are not specific to social-ecological interaction), the results are not unexpected. The resulting SES conceptual framework addresses both these shortcomings, as well as the incorporation of ecological component interactions which was also identified as a shortcoming of SES theory when applied to NRBEs. Thus, previous SES theory is more applicable when used at a broad, strategic, long-term level, than at a short-term, operational enterprise level, where internal business dynamics play more of a key role with resilience.

Combining SES theory with the concepts of resilience, risk and ecosystem services has proven to be very appropriate for contributing towards natural resource management practices which help alleviate poverty. Furthermore, the study demonstrates how EIA practice could benefit from incorporating SES theory as a way of encouraging the EIA practitioner to co-create a conceptual model of the current and future social-ecological system. This probably constitutes the first attempt to apply and formalise SES constructs to EIA practice within a regulated procedure. Although this study has identified limitations with applying SES theory to assessing the SESs which surround natural resource-based enterprises, SES theory has provided a strong foundation for achieving resilient natural resource-based enterprises which will contribute toward poverty alleviation.

This research furthers SES theory in the realm of NRBEs and provides the first ever theoretically-based methodology for selecting, assessing, evaluating and operating resilient NRBEs. The developed conceptual framework and practical contributions have the ability to not only help towards poverty alleviation, but proved applicable to sophisticated entrepreneurial activities for the more affluent. The contributions, both theoretical and practical take into consideration the complex nature of South African SESs, and are applicable to a variety of types and scales of NRBEs. The contributions strongly encourage stakeholder identification, consideration and engagement, and this emphasis contributes towards the balancing of both economic empowerment and sustainable resource use. Although not directly aimed at governmental decision-makers, the contributions show versatility as they have the potential to help inform and guide policy development at a strategic level. By applying SES theory to the development of a conceptual framework specifically for NRBEs, and through the development of practical applications based on the conceptual framework, this research has helped towards addressing the hiatus between theory and practice which has widely been documented.

DECLARATION

I, Rebecca Bowd, declare that:

- (i) The research reported in this thesis, except where otherwise indicated, is my original research.
- (ii) The thesis has not been submitted for any degree or examination at any other university.
- (iii) This thesis does not contain other person's data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons.
- (iv) This thesis does not contain other persons writing, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:
 - a. Their words have been re-written but the general information attributed to them has been referenced;
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- (v) Where I have reproduced a publication of which I am author, I have indicated in detail which part of the publication was actually written by myself alone and have fully referenced such publications.
- (vi) Where articles/papers comprise this thesis, published or unpublished, these are all works of my own, although, due to their assistance, my supervisor and co-supervisor names appear as co-authors.
- (vii) This thesis does not contain text, graphics or tables copied and pasted from the Internet, unless specifically acknowledged, and the source being detailed in the thesis and in the References sections.



Rebecca Bowd

9 March 2015

As the candidate's supervisor I have approved /~~not approved~~ this thesis for submission

A handwritten signature in black ink, appearing to be 'DK', written in a cursive style.

Dr. Donovan Kotze

9 March 2015

As the candidate's co-supervisor I have approved /~~not approved~~ this thesis for submission

A handwritten signature in black ink, appearing to be 'N Quinn', written in a cursive style.

Prof. Nevil Quinn

9 March 2015

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This thesis is dedicated to my late mother and father,
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LIST OF ABBREVIATIONS AND ACRONYMS

EAP	Environmental Assessment Practitioner
EAPSA	Registration body for Environmental Assessment Practitioner in South Africa
EIA	Environmental Impact Assessment
ESF	Ecosystem Services Framework
IDP	Integrated Development Plan
KZN	KwaZulu-Natal
MEA	Millennium Ecosystem Assessment
NEMA	National Environmental Management Act
NPBE	Natural Product-Based Enterprise
NRBP	Natural Resource-Based Product
NRBE	Natural Resource-Based Enterprise
PNS	Post-Normal Science
SA	South Africa
SAWRC	South African Water Research Commission
SES	Social-ecological systems
SES-EA	Social-ecological system - Environmental Assessment
SETS	Social-ecological-technical system
SIA	Social Impact Assessment
SSA	Sub-Saharan Africa

CHAPTER 1: INTRODUCTION

1.1. GENERAL INTRODUCTION

South Africa is challenged by the imperative of economic growth, particularly for those who have been and are still disadvantaged. As we have come to understand the role of ecosystems better as providers of services from which society benefits, we appreciate the fundamental role they play in progress toward sustainable social and economic development (Tallis et al. 2008). Which ecosystem services we choose to use and how we use them to promote social and economic development, impacts on the capacity of the ecosystem to deliver services. So, the decisions we make involve trade-offs among both the services we can use and the people who will benefit. Making choices among use options is challenging, particularly when the decision may further disadvantage the poor whose well-being is dependent on ecosystem services.

Whilst there is wide appreciation of the variability in demand for ecosystem services (the seasonality of tourism, for example) there is rather less appreciation for the variability in the potential of ecosystems to deliver services (plentiful fish at some times and hardly any at other times). Economic enterprises that are based on ecosystem services are thus continuously subject to risk and uncertainty in both demand and supply. Business enterprises based on natural resource systems, referred to as natural resource-based enterprises (NRBEs), are vulnerable to failure when this complexity and uncertainty is not taken into account.

Ecosystem services are the processes through which ecosystems and the species that make them up provide for human life (Daily 1997). The concept encompasses the delivery, provision, production, protection or maintenance of goods and services that people regard as important (Chee 2004). In the realm of poverty alleviation, Ecosystem Services Frameworks (ESF) have been developed which intend to balance resource conservation and use according to how society values consumptive and non-consumptive services provided by an ecosystem (Brown et al. 2008, Shackleton et al. 2008, Tallis et al. 2008). However, projects that have successfully achieved both conservation and economic objectives are relatively rare. For example, in an analysis of World Bank projects that had the dual aims of poverty alleviation and biodiversity conservation, Tallis et al. (2008) found that only 16% made significant progress on both objectives. Part of the reason for this has been the hiatus between theory and practice. As suggested by Turner and Daily (2007:25), despite this attention in the literature, “an operational decision support system” for implementing an ESF has been “slow to emerge”. Daily and Matson (2008: 9456) put the challenge more strongly:

“radical transformations will be required to move from conceptual frameworks and theory to practical integration of ecosystem services into decision-making, in a way that is credible, replicable, scalable and sustainable”.

Natural resource-based enterprises depend on interactions between ecological and socio-economic aspects. These interactions form a social-ecological system (SES), which is a complex adaptive system whereby the ecological and socio-economic aspects interact with each other at multiple spatial and temporal scales (Janssen and Ostrom 2006). An example of these interactions is a fly-fishing business, a socio-economic activity, which is established based on the occurrence of a highly sought-after species of fish which occurs in abundance at a particular estuary. The occurrence of this fish is the result of the ecological (also referred to as ‘biophysical’ in this thesis) conditions of a specific estuary. This is an example of a simple SES which involves an estuary, fish and a business. However, when investigated more closely, this SES is more complex. At a national scale the government can declare a particular estuary as a marine sanctuary with formal protection, due to the occurrence of highly valuable fish. The legislation governing the sanctuary is likely to insist on stringent conditions for the fly-fishing operation. At a local scale, the local population may illegally fish for food, having fished there for generations, which is likely to result in tension between locals and the business operator. The overall result is a complex set of linkages between the ecological and the socio-economic environment which occur within and across different scales of time and space.

Compounding the complexity is the dynamic nature of ecosystems. Ecosystems can change rapidly and profoundly in response to various impacts. Further complexity arises due to the nature of society in South Africa. This country is a relatively young democracy, which is trying to get to grips with new policies, new institutions, old legacies, new tenure arrangements, disease and poverty. In South African society development is evolving at a rapid rate, and a lack of management over this development has the potential for detrimental ecological and socio-economic impacts throughout the country if not controlled.

The concept of resilience, which is known to provide a conceptual foundation for dealing with complexity, uncertainty and risk in the realm of sustainable development (Folke et al. 2002), emerged in the 1970s and, since then, a variety of definitions and interpretations have appeared (Pimm 1991, Grimm and Wissel 1997, Neubert and Caswell 1997, Walker et al. 2004). For the purpose of this study, the Carpenter et al. (2001), Walker et al. (2006) and Holling (2010) definition of ecological resilience has been adopted: the amount of disturbance that a system can absorb while maintaining its ‘state’, usually defined by its

structure and function. Although the concept of resilience was originally developed for ecological systems (Holling 1973), it has since been applied to social systems which feature ecological aspects, which are SESs. For this study, resilient NRBEs are defined as those that are able to continue profitably under conditions of varying supply of, demand for, and shocks to the services upon which they are dependent.

The concept of resilience was considered relevant to this research as it: i) has been applied widely to SESs and is increasingly being used to help understand, manage and govern complex SESs (Walker et al. 2002, Anderies et al. 2004, Folke et al. 2004, Ostrom 2007); ii) suggests that the major entities of an SES, and the level at which they interact, are identified through methods which involve constructive communication between experts and stakeholders who understand the SES at different scales and perspectives (Walker et al. 2002, Westley et al. 2002); and iii) emphasises the need to consider human adaptability (Gunderson and Holling 2002, Walker et al. 2006).

A second concept, 'risk', is also central to this research. This concept is helpful in understanding the specific shocks a SES may be subjected to and how these shocks might be mitigated. In classic decision theory, the concept of risk is most commonly defined as the "variation in the distribution of possible outcomes, their likelihoods and their subjective values" (Christopher and Peck 2004:4).

1.2. RESEARCH PROBLEM, AIMS AND OBJECTIVES

Natural resource-based enterprises have the ability to help towards alleviating poverty, however poorly chosen or operated NRBEs have the ability to detrimentally affect the livelihoods of the rural poor, as well as the ecological environment. The SESs NRBEs are based on in South Africa are naturally complex, and due to factors such as ecological diversity and varied affluence, education and infrastructure across the country, NRBEs vary widely in type, scale and the benefits they provide.

Natural resource-based enterprises affect and are impacted upon by a range of stakeholders. The impacts on these stakeholders can be social, economic or ecological, or a combination. While some stakeholders prioritise poverty alleviation, others favour biodiversity conservation. Tallis et al. (2008) report that achieving both objectives is rare, and attributes this to there being a hiatus between theory and practice. Natural resource-based enterprises, if effectively chosen and managed, have the potential to achieve both objectives, however at present there is no proven theoretical methodology for selecting,

assessing, evaluating and operating NRBEs in the interests of both natural resource management and poverty alleviation, and which is applicable to a range and type of NRBEs.

The aim of this research is to integrate SES theory into natural resource management practice, so that the concepts of resilience, risk and ecosystem services assessment can be applied effectively in the understanding of NRBEs.

To meet this aim, the following four objectives were devised which collectively investigate a diversity of NRBEs in South Africa, and which represent successive development of SES theory:

- i) Integrate ecosystems services evaluation and SES theory to derive a conceptual framework to identify and assess opportunities for natural resource-based economic empowerment at two estuary study sites in the Eastern Cape, South Africa;
- ii) Apply and adapt the resulting SES conceptual framework to enhance understanding of the resilience of a SES supporting a wetland-based craft enterprise in KwaZulu-Natal, South Africa;
- iii) Apply and adapt the resulting SES conceptual framework to an EIA setting to evaluate whether such a framework would constitute a useful tool in EIA practice; and
- iv) Apply and adapt the resulting SES conceptual framework to build understanding of key issues linked to the pellet bioenergy sector in South Africa.

1.3. EVOLUTION OF THE THESIS

The starting point of this study was the commissioning of research by the South African Water Research Commission (SAWRC), as part of their Eastern Cape Estuaries Management Programme. This programme was founded in 1998, on the premise that estuaries of the Eastern Cape of South Africa are valuable economic, environmental and social assets and that conserving these assets requires active management.

Recognising that estuary management is inherently the responsibility of local municipalities, the programme focused on exploring how estuary management and planning should integrate with the Integrated Development Plan (IDP) process. Through this exploration it became apparent that there was a need to demonstrate that estuary ecosystem services provide economic opportunities to empower disadvantaged people living at or near them (MEA 2005).

The candidate, along with a project team which comprised Mr. Duncan Hay, Prof. Charles Breen, and Dr. Donovan Kotze, all associates of the University of KwaZulu-Natal, and Mr. Myles Mander, from a private environmental consultancy (Futureworks), were commissioned to demonstrate that estuaries are valuable sources of economic empowerment, and to provide recommendations on what conditions are required for the establishment of resilient enterprises which rely directly or indirectly on the natural resources of estuaries. The principal beneficiaries of these enterprises were required to be the local disadvantaged community.

Having developed a conceptual framework for estuaries, the candidate saw merit in applying the research to a wetland system. From reviewing the findings of these two applications the candidate, who is a registered Environmental Assessment Practitioner, saw further value in applying the conceptual framework to the context of EIA practice in South Africa. Finally the conceptual framework was applied to the woody-biomass industry in South Africa. This NRBE was chosen for two reasons: firstly, because the candidate wanted to test the theory on a highly complex SES, and secondly, because this industry has significant potential to help alleviate poverty, which is a main purpose of NRBEs.

1.4. THE UNDERLYING METHODOLOGICAL APPROACH OF THE THESIS

For this thesis the term “approach” is used in a broad sense, referring to the philosophical foundation underlying the methodology. There are multiple ways of categorising scientific approaches, however two common groupings are 'normal' science (also commonly referred to as 'hard' or 'traditional' science) or post-normal science (PNS). Normal science involves methodologies which are primarily puzzle-solving, have an accepted set of goals, and virtually no non-specialists are involved (Kuhn 1977). Post-normal science is defined as the management of complex science-related issues, and, in doing so it explicitly engages uncertainty, value loading and multiple legitimate perspectives as integral parts of the scientific process (Funtowicz and Ravetz 2008). Post-normal science complements 'normal' science, where 'getting the facts right' is the main aim (van der Sluijs 2012), with exploring uncertainties which helps decisions to be made before conclusive evidence is available (van der Sluijs 2005). Although the PNS approach was originally received with scepticism it quickly gained in popularity as understanding of the concept developed, for example in climate change (Salovanta 2007, Friedrichs 2011), nanotechnology (Delgado 2010) and biotechnology (Mehta 2005).

Post-normal science is particularly suited to issue-driven science, such as environmental management, where the factual basis of the issue is often uncertain, where numerous contrasting value systems are evident, where stakes are high and where decisions are urgent (Funtowicz and Ravetz 2008). The key attributes or characteristics of PNS identified by Funtowicz and Ravetz (2008), and other scholars are:

- i) Science is appreciated within the context of uncertain natural systems, uncertain social systems and uncertain SESs;
- ii) Political and social contexts are included in economic analyses;
- iii) Panacea or 'cure-all' based methods are avoided (Ostrom 2007);
- iv) Participation in decision making is extended;
- v) The value of local knowledge and ingenuity is acknowledged and included;
- vi) Dialogue is inclusive and rigid demonstration is avoided; and
- vii) Humility, modesty and accountability are essential requirements in engaging uncertainty and complexity (Sardar 2009).

Traditionally natural resource management has been in the domain of 'normal' science, where management strategies, and thus the control of natural resources can, and has been, influenced by biased agendas. However, these natural resources are strongly influenced by natural phenomena which cannot be controlled. Thus scientific thinking has evolved from using 'normal' science to control these resources, to the use of PNS to manage, accommodate and adjust to the consequences of natural phenomena (Ravetz 2006).

This study seeks to integrate SES theory into natural resource management practices with the purpose of assessing NRBEs. For this study a PNS approach is considered to be more appropriate than a 'normal' science approach for two reasons. Firstly, the SESs in which NRBEs are located are highly socially complex, and to gain a deeper understanding of these complex social systems, a participatory approach, which includes engagement with stakeholders from a range of backgrounds, is the only method to achieve this. Secondly, decisions surrounding the management of natural resources in the interests of NRBEs will have to be made with inconclusive scientific evidence being available, thus a 'normal' science approach is not feasible.

A well-documented weakness in natural resource management is the hiatus between theory and practice (Pullin et al. 2004, Knight et al. 2006, Turner and Daily 2007, Daily and Matson 2008, Temperton et al. 2013). Normal science does little to address this deficiency, as research is focused on isolated scientific input (van den Hove 2007). However PNS, which values participation and local knowledge, provides a means to incorporate non-scientific

sources, and apply the principles of co-developing practical solutions for resolution of resource management problems.

1.5. STRUCTURE OF THESIS

At the core of this thesis are four journal articles (referred to as papers, see Table 1.1), as opposed to the traditional thesis format, as the candidate wants the research to be accessible to the widest possible audience. It is hoped that the availability of this research will encourage further work in the field of development, resilience and SESs.

The numbering of the objectives correspond with the numbering of the papers (i.e. Paper 1 documents the research undertaken to meet Objective 1), and each of the papers is presented as an individual chapter with its own introduction, methods, results, discussion and conclusion (Chapters 3-6). The formats of the papers comply with the requirements of the respective publishers, and thus differ in style. Preceding the paper chapters, are two chapters which provide background on the purpose, aims and objectives of the study (Chapter 1) and a literature review of the key concepts surrounding the study area (Chapter 2). Following the paper chapters is a final chapter (Chapter 7) which presents the key findings and limitations of the research, together with suggestions for further work, and which summarises the key practical and theoretical contributions of the study.

Table 1.1. Summary of papers

Paper	Details
Paper 1	<p>Title The identification of potential resilient estuary-based enterprises to encourage economic empowerment in South Africa: A toolkit approach</p> <p>Status Published by <i>Ecology and Society</i></p> <p>Citation Bowd, R., Quinn, N., Kotze, D. C., Hay, D. G., & Mander. M. (2012a). The identification of potential resilient estuary-based enterprises to encourage economic empowerment in South Africa: A toolkit approach. <i>Ecology and Society</i>, 17(3): 15 http://www.ecologyandsociety.org/vol17/iss3/art15/</p>
Paper 2	<p>Title Risk, resilience and natural product-based enterprises: a case study of the Mbongolwane Wetland, northern KwaZulu-Natal, South Africa</p> <p>Status Submitted to <i>World Development</i> (7 March 2015)</p> <p>Citation Bowd, R., Quinn, N., & Kotze. D. C. (Unpublished). Risk, resilience and natural product-based enterprises: A case study of the Mbongolwane Wetland, northern KwaZulu-Natal, South Africa</p>
Paper 3	<p>Title Towards an analytical framework for understanding complex social ecological systems when conducting Environmental Impact Assessments in South Africa</p> <p>Status Published by <i>Ecology and Society</i></p> <p>Citation Bowd, R., Quinn, N., & Kotze. D. C. (2015). Towards an analytical framework for understanding complex social ecological systems when conducting Environmental Impact Assessments in South Africa. <i>Ecology and</i></p>

Society, 20(1): 41
<http://www.ecologyandsociety.org/vol20/iss1/art41/>

Paper 4	Title	A systems approach to analysing risks and resilience of the woody-biomass industry in South Africa
	Status	Submitted to <i>Biomass and Bioenergy</i> (7 March 2015)
	Citation	Bowd, R., Quinn, N., & Kotze D. C. (Unpublished). A systems approach to analysing risks and resilience of the woody-biomass industry in South Africa

Paper 1 documents the research commissioned by the SAWRC, which was to demonstrate that estuaries are valuable sources of economic empowerment, and to provide recommendations on what conditions are required for the establishment of resilient enterprises which rely directly or indirectly on estuarine natural resources. The product of this research is a conceptual Ecosystems Services Framework (ESF), and a practical ecosystem services inventory and risk assessment (presented as a series of pre-programmed Excel spreadsheets – refer to Appendix A) which are based on SES theory, and which can be used to identify potentially resilient estuarine NRBEs. The ecosystem services inventory and risk assessment were tested at two estuaries in the Eastern Cape: i) Umngazi estuary, near to Port St. Johns, on a small-scale community-based tourist accommodation enterprise; and ii) Tyolomnqa estuary, near to East London, on a wilderness camp. Also produced as part of the SAWRC project was a SAWRC Report (Bowd et al. 2012b). As the SAWRC Report incorporates much of Paper 1, and presents the research in a much more practical context (as opposed to being an academic-based publication), this published report has not been included as part of this thesis.

Equipped with knowledge of how to disaggregate and understand the interrelations and dependencies between social and social-ecological systems gained from Paper 1, Paper 2 investigates the threats and opportunities associated with the commercialisation of natural product-based enterprises (NPBEs), and documents a toolkit which contributes to the establishment of resilient NPBEs which benefit the rural poor in South Africa. Paper 2 applies an amended version of the conceptual framework developed for Paper 1 to an inland wetland-based enterprise located at Mbongolwane, approximately 30km inland of Eshowe, KwaZulu-Natal. This enterprise made and sold wetland fibre craft products for several years and had been subject to a variety of shocks, which added to its value as a case study for better understanding the resilience of NRBEs.

Environmental Impact Assessment (EIA) practice in South Africa can benefit from incorporating evolving theory in SES and complex systems literature. In fact Pope et al. (2013) acknowledge that emerging opportunities for EIA practice lie in the further

incorporation of concepts such as system dynamics, resilience and ecosystem services into impact assessment. Paper 3 describes the development of a framework, referred to as the social-ecological system - Environmental Assessment (SES-EA) framework, and its application to two case study sites: i) the small-scale community-based tourist accommodation enterprise at Umngazi estuary (which features in Paper 1); and ii) a proposed wine estate (comprising residential units, commercial node, vines and a winery) located near to Howick, KwaZulu-Natal Midlands. The wine estate was chosen to explore the versatility of the SES-EA framework, as the SES-EA framework was originally developed for an estuary-related enterprise, and to assess whether the framework could be applied to a very different and more complex social-ecological system.

The practical contributions of Papers 1 and 2 included risk assessments, which are centred on SES theory, and which can be used to assess the resilience of NRBEs. Although the practical contributions performed well for relatively simple NRBEs, the candidate wished to explore to what extent they could be successfully applied to a NRBE which was located within a much broader and complex SES. The woody-biomass industry is considered an industry which is natural resource-based, and which has complex and potentially far-reaching social, ecological and economic impacts. The industry is highly developed throughout the US and Europe and involves the pelletising of waste wood which is then used as an alternative fuel to coal and gas. With four failed woody-biomass pellet plants in South Africa, and Europe and the US looking to the developing world to meet the demand for biomass (Openshaw 2011, Kranzl et al. 2014), the candidate considered that the development of a specific risk assessment for the industry had potential to increase the likelihood of a resilient woody-biomass industry, should attempts be made to re-establish the industry in South Africa. Paper 4 advances previous SES conceptual frameworks, by introducing a prominent production process element to the framework, and presents a 'broad-level' risk assessment which can be used at a feasibility stage, or as a foundation for the development of a more rigorous and in-depth assessment tool.

The case studies used in this thesis are all rural and located in South Africa. All papers promote the importance of public participation, and feature the same key stakeholder groups (e.g. government departments responsible for service provision, local communities who can either benefit or be detrimentally affected by a development, and interest groups, who may support or oppose a development). The SESs which are explored in this thesis range from a community-based accommodation enterprise, which benefits only a few individuals within a rural community and located within a relatively simple SES to a global industry which is located within a highly complex SES (which extends beyond the borders of South Africa) and

which has the potential to not only create large numbers of jobs, and thus help alleviate poverty, but to also bring a reliable power supply to rural areas which would enable business development and social upliftment.

CHAPTER 2: LITERATURE REVIEW

This research intends to contribute to the discourse around sustainable use of natural resources, and specifically to develop practical methods to describe and assess underpinning social-ecological systems (SESs). The literature review therefore focuses on analytical frameworks for understanding SESs and publications on the concepts of resilience, risk and ecosystem services. This review is not an exhaustive coverage of all literature reviewed in this study. In addition, some specific aspects in the literature review are covered within the individual case chapters.

2.1. SOCIAL-ECOLOGICAL SYSTEMS

A SES is an ecological system that is linked to one or more social systems, and comprises 'ecological systems', defined as interdependent systems of ecological units (Walker et al. 2004), and 'social systems' which can be defined as living in communities and interacting with others of the same kind as interdependent systems of organisms (Walker et al. 2002). Social and ecological systems are able to interact interdependently and, at the same time, can contain interactive subsystems (Walker et al. 2002, Anderies et al. 2004). Social-ecological systems therefore refer to social systems in which some of the interdependent relationships between humans are mediated through interactions with ecological units (Anderies et al. 2004).

A SES is not made up of only one set of interactions occurring at one scale, but rather they are complex and adaptive systems (Kay and Schneider 1994, Kay and Regier 2000, Anderies et al. 2004). Holling et al. (1998:352) suggest they are found "... where aspects of behaviour are complex and unpredictable and where causes, while at times simple (when finally understood), are always multiple. They are non-linear in nature, cross-scale in time and in space, and have an evolutionary character. This is true for both natural and social systems. In fact, they are one system, with critical feedbacks across temporal and spatial scales". A SES thus functions as a nested, hierarchical structure, with processes occurring within different subsystems at different rates and scales (Kay et al. 1999, Gunderson and Holling 2002, Walker et al. 2002), and it is recognised that developing an understanding of these cross-scale interactions is vital for achieving a more resilient system (Walker et al. 2002).

2.2. THE CONCEPT OF RESILIENCE

As resilience is one of the key concepts used in this study to understand natural resource-

based enterprises (NRBEs), various definitions of resilience have been examined, together with aims of managing for resilience.

The concept of resilience provides a conceptual foundation for sustainable development (Folke et al. 2002), and has been around for over four decades (Holling 1973). Since the 1970s a variety of definitions have appeared (Grimm and Wissel 1997, Neubert and Caswell 1997) which has led to a variety of different management actions, and ultimately policies (Gunderson 2000). There are two popular definitions of resilience in ecological literature: one relates to global equilibrium, the other to multiple equilibrium (Gunderson 2000). Resilience as a global equilibrium is defined as the time a system takes to return to an equilibrium or steady state following a perturbation (Tilman and Downings 1994, Ives 1995, Neubert and Caswell 1997). Basically this definition means how far a system can move from an identified equilibrium and how quickly it can return (Ludwig et al. 1996). Holling (1996) describes the return time meaning of resilience as 'engineering resilience'. Resilience as a multiple equilibrium is the measure of a disturbance that can be absorbed before a system changes its stable states, and has been referred to as 'ecological resilience' by Holling (1996). The multiple definitions of resilience are dependent on the assumption that either a single equilibrium or multiple equilibria are present in a system (Holling 1996).

Although the concept of resilience was originally developed for ecological systems (Holling 1973), it has since been applied to SESs. Human intervention within an ecosystem can alter the key variables that control the underlying stable domains (Gunderson 2000), and some scholars propose that alternative stable states do not exist in systems which have had no human intervention (Sousa and Connell 1983). However, others suggest that alternative stable states have occurred in systems with and without humans (Dublin et al. 1990).

Due to technological advancements during the 20th century, humans have been able to control variability in order to achieve a single objective (e.g. maximise yields). The implementation of this technology contributes to the myth that science can resolve most uncertainties in management (Gunderson 2000). In addition, there is growing consensus that traditional scientific approaches do not work (Ludwig et al. 1993). The technological approach involves controlling a single variable but, at the same time, changing other parts of a system (Holling and Meffe 1996). This human intervention has often resulted in a loss of ecological resilience within a system (Gunderson 2000). However, a unique human attribute is the ability to adapt and respond to uncertainties with novelty (e.g. humans can organise help groups in response to crisis) (Gunderson 2000).

It has proved challenging to apply the concept of resilience to a system in which some variables are consciously designed (a system which features human interactions) (Carpenter et al. 2001), and as a consequence the concept of adaptive capacity, which considers interactions across different scales, has emerged (Anderies et al. 2004). Adaptive capacity can be defined as the capability to adapt and to shape change (Anderies et al. 2004), and adaptability is the capacity of actors in a system to influence resilience. In a SES, this amounts to the capacity for humans to manage a system (Walker et al. 2004, Resilience Alliance 2007). Even though the concept of resilience was developed for ecological systems, the terms 'resilience' and 'adaptive capacity' are sometimes used interchangeably (Walker et al. 2002).

Panarchy is the hierarchical structure in which SESs are interlinked in a never-ending adaptive cycle, and is the term used to describe a concept that explains the evolving nature of complex adaptive systems (Holling 2001).

The Resilience Alliance (2007) identifies five key components of resilience. The first component is the 'resilience of what and to what'. This refers to identifying the boundaries of the 'focal' system by considering and describing the natural resources, the people managing and using them, the institutions which govern access to them and the commercial and non-commercial services offered by them. Once the boundaries of the focal system have been identified, the system is expanded by considering the ways in which larger systems can impact on the 'focal' system, and how the dynamics of subsystems can influence the 'focal' system. A historical timeline of the SES, which considers past human interventions and management actions on the system, can be assembled. Following this, disturbances can be identified by those impacts which can or have caused past disruption to the system.

The second component of resilience is the identification of alternate states and thresholds. This is done by considering what disturbances might move a system temporarily away from a stable state, and what disturbances might push a system to a point where it cannot return to a stable state. Some systems have one stable state, others can have more.

The third component is the adaptive capacity cycle (Figure 2.1). This cycle helps identify a system's vulnerability and opportunity, which can be used to assist with the management of that system. The adaptive cycle involves a system moving through four phases: The rapid growth and exploitation phase (r), which leads into a long phase of accumulation and conservation (K) (during which resilience tends to decline), then a very rapid breakdown or release phase (Ω), and finally a short phase of renewal and reorganisation (α). These four

phases are to be considered in terms of potential disturbances to the system. If during these phases the system still features more components of its previous system, it can reorganise and remain within the same configuration as before. However, during the renewal and reorganisation phase, novelty can enter (e.g. new institutions, policies, industries) and the 'new' system gains resilience (Walker et al. 2002).

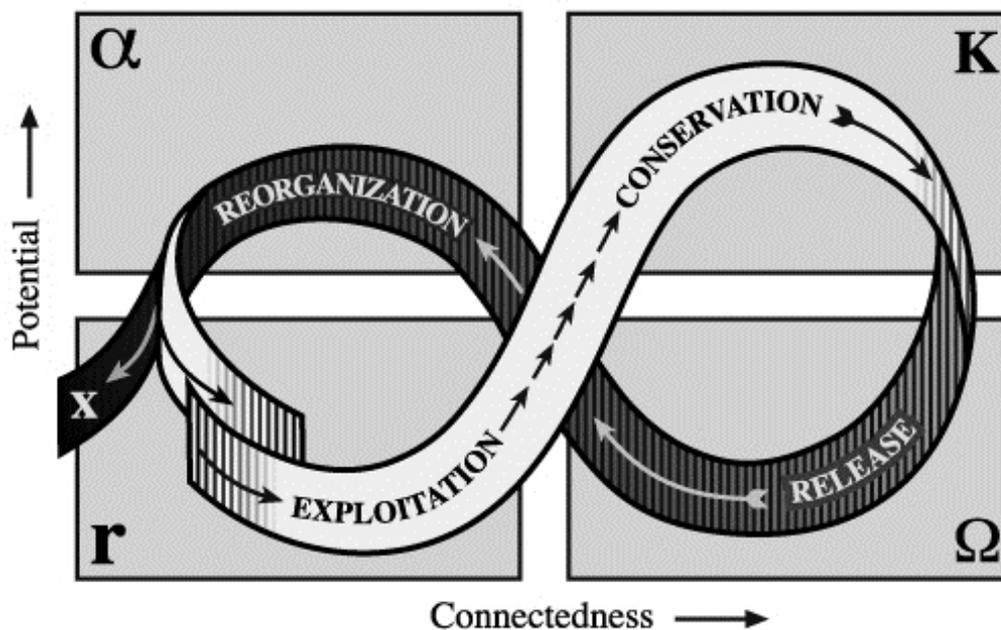


Figure 2.1. The adaptive capacity cycle. Source: Gunderson and Holling (2002)

The fourth component is the evaluation of the adaptability and transformability of the system. Adaptability relates to the capacity of people to manage ecological resilience of the system. Transformability refers to whether a system can or should be transformed, and to the sources of natural and social capital needed for transformation. Transformability has been defined as the “capacity to create a fundamentally new system when ecological, economic or social (including political) conditions make the existing system untenable” (Walker et al. 2004:1).

The fifth component is the assessment and implementation of interventions and adaptive management. Interventions are required to be managed holistically, and knowledge of how multiple interventions might interact with each other when planning the sequencing of action is required. Adaptive management involves the development of methods which integrate an understanding of a system from various disciplines. When a system is managed for resilience, which means preventing a system from moving to an undesired configuration as a result of external stresses and disturbance, increasing the level of external pressures required to alter a system in the short-term can make a SES more inflexible. This often leads to a system becoming less resilient in the long-term (Gunderson et al. 1995, Cabell and

Oelofse 2012). However, long-term resilience may only be achievable with short-term instability (Carpenter et al. 2001, van Apeldoorn et al. 2011). Thus a resilient system is not always desirable (Walker et al. 2002, Cabell and Oelofse 2012), and an explicit example of this is a system that can become caught in a cycle of social deprivation which prevents it from transforming into a more positive configuration (Cabell and Oelofse 2012).

This brief review of the concept of resilience has suggested that it can be a useful construct in evaluating the sustainability of NRBEs. This review highlights that the following should be considered when applying the concept of resilience to assessing NRBEs:

- The boundaries of the SES must be identified by demarcating the natural resource upon which the NRBE is reliant, identifying who manages, governs and uses this resource, and what services influence access to the resource;
- Understand that the 'focal' system the NRBE is located within is i) part of a larger system; and ii) comprises many subsystems; and interactions within these larger systems and smaller subsystems impact on the 'focal' system;
- Consider what past ecological and social disturbances have affected the system and what management actions were implemented;
- Consider the adaptive capacity of the NRBE, by assessing the ability of those responsible for: i) operating the NRBE; and ii) managing the natural resource the NRBE is reliant upon; and
- Increasing the resilience of a NRBE may benefit those involved with a particular NRBE, however this increase in resilience may reduce the resilience of i) other NRBEs or communities which rely on the same resource; and ii) the ecological resource. Increasing the resilience for a NRBE, at the expense of other NRBEs or community livelihoods, could have an overall negative impact on poverty alleviation. Thus consideration of other resource users is paramount.

Examination of the risks facing a SES can provide a useful contribution to assessing the resilience of a SES, and the NRBE it supports. A SES has characteristics which affect its ability to adapt and manage for risks (Walker et al. 2004). The concept of risk can be hard to conceptualise, as there are numerous definitions and interpretations in academic literature (Christopher and Peck 2004). Slovic (2000:478) sees the concept of risk as an “outgrowth of society's great concern about coping with danger”, whereas Kasperson et al. (1988) define risk as a technical concept which focuses on the probability of events occurring and the magnitude of specific consequences. In terms of risk management, a hazard-focused interpretation which is commonly used is “risk-probability (of a given event) x severity

(negative business impact)” (Skorna et al. 2011:2). However, the most common definition which draws from classical decision theory is the “variation in the distribution of possible outcomes, their likelihoods and their subjective values” (Christopher and Peck 2004:4).

Risks associated with NRBEs include the impact of extreme weather events on the natural resource utilised by the NRBE, and competition for the resource from other resource users. As this study is concerned with incorporating potentially conflicting and subjective viewpoints, and the understanding of varying types and degrees of impacts on the management of NRBEs, the definition of Christopher and Peck (2004), which draws from classical decision theory, appears most appropriate. Although the Skorna et al. (2011) definition of risk management could be considered suitable, as this thesis is unlikely to be dealing with a 'given event', it may have been difficult to apply in the case of this study.

2.3. THE CONCEPT OF ECOSYSTEM SERVICES

Ecosystem services are the processes through which ecosystems and the species that make them up provide for human life (Daily 1997), and the concept encompasses the delivery, provision, production, protection or maintenance of goods and services that people regard as important (Chee 2004). Goods can include: natural fibre, biomass and timber, and services can include waste assimilation, maintenance of biodiversity (Norberg 1999) and scenic beauty.

The concept of ecosystem services originated in the 1970s (de Groot et al. 2010) and became popular during the 1990s (e.g. Daily 1997, Constanza et al. 1998). The Millennium Ecosystem Assessment (MEA 2003, 2005) publicised the concept during the 2000s, and since then the concept has increasingly grown in popularity (e.g. Pullin et al. 2004, Knight et al. 2006, Turner and Daily 2007, Daily and Matson 2008, Tallis et al. 2008, Temperton et al. 2013). Although widely used, there is still much debate around distinguishing between ecosystem functions and services, and how to quantify these services (e.g. Fisher et al. 2009).

Challenges with the concept, which still need to be addressed, are: understanding and quantifying how ecosystems provide services; valuing the services; use of the services in trade-off analysis, decision-making and planning and management; and financing sustainable use of the services (de Groot et al. 2010). These challenges are sourced from MEA (2003, 2005), European Communities (2008), ICSU et al. (2008), and Verburg et al. (2009) and must be considered when applying this concept to understanding the ecosystem

services used by NRBEs. For this study, attention must be paid to quantifying and valuing services, especially as a variety of stakeholders will be engaged with, and will place different values on these services.

Turner and Daily (2007) identified that although the concept of ecosystem services has been popular with academics, there is a lack of an operational decision support system which addresses better biodiversity conservation and environmental management. In response, they document an Ecosystem Services Framework (ESF) which highlights the role healthy ecosystems play in human well-being, poverty alleviation and economic development. They document three constraints which impede ESFs from becoming operational: i) information failure – which is the lack of detailed information about the way in which people benefit from ecosystem services, and at a scale that is relevant to decision-makers; ii) institutional failure – which arises as a result of the failure to consider local socio-ecological contexts (including property rights and institutions) and the fact that those who benefit from ecosystem transformation are not the same as the recipients of ecosystem services; and iii) market failure – which arises because of the public-good nature of benefits and as many of the benefits cannot be quantified or measured in a single currency (Turner and Daily 2007).

With the basic concepts of resilience, risk and ecosystem services introduced, it is now necessary to investigate the different methods for assessing the SESs which characterise NRBEs. The following section provides a brief overview of popular assessment methods for assessing the resilience of SESs.

2.4. APPROACHES USED IN DEVELOPING RESILIENCE MODELS

Social-ecological systems cannot be designed or controlled, nor can their performance be accurately or directly measured (Anderies et al. 2004). However, during the last four decades, researchers have developed methods which attempt to assess the resilience of SESs. Table 2.1 provides a summary of methods used to develop resilience models. These models are practical devices which enable observations to be manipulated and compared, thus they bring an applied perspective to SES theory (Carpenter et al. 2005).

Table 2.1. Methods used in the development of resilience models

Method	Description
Model exploration	Models of the SES (e.g. computer simulation, scenarios models) are developed to explore potential thresholds for change. They also identify measurable elements of the SES that have systematic relationships to the modelled thresholds

Stakeholder engagement	Aspects of SES resilience are identified through workshops to help build a common understanding of change in the SES
Historical profiling	The history of the SES is assessed to identify reactions to distinct past disturbances
Case study comparison	Similar SESs which appear to be changing in different directions are observed to see how these changes relate to resilience

Model Exploration

The modelling of SESs has arisen as it is not possible to directly observe the resilience of an SES, due to most SESs having barriers which prevent part of the system from being observed (Carpenter et al. 2005). Barriers can be socio-economic in nature (e.g. political interference) or ecological (e.g. inaccessibility to assess the resources). Walker et al. (2002) identified two limitations associated with model exploration. The first limitation is that statistical methods underestimate uncertainties, and this is because uncertainties, such as climate change and technology, are key drivers and are ever changing and unpredictable. These factors, combined with statistical methods, are generally used to assess variables which are narrowly focused, which leads to inaccurate results. In addition "... human action in response to forecasts is reflexive. If important ecological or economic predictions are taken seriously, people will react in ways that will change the future, and perhaps cause the predictions to be incorrect" (Walker et al. 2002:1). The second limitation is that systems change quicker than predictive modelling can adapt to a situation, thus a predictive model is most unreliable when it is most needed. The use of predictive models is very limited, especially in systems that are experiencing transition. A lack of appropriate information to populate the models has also been noted as a failing of these models (Gunderson 2000).

Although drawbacks of model exploration have been documented by Walker et al. (2002), they use a scenario modelling technique to understand how possible scenarios for SESs might be analysed, envisioned, and managed in terms of their resilience. Walker et al. (2002) are aware that, in the past, the use of assumptions for scenario modelling has led to unaccepted and unwanted outcomes in SESs, and suggest that resilience analysis can provide input into assumptions in order to reduce the likelihood of unexpected and uncontrolled outcomes occurring. Walker et al. (2002) consider that a resilience-centred method make six main assumptions. The first assumption is that SESs may contain thresholds and exhibit irreversible changes, and that resilience assessment focuses on identifying and understanding the processes that produce these thresholds. Carpenter (2003) suggests that the only way to identify a threshold in a complex system is to cross it, which is rare; and that it may be impossible or unethical to induce a threshold-crossing in a SES. However, an understanding of thresholds has been derived from deliberate

manipulations of ecosystems, before and after studies of major disturbances (Turner and Dale 1998, Groffman et al. 2006) and through historical analysis (Carpenter et al. 2005).

The second assumption is that the probability distributions for key decision variables are highly uncertain, and that both the functional form and parameters of distributions may be unknown. The third assumption is that decision-makers within SESs must make decisions based on imperfect knowledge, with limited resources, and that decisions do not solely concern the consumption of goods and services. The fourth assumption is that market imperfections are the norm, and not the exception, and thus market-based valuations are usually distorted. The fifth assumption is that decision-makers have preferences, not only over outcomes (consumption bundles), but over the social, economic, and political processes that govern those outcomes (Pritchard et al. 2000). The final assumption is that well-defined property rights do not exist for many important ecological goods and services and, therefore, markets do not exist.

Gunderson (2000) supports the use of scenarios when dealing with the highly complex and non-linear relationships within a SES, and recommends adopting the method of adaptive management. The basic process for adaptive management is to identify uncertainties, develop and evaluate hypotheses around a set of desired system outcomes, and derive a set of actions to evaluate these ideas (Walters 1986). This method assumes surprises are inevitable, that human interaction with ecosystems will always evolve, and knowledge will always be incomplete (Walters 1986). Adaptive management acknowledges that managed natural resources will always change, and thus humans must adapt as situations change (Gunderson 2000), and that policies must meet social objectives but, at the same time, must be continually able to be modified to be compatible with change (Walters 1986).

The brief review of model exploration literature highlights that variables within a systems are constantly changing and are unpredictable, and thus the accuracy of implementing models to assess and predict future events can be limited. Also of concern is that the measure of specific variables may bias a result, and / or the scale of variables assessed may be too small to obtain an accurate understanding of the SES within which a NRBE is located. Walker et al. (2002:1) suggest that we must learn to live within systems, rather than 'control' them, and that "SESs might not be so unpredictable if their behaviour were looked at from a larger perspective". This emphasises the need to assess a SES at a large enough scale, and that adaptive management is fundamental to the resilience of a NRBEs. Although these limitations are acknowledged, the methods chosen for this thesis are considered a type of

model exploration, however the method of stakeholder engagement (introduced below) will play more of a dominant role with the contributions of this thesis.

Stakeholder Engagement

There are numerous definitions for the terms 'stakeholders' and 'stakeholder engagement', however for this study the Deverka et al. (2012) definitions have been chosen as most appropriate for this thesis, given their context of comparative effectiveness research. Deverka et al. (2012:185) define stakeholders as "Individuals, organizations or communities that have a direct interest in the process and outcomes of a project, research or policy endeavour", and stakeholder engagement as "an iterative process of actively soliciting the knowledge, experience, judgment and values of individuals selected to represent a broad range of direct interests in a particular issue, for the dual purposes of: i) creating a shared understanding; and ii) making relevant, transparent and effective decisions".

Six different levels of stakeholder groups are identified by Leemans (2000): international, national, state / provincial, municipal, family and individual. Gunderson et al. (2006) list five factors for constructive communication between stakeholders and stakeholder groups: i) the development and maintenance of open communication channels (Berkes et al. 1998, Folke et al. 2005); ii) identification of the roles of the different stakeholders through scientific activities or social communication (Fazey et al. 2005); iii) the designation of a meeting place at which discussions can take place between the different stakeholders; iv) the establishment of trust between the stakeholders; and v) the establishment of leadership, as this is required to integrate social and ecological understanding, and to delegate responsibility to ensure progress.

As previously mentioned, the SESs in which NRBEs are located are socially highly complex, and engagement with stakeholders from a range of levels (e.g. from individual to international) is the only method of obtaining an accurate understanding of these systems. With a well-documented weakness in natural resource management being the hiatus between theory and practice (Pullin et al. 2004, Knight et al. 2006, Turner and Daily 2007, Daily and Matson 2008, Temperton et al. 2013), it is anticipated that adequate stakeholder engagement can help contribute to addressing this weakness. Given the above, stakeholder engagement plays a pivotal role in this study.

Historical Profiling

Many authors have made reference to the need to investigate the historical profiles of a system, as they can give an indication as to how a system might react to future external

disturbances (Resilience Alliance 2007). Walker et al. (2002) found it helpful to investigate a historical profile at three scales – local (ecological boundaries), regional (area being studied) and multi-regional, and then a look for cross-scale effects. Ecological, technological, economic and social changes must be considered at all three scales (Resilience Alliance 2007). For this study, social historical profiling could be useful to help determine the adaptive capacity of those involved with the management of NRBEs. This in turn could help contribute towards assessing the risks to and the resilience of NRBEs.

Case Study Comparison

This method can involve the modelling of different types of impacts on similar case studies (e.g. a comparison of various rural craft enterprises, each being assisted, to varying degrees, by a different mix of public and private institutions) or similar impacts on dissimilar case studies (e.g. a comparison of the impact of low literacy levels on different types of enterprises). Walker et al. (2002) consider that this method is most useful when comparing similar SESs. As this thesis will be applying concepts of risk, resilience and ecosystem services to a range of enterprises which are all based on natural resources, it is expected that these case studies will have similar SESs.

2.5. REVIEW OF GENERAL SOCIAL-ECOLOGICAL SYSTEM FRAMEWORKS AND PRINCIPLES

A framework provides the basis for the concepts and terms that can be used to explain a theory (McGinnis and Ostrom 2014). Through reviewing literature on conceptual SES frameworks a total of eight frameworks were identified (Table 2.2). However for this study three frameworks were selected for detailed review: Walker et al. (2002), Anderies et al. (2004) and Ostrom (2007, 2009). The Anderies et al. (2004) and Ostrom (2007, 2009) frameworks stem from the Ostrom (1990) design principles for common pool resource institutions. McGinnis (2010) suggests further amendments to the Ostrom (2007) SES framework, some of which are incorporated into Ostrom and Cox (2010), however McGinnis and Ostrom (2014), which was published after Ostrom's death in 2012, present these, as well as additional amendments, and document the challenges of evolving the Ostrom (2007) SES framework.

The Ostrom et al. (2007, 2009) and McGinnis and Ostrom (2014) frameworks, together with the Anderies et al. (2004) framework, were selected as their key elements (which are very similar) are considered applicable to the NRBE context. The Walker et al. (2002) framework was chosen as it has a high degree of detail, and incorporates questions which surround

many of the key aspects featured in the Ostrom (2007, 2009) and McGinnis and Ostrom (2014) framework as well as the Anderies et al. (2004) framework. These questions stimulate a deeper understanding of these key aspects, and thus complement the other chosen frameworks.

The following section presents the common pool resource principles, followed by a summary of the three chosen SES conceptual frameworks. This section concludes with a summary of the Binder et al. (2013) criteria for evaluating the effectiveness of social-ecological conceptual frameworks. The amendments discussed in McGinnis (2010) and Ostrom and Cox (2010) have not been reviewed here, as McGinnis and Ostrom (2014) effectively incorporate these.

Table 2.2. A list of frameworks for analysis of social-ecological systems

Framework	Author
The Driver, Pressure, State, Impact, Response Framework	Eurostat (1999)
The Ecosystem Services Framework	Boumans et al. (2002), de Groot et al. (2002), Limburg et al. (2002)
The Human-Environment System Framework	Scholz and Binder (2003, 2004), Scholz et al. 2011a,b)
The Natural Step Framework	Burns (1999)
The Resilience Analysis Social-ecological Framework	Walker et al. (2002)
The Robustness Analysis Social-ecological Framework	Anderies et al. (2004)
The Social-ecological Systems Framework	Ostrom (2007, 2009), McGinnis and Ostrom (2014)
The Sustainability Livelihood Approach	Scoones (1998), Ashley and Carney (1999)

2.5.1. The Ostrom (1990) design principles for common pool resource institutions

The role of the principles is to explain under what conditions collective actions can be built and maintained to solve social dilemmas associated with common pool resources (Cox et al. 2010). There are eight design principles and these are described in Table 2.3.

Table 2.3. Design principles from studies of long-enduring institutions governing sustainable resources. Source: Anderies et al. (2004), based on Ostrom (1990)

Principle	Description
1. Clearly defined boundaries	The boundaries of the resource system (e.g. irrigation system or fishery) and the individuals or households with rights to harvest resource units are clearly defined
2. Proportional equivalence between benefits and costs	Rules specifying the amount of resource products that a user is allocated are related to local conditions and to rules requiring labour, materials, and / or money inputs
3. Collective-choice	Most individuals affected by harvesting and protection rules are included in the group who can modify these rules

arrangements	
4. Monitoring	Monitors, who actively audit biophysical conditions and user behaviour, are at least partially accountable to the users or are the users themselves
5. Graduated sanctions	Users who violate rules-in-use are likely to receive graduated sanctions (depending on the seriousness and context of the offence) from other users, from officials accountable to these users, or from both
6. Conflict-resolution mechanism	Users and their officials have rapid access to low-cost, local arenas to resolve conflict among users or between users and officials
7. Recognition of rights to organise	The rights of users to devise their own institutions are not challenged by external governmental authorities, and users have long-term tenure rights to the resource
For resources that are part of larger systems:	
8. Nested enterprises	Appropriate, provision, monitoring, enforcement, conflict resolution and governance activities are organised in multiple layers of nested enterprises

Principle 1 helps identify who should receive benefits and pay costs, and Principle 2 helps compare the benefits a resource user obtains, and his / her contributions to the public infrastructure. Principle 3 enables those with the most to lose by a collapse of a system to have a major say in regulating the use of a resource. Rules that are established by the resource users are better understood, known and perceived as being legitimate (Anderies et al. 2004). The first three principles in isolation do not improve the robustness of a SES, as rules made to solve the problems of overuse and free riding are not self-enforced but require principles 4 to 6. These principles can collectively be considered as a feedback control for resource utilisation. The obeying of these rules depends on the resource users' perceptions of legitimacy of the rules, and the monitoring and enforcement of these rules (Anderies et al. 2004). The establishment of local institutions among medium to large scale institutions helps to ensure that local (small) scale problems are dealt with, as well as those that are at a large scale (Principle 7). Berkes et al. (2006) also identify the need for multilevel governance institutions to be established, from small-scale local institutions to large-scale international organisations.

Although there has been general support for these principles, there has been criticism of their theoretical grounding and over-precision, which has resulted in limiting the conditions to which they are applicable to (Cox et al. 2010). Cox et al. (2010) evaluate the application of the Ostrom (1990) design principles and consider what theoretical issues have arisen since their emergence through analysing 91 case studies which explicitly or implicitly evaluate these principles. Table 2.4 below summarises the findings of the Cox et al. (2010) evaluation, together with their recommendations for amendments.

Table 2.4. Summary of the Cox et al. (2010) review of Ostrom's (1990) design principles for common pool resources

Principle	Findings and recommendations
1. Well-defined boundaries	This principle was the most frequently criticised. The main criticism is that it is too rigid, and more fuzziier social and geographical boundaries are needed to facilitate more ad hoc relations between participants The suggested amendments to this principle are that it is split into two and re-written as follows: 1a User boundaries: Boundaries between legitimate users and non-users must be clearly defined 1b Resource boundaries: Clear boundaries are present that define a resource system and separate it from the larger biophysical environment
2. Congruence between appropriation and provision rules and local conditions	This principle has been split into two because what is considered equitable may vary depending on how much of the resource is available The suggested amendments to this principle are as follows: 2a Congruence with local conditions: Appropriation and provision rules are congruent with local social and environmental conditions 2b Appropriation and provision: The benefits obtained by users from a common pool resource, as determined by appropriation, are proportional to the amount of inputs required in the form of labour, material, or money, as determined by provision rules
3. Collective-choice arrangements	This principle was moderately well supported, however there are concerns with situations wherein the principle exists in form, but in practice has been co-opted or undermined by locally powerful or external bureaucratic actors No amendments are proposed
4. Monitoring	This principle has been split into two as it is important to differentiate between monitoring the users of the resource, and monitoring the resource itself The suggested amendments to this principle are as follows: 4a Monitoring users: Monitors who are accountable to the users monitor the appropriation and provision levels of the users 4b Monitoring the resource: Monitors who are accountable to the users monitor the condition of the resource
5. Graduated sanctions	This principle was moderately well supported, however there was a small subset of literature which argued that sanctions are not needed in the presence of strong social capital and should not be implemented as a replacement for it No amendments are proposed
6. Conflict-resolution mechanism	This principle was moderately well supported. It has emerged that when conflict resolution mechanisms are not available or easily accessible, successful common pool resource management is more challenging No amendments are proposed
7. Recognition of rights to organise	This principle was moderately supported. It is apparent that violations of this principle can be associated with less successful resource management regimes No amendments are proposed
8. Nested enterprises	This principle was moderately supported. However one clarification noted was that nesting may occur either between user groups and larger governmental jurisdictions, or between user groups themselves No amendments are proposed

Cox et al. (2010) document various shortfalls of the Ostrom (1990) design principles. They regard the principles as being incomplete, and claim that additional criteria, such as social

variables, are needed for sustainable management. They also consider that more sophisticated treatment of ecosystem properties and structures should be incorporated to match institutional arrangements to those properties and structures, that the relevant properties of the resource system must be given in more detail, and that the importance of external socio-economic factors must be stressed.

Ostrom (2007:15181) states that “we need to recognize and understand the complexity to development diagnostic methods to identify combinations of variables that affect the incentives and actions of actors under diverse governance systems”. Cox et al. (2010) see the diagnostic and design principles as complementary, and not mutually exclusive, and recommend that a significant amount of work is needed to combine the principle with a well-developed diagnostic approach.

The SES conceptual frameworks that are based on Ostrom’s (1990) design principles can be considered attempts at combining these principles with a diagnostic approach. The three main conceptual frameworks presented below incorporate many of the Ostrom (1990) design principles, and it is important that these principles are considered with any new or advanced SES conceptual framework.

2.5.2. Walker and others (2002) resilience analysis framework

Walker et al. (2002) present a resilience analysis framework, which is predominantly based on stakeholder engagement and comprises four steps (refer to Figure 2.2). The Walker et al. (2002) framework borrowed some aspects of the adaptive management approach developed by Holling (1978) and Walters (1986), as well as ideas of scenario planning from van der Heijden (1996). This framework was developed based on the developed world; however, they felt that the issues raised were even more pertinent to the developing world context (Walker et al. 2002).

Walker et al. (2002:4) stress the importance of involving all associated stakeholders at the onset of an assessment as “without their participation, achieving a collectively and socially desirable outcome is not possible, because key information resides in the knowledge and mental models of stakeholders, and because, without the inclusion that comes from participatory approaches, any proposed solution would face a legitimacy problem”. To assist with the identification of all relevant stakeholders, Walker et al. (2002) suggest that it is desirable to have knowledge of the institutional framework that determines the rules for ecosystem usage, with particular reference to property or user rights and the decision-

making processes.

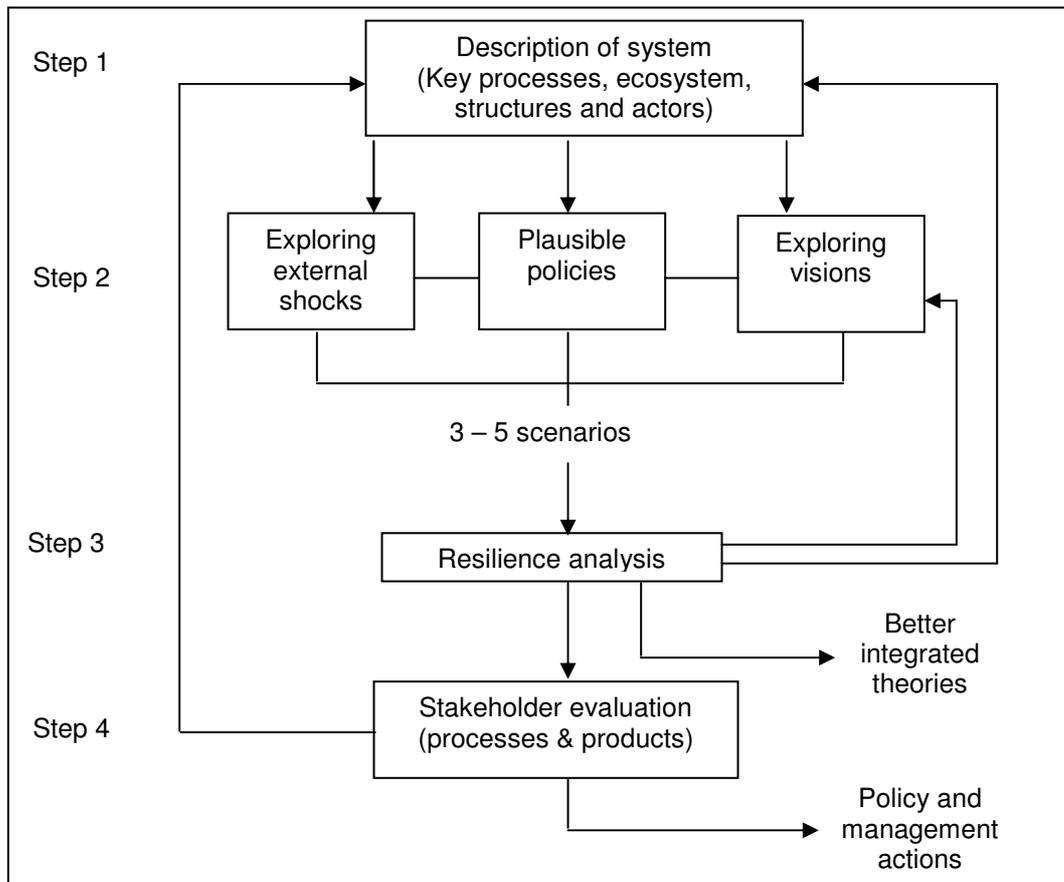


Figure 2.2. The Walker et al. (2002) framework for the analysis of resilience in social-ecological systems

The four steps of the Walker et al. (2002) framework are as follows:

Step 1 – Resilience of what? This step provides knowledge on what ecosystem services and variables are of concern to the stakeholders and, most importantly, defines the resilience “of what” (Carpenter et al. 2001). It includes defining the spatial boundaries of the SES, identifying the key stakeholders and ecosystem services, and how the stakeholders value these services, identifying the key components of the system, and how their dynamics are influenced by exchanges across the boundaries of the SES, and historically profiling the system and considering how past changes in ecosystem (in terms of technology, society and economy) influence the system. It also includes identification of the important controlling variables that act as drivers of the key ecosystem goods and services people want, and what ambiguities are in the system. Finally, this step requires investigation into how the current institutional arrangements (e.g. property rights) and the distribution of power and wealth influence formal and informal decision-making and access to information.

Step 2 – Resilience to what? This step involves the identification of a range of possible trajectories that the stakeholders might try to make, and aims to develop a number of possible scenarios that consider the outcome of uncontrollable external disturbances. During this step, external disturbances, policy drivers and stakeholder actions are examined (Walker et al. 2002). This examination enables the formulation of responses to unexpected disturbances. In addition, this exercise makes stakeholders aware of possible shocks the system could experience. Due to stakeholders having different priorities and interests within a system, the various stakeholders will attempt to drive the system along different trajectories. The actual trajectory a system follows will be the result of stakeholder interactions and external drivers.

Step 3 – Quantitative analysis to identify where resilience resides. This step involves examining the dynamics of a SES under a range of different scenarios by exploring the major issues within a system identified by stakeholders; and the major uncertainties about how a system will respond to drivers of change. This step aims to identify those variables and processes (e.g. local, traditional, national laws, gender dynamics) within a system that governs the workings of those variables stakeholders consider to be important (ecosystem goods and services). In order to do this, it is necessary for discussions to take place between stakeholders, policy-makers, other experts and scientists to analyse how a system will respond and change under the influence of different scenarios. In addition, stakeholder reflective behaviour must also be considered. This is usually investigated during a second round of discussions amongst the different stakeholders.

Step 4 – Resilience management (evaluation and implications). This step involves the evaluation of management and policy implications by both scientists and stakeholders.

2.5.3. The Anderies and others (2004) framework for studying the robustness of social-ecological systems

Anderies et al. (2004) developed a framework to study the robustness of SESs, as they believe that robustness is a more appropriate concept when trying to understand how SESs can deal with disruptions, and that the concept of resilience is more appropriate when trying to understand the self-organising components of a SES and how they interact. Anderies et al. (2004) are of the opinion that a robust system will not typically perform as efficiently as a non-robust system, however a robust system's performance will not decline as quickly as a non-robust system when it is faced with external disturbance or internal disturbances. To investigate the robustness of an SES, Anderies et al. (2004) recommend that the relevant system is first defined, followed by the identification of the desired systems characteristics,

and finally the determination of when the collapse of one part of a SES implies that the entire system loses its robustness.

This SES conceptual framework highlights that ecological systems are dynamic, as are the rules of the games that decision-makers play amongst themselves (governance system), and that they can occupy multiple stable states and move rapidly between them. Anderies et al. (2004) also consider that cooperation, and the potential for collective action, must be maintained within the social system (the resource). The framework can be used to answer four possible questions: i) how do institutional arrangements affect the robustness of SESs?; ii) why do some systems survive in highly varying environments over time and others collapse?; iii) which attributes of the institutions are more likely to lead to the creation of robust SESs?; and iv) how do these attributes depend on the underlying ecological system?

Anderies et al. (2004) note the difficulties in defining the appropriate scale of analysis, and give the example that a small-scale resource might collapse in order to maintain a desired function of a larger scale resource. Anderies et al. (2004) require that both social and ecological systems collapse before it is classified as a collapsed system, and this requirement allows a system's boundaries to be defined by the ecological systems that the social system extracts its goods and services from. Anderies et al. (2004) suggest that a SES is robust if the ecological systems upon which it relies are prevented from moving into a new domain, which are detrimental in the long-term to social welfare.

Four main components make-up the Anderies et al. (2004) framework: 'a resource', 'resource users', 'public infrastructure' and 'public infrastructure providers' (Figure 2.3 and Table 2.5). 'Resource users' and 'public infrastructure provider' may be the same individuals, and this is dependent on the social systems governing and managing the SES. 'Public infrastructure' features two forms of human capital – physical (engineered works, e.g. irrigation canals) and social capital (Costanza et al. 2001), which refers to the rules used by those governing, managing, and using the system, as well as those factors that affect monitoring and enforcement of those rules (Ostrom and Ahn 2003).

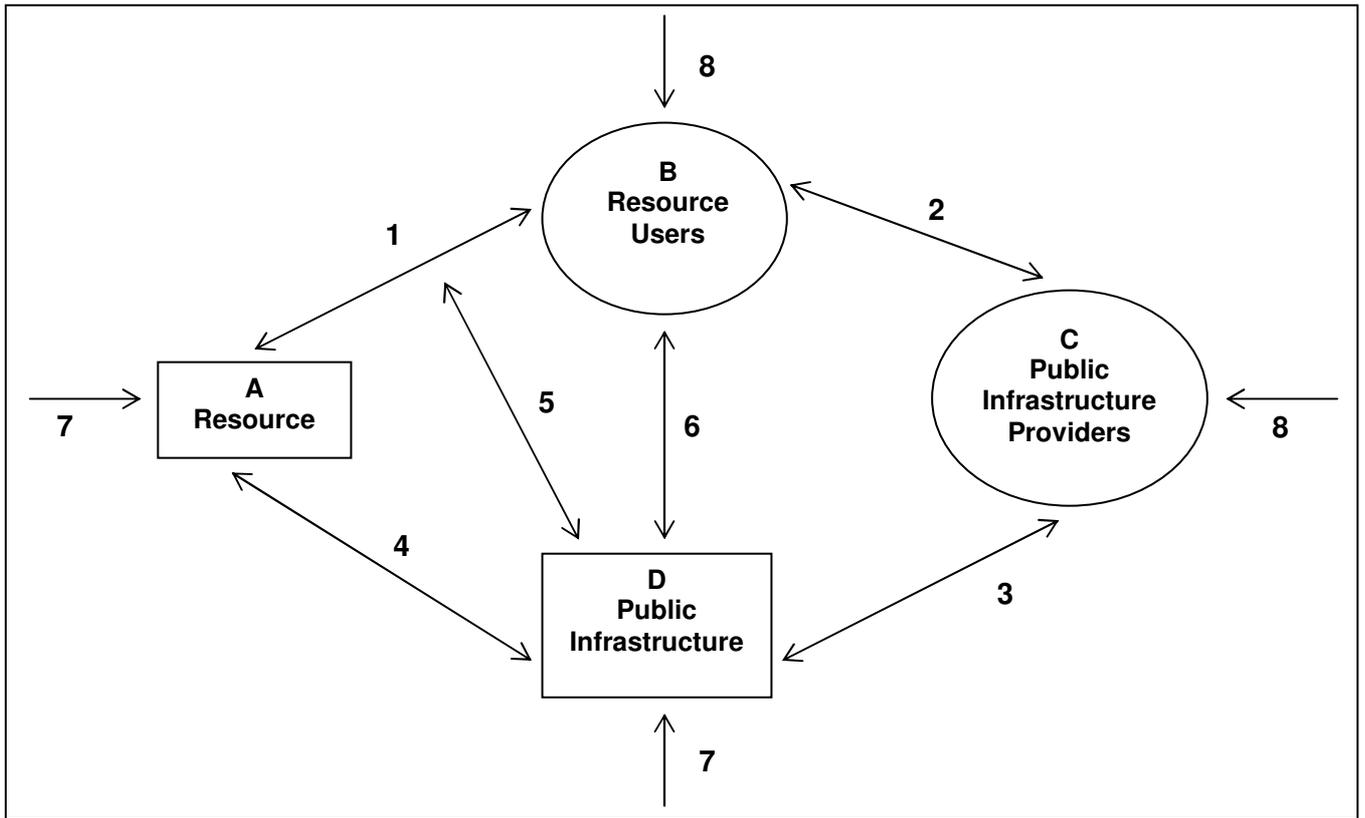


Figure 2.3. Anderies et al. (2004) conceptual model of a social-ecological system. Links 1 to 8 are described in Table 2.5

Two types of disturbances are identified by Anderies et al. (2004); external and internal. External disturbances are impacts that affect the resource and the public infrastructure (e.g. floods, climate change, new technologies) (Arrow 7), and impacts that affect the resource users and the public infrastructure providers (e.g. population increases, economic change, political changes, new job opportunities) (Arrow 8). Internal disturbances are the reorganisation of the ecological or social system caused by the subsystems of the ecological or social system.

Table 2.5. Links involved in a social-ecological system, identified by Anderies et al. (2004)

Link	Examples	Potential problems
(1) Between resource and resource users	Availability of water at time of need / availability of fish	Too much or too little water / too many uneconomic fish-too many valued fish
(2) Between users and public infrastructure providers	Voting for providers Contributing resources Recommending policies Monitoring performance of providers	Indeterminacy / lack of participation Free riding Rent seeking Lack of information / free riding
(3) Between public infrastructure providers and public infrastructure	Building initial structure Regular maintenance Monitoring and enforcing rules	Overcapitalisation or undercapitalisation Shirking disrupting temporal and spatial patterns of resource use Cost / corruption Ineffective
(4) Between public infrastructure and resource	Impact of infrastructure on the resource level	
(5) Between public infrastructure and resource dynamics	Impact of infrastructure on the feedback structure of the resource-harvest dynamics	Ineffective, unintended consequences
(6) Between resource users and public infrastructure	Co-production of infrastructure itself, maintenance of works, monitoring and sanctioning	No incentives / free riding
(7) External forces on resource and infrastructure	Severe weather, earthquake, landslide, new roads	Destroys resource and infrastructure
(8) External forces on social actors	Major changes in political system, migration, commodity price and regulation	Conflict, uncertainty, migration, greatly increased demand

2.5.4. The Ostrom (2007, 2009) framework for identifying the social and ecological variables that affect the resilience of a social-ecological system

Ostrom (2007) presents a framework to identify which variables, within both ecological and social domains, affect human behaviour, and thus the resilience of a SES over time. This framework is designed for application to a well-defined common pool resource management situation (McGinnis and Ostrom 2014). Researchers have identified a variety of different variables which affect interactions within SESs (Agrawal 2001, Ostrom 2007). Ostrom (2007) proposes organising these variables into a nested multi-tier framework (Figure 2.4). The Ostrom (2007) framework allows analyses of how the attributes of i) a resource system (e.g. grazing land); ii) the resource units generated by that system (e.g. fodder); iii) the users of that system (e.g. herders); and iv) the governance system which, combined, affect interactions (both directly and indirectly) and outcomes at a particular time and place. These are first-level variables. The framework also allows identification of how these attributes can affect and be affected by both small and large scale social, economic, political and ecological impacts.

The Ostrom (2007) framework builds on the research of Agrawal (2001) which examines the factors that affect self-organisation and robustness of common property regimes. Agrawal

(2001) identifies thirty variables in major theoretical work that have affected incentives, actions, and outcomes that related to sustainable resource governance.

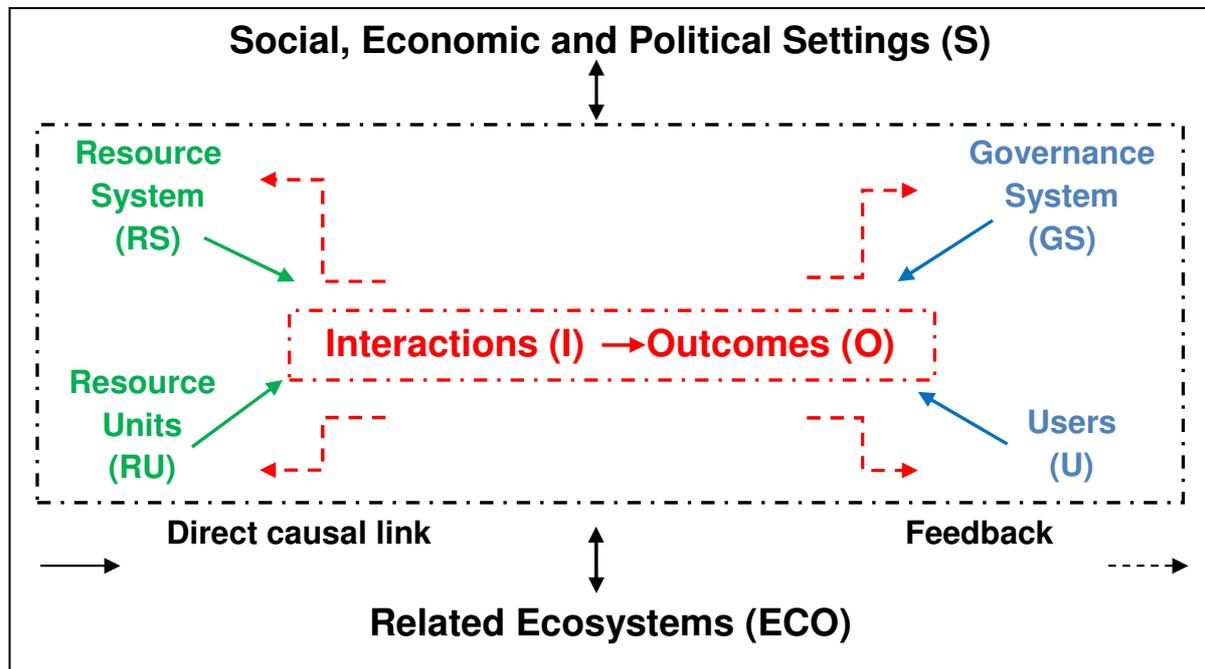


Figure 2.4. The Ostrom (2007) multi-tier framework for analysing a social-ecological system

There is a need to identify both vertical and horizontal relationships between different levels of variables within a system (Cash et al. 2006). Table 2.6 shows the major second-level variables that have been shown to impact on interactions and outcomes within a SES. This list includes all 30 variables identified by Agrawal (2001). Third, fourth and fifth level variables are only relevant when they are sub-components of a second level variable which affects interactions and outcomes (Ostrom 2007).

Table 2.6. The Ostrom (2007) major second-level variables that have been shown to impact on interactions and outcomes (NRC 2002, Mitchell et al. 2006, Moran 2006, NRC 2005, Ostrom 1999, cited in Ostrom 2007). This list includes all 30 variables identified by Agrawal (2001)

Social, Economic and Political Settings (S)			
S1 - Economic development, S2 - Demographic trends, S3 - Political stability, S4 - Government settlement policies, S5 - Market incentives, S6 - Media organisation			
Resource System (RS)		Governance System (GS)	
RS1	Sector (e.g. water, forests, pasture)	GS1	Government organizations
RS2	Clarity of system boundaries	GS2	Non-government originations
RS3	Size of resource system	GS3	Network structure
RS4	Human-constructed facilities	GS4	Property-rights systems
RS5	Productivity of system	GS5	Operational rules
RS6	Equilibrium properties	GS6	Collective-choice rules
RS7	Predictability of system dynamics	GS7	Constitutional rules
RS8	Storage characteristics	GS8	Monitoring and sanctioning processes
RS9	Location		
Resource Units (RU)		Users (U)	
RU1	Resource unit mobility	U1	Number of users
RU2	Growth or replacement rate	U2	Socio-economic attributes of users
RU3	Interaction among resource units	U3	History of use
RU4	Economic value	U4	Location
RU5	Size	U5	Leadership / entrepreneurship
RU6	Distinctive markings	U6	Norms / social capital
RU7	Spatial and temporal distribution	U7	Knowledge of SES / mental models
		U8	Dependence on resource
		U9	Technology used
Interactions (I) → Outcomes (O)			
I1	Harvesting levels of diverse users	O1	Social performance measures (e.g. efficiency, equity, accountability)
I2	Information sharing among users	O2	Ecological performance measures (e.g. over harvesting, resilience, diversity)
I3	Deliberation processes	O3	Externalities to other SESs
I4	Conflicts among users		
I5	Investment activities		
I6	Lobbying activities		
Related Ecosystems (ECO)			
ECO1 - Climate patterns, ECO2 - Pollution patterns, ECO3 - Flows into and out of focal SES			

Agrawal (2001) questions how research can be performed in a repeatable and thorough fashion with so many variables. However, it has been suggested that practitioners do not need to measure all the variables identified by Agrawal (2001), as all the variables are not relevant to every study; due to SESs being partially decomposable systems (Ostrom 2007). A partially decomposable system is a system where interactions among the subsystems are weak but not negligible (Simon 2000).

Ostrom (2007) identifies three aspects of decomposability of complex subsystems: i) the dividing of variables into classes and subclasses (each class must be understood to aid scientific understanding); ii) the identification of subsystems that are independent of one another in conducting many functions but, in time, eventually affect each other's performance (this enables policies to be explored for sections of a system without imposing the same policy on the larger system – which might result in the collapse of the whole system); and iii) a complex system is greater than the sum of its parts (this enables

practitioners to be aware of the fact that different combinations of variables can result in a variety of systems which have significantly different properties). Ostrom (2007:15183) also emphasises the need for stakeholder engagement and believes that enabling stakeholders to engage face-to-face will achieve optimal resource use, rather than exploitation “In face-to-face discussions, participants tend to discuss what they all should do and build norms to encourage conformance”.

In 2009 Ostrom presented an updated version of the 2007 SES conceptual framework, and illustrated how it could be used to help identify relevant variables (and sub-components) for studying a single SES, and that it can help identify a common set of variables for organising studies of similar SESs. Ostrom (2009) also states how the framework can be used in the design of fieldwork data collection instruments, and in the analysis of findings about the sustainability of complex SESs. The main amendments made to the original Ostrom SES conceptual framework documented in Ostrom (2009) are: the introduction of two new second-tier variables: self-organising activities and networking activities; the separation of two first-tier variables: ‘Outcomes’ from ‘Interactions’; the introduction of two-way arrows, as opposed to two separate types of arrows, to display feedback links between ‘Interactions’ and ‘Resource Units’, ‘Resource System’, ‘Governance System and Users’; and the removal of ‘Direct casual link’ and ‘Feedback’ labels.

McGinnis and Ostrom (2014) explain that the Ostrom (2007) framework is still work in progress. The article reconfirms that the conceptual framework was designed to identify basic working parts and key relationships between the different elements which require consideration when analysing SESs, and that the framework seeks to provide a coherent method for analysing complex systems which operate at multiple scales.

It is acknowledged that the Ostrom (2007) framework was originally presented as being relevant to common pool resources, however as many SESs also generate public goods and services (which includes ecosystems services), which enterprises depend on for their continued operation, the paper questions how broadly applicable the SES framework is to other applications. Hinkel et al. (2015) conclude that the original Ostrom (2007, 2009) framework has limitations when applied to complex, multi-use SES, because it does not provide a means to capture how multiple uses and benefits are connected, nor does it represent the dynamic aspects of 'resource unit' stocks and activities of actors. McGinnis and Ostrom (2014) present amendments which have been made to extend the 2007, 2009 SES framework to apply to complex SESs in which multiple actors use a diversity of

resource units, which are derived from multiple interaction resource systems where there are multiple and overlapping governance systems (Table 2.7, Figure 2.5).

Table 2.7. Summary of amendments, with explanations, made to the Ostrom (2007, 2009) framework for identifying the social and ecological variables that affect the resilience of a social-ecological system by McGinnis and Ostrom (2014)

Amendment	Explanation
'Users' substituted with 'Actors'	It is important to consider the behaviour of third parties who are not direct users or consumers of the product or service in question. This amendment is considered to greatly expand the potential application of this framework. 'Users' are now a sub-category of 'Actors'
Multiple versions of top-tier variables	Initial figures made it appear as though the framework allowed only one instance of each of the first-tier components. The amendment accentuates the need to consider multiple Governance Systems, Resource Systems, Resource Units and Actors
Introduction of 'Focal Action Situations'	This indicates that stakeholder interactions can jointly affect outcomes that are differentially viewed by those actors
Introduction of labels to summarise relationships between first-tier variables	Resource Units are now considered to be parts of the broader Resource Systems, and Governance Systems set out and define the rules for the Actors. The Resource Systems and Governance Systems set conditions for the Focal action situation. The Resource Units are Inputs to the Focal situation and Actors participate in the Focal Action Situation. These additions intend to make the framework more explicit
Change in Monitoring Activities	Monitoring Activities are now included as an Action Situation, however rules under which monitoring takes place are left under Governance Systems. This has occurred because monitoring should be considered as a form of interaction, and monitoring is distinct from monitoring rules, which are part of the Governance Systems variable
Change in Evaluation Activities	Evaluation activities are included as another Action Situation, and Outcome Criteria are specified as such due to the change with monitoring activities
Changes in list of social, political, or economic settings	Technology has been included as a potential source of exogenous shocks, and generalisation of market incentives to any factors relating to markets and government resource policies to other potentially relevant governance systems
Distinctive characteristics replaces Distinctive Markings	Distinctive Markings is more animal associated, and this is not appropriate to all possible applications
'Level' deleted	'Level' was deleted from Harvesting Levels to keep the focus on interactions rather than outcomes

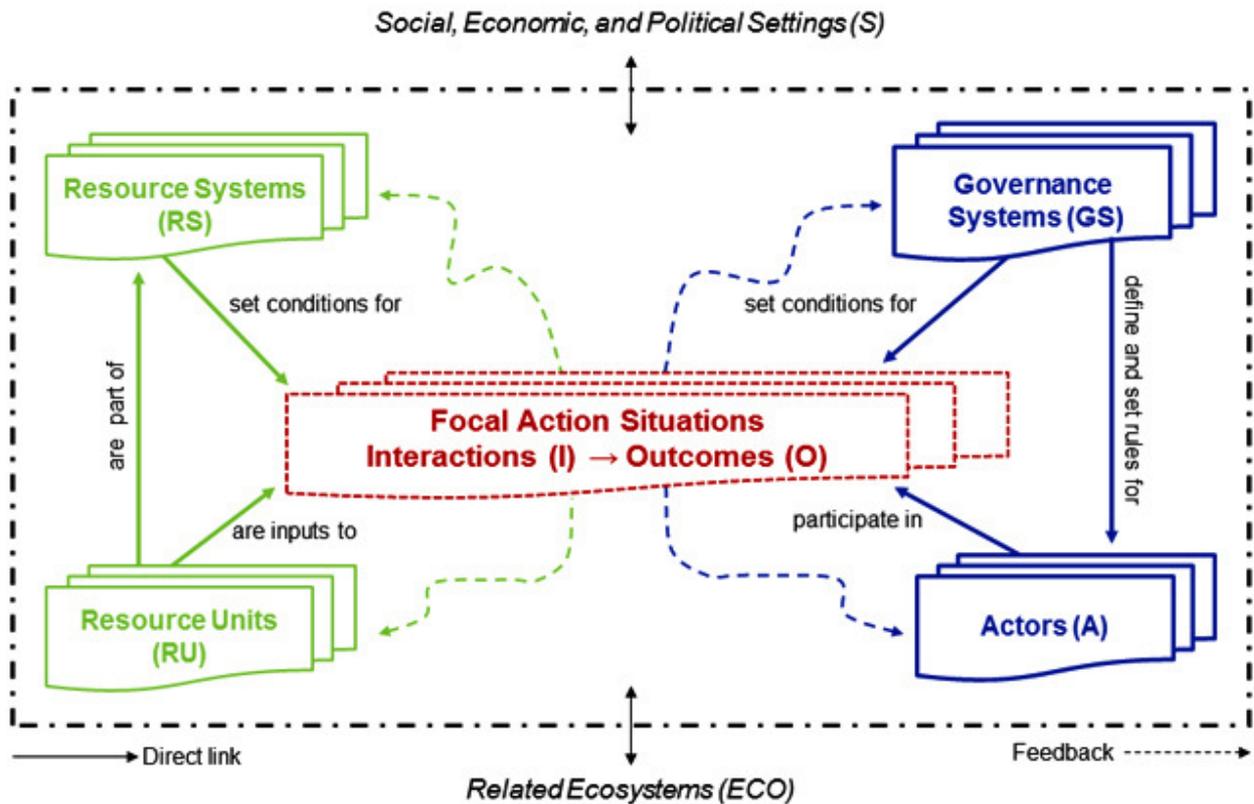


Figure 2.5. The McGinnis and Ostrom (2014) revised social-ecological system framework with multiple first-tier components

McGinnis and Ostrom (2014) are convinced that the revised framework may be applicable to the governance of artificially constructed technological systems in which users experience interaction with a social-ecological-technical system (SETS). The authors cannot specify how a SETS differs from an SES, as the social elements appear the same for both systems. They identify that there is an important distinction between the natural dynamics of ecological systems, and the built dynamic process of complex technical systems, however the differences are hard to determine, as few ecological systems do not feature human interference, and few technologies are not dependent on natural phenomena. One element they note is that the dependence on a SETS may be more in terms of a continuous supply of a services, rather than the purchase of a particular resource unit (McGinnis and Ostrom 2014).

2.5.5. The Binder et al. (2013) criteria for evaluating the effectiveness of social-ecological conceptual frameworks

Binder et al. (2013) compare ten established frameworks for analysing SESs. These largely differ in their: i) applicability, disciplinary background; ii) conceptualisation of the ecological and social systems and interactions; and iii) goals and the spatial scale addressed (Binder et al. 2013). The five criteria for evaluating their effectiveness as defined by Binder et al. (2013)

are given below, and were derived from questions which relate to issues identified by scholars when designing integrative or interdisciplinary studies.

i) Conceptualisation of the social system and its dynamics

This refers to the diversity of social (hierarchical) levels of the system (e.g. individual, group, society) that is represented, and then to the level of interaction across these levels (macro – influence of governance system on individuals vs. micro – individual decision-making and learning changes governance). It is suggested that better representation arises in a system where individual behaviour can influence the social structure and vice versa.

ii) Conceptualisation of the ecological system and its dynamics

Considers the conceptualisation of the ecological system in relation to the two opposing paradigms: the anthropocentric versus the ecocentric. The ecological system is regarded as a provider of services that increases human well-being.

iii) Conceptualisation of the interaction between the social and the ecological systems

Refers to whether the ecological system influences the social system (E→S), human activities affect the ecological system or ecosystem services (S→E), or whether the framework permits evaluation of reciprocity between the social and ecological systems.

iv) Degree to which the social and ecological systems are treated in equal depth

Analysis of the extent to which both ecological and social systems are considered in equal depth.

v) Orientation: analysis-oriented frameworks versus action-oriented frameworks

‘Analysis-oriented’ frameworks are aimed at framing research questions, and ‘Action-oriented’ frameworks are aimed at interventions.

Unfortunately the Binder et al. (2013) criteria for evaluating the effectiveness of SES conceptual frameworks were not published at the commencement of this study, as they would have been useful for determining which conceptual SESs framework to base this study on. However, the criteria were identified as being useful for evaluating the effectiveness of SES frameworks in EIA practice, and for guiding the development of any advancements of a SES conceptual framework for NRBEs.

2.6. CONCLUSION

Key elements which have been drawn from the reviewed literature are:

- Stakeholder engagement with representatives from a variety of levels (Leemans 2000) must play a key role. This engagement must adhere to the Gunderson et al. (2006) five factors for constructive communication, and transparency, to avoid issues associated with hidden agendas (Anderies et al. 2004);
- The boundaries of a NRBE SES (also considered the focal SES) must be identified, however they must not be too precise (Cox et al. 2010). The boundaries must allow for a large enough system to be considered (Walker et al. 2002), however there are concerns with obtaining sufficient information to fully understand a focal system (Cumming et al. 2006);
- Historic disturbances and the management actions in response to these disturbances should be investigated;
- The adaptive capacity of i) those responsible for operating a NRBE; and ii) those managing the natural resource a NRBE is reliant upon, plays a vital role in the resilience of a NRBE; and
- A resilient NRBE may reduce the resilience of other NRBEs and ecological resources.

The Anderies et al. (2004) SES framework will be used as the primary basis for the development of a conceptual framework to identify and assess opportunities for natural resource-based economic empowerment. This work is presented in the following chapter (as Paper 1). The Anderies et al. (2004) framework was chosen as it divides a SES into four distinct aspects which are directly relevant to NRBEs, and enables multiple users of a resource to be considered when being applied. In comparison to the Walker et al. (2002) framework and the Ostrom (2007, 2009) frameworks, the Anderies et al. (2004) framework is far less detailed, and thus is more easily transferable to the context of NRBEs. The resulting SES conceptual framework will then be applied and adapted to enhance the understanding of the resilience of a SES supporting a wetland-based craft enterprise (Paper 2). The SES conceptual framework will then be applied and adapted to an EIA setting to evaluate whether such a framework would constitute a useful tool in EIA practice (Paper 3). Finally, the resulting SES conceptual framework will be applied and adapted to build an understanding of key issues linked to the production of woody-biomass for energy generation (Paper 4).

CHAPTER 3: PAPER 1

The identification of potential resilient estuary-based enterprises to encourage economic empowerment in South Africa: A toolkit approach

Table 3.1. Summary of Paper 1

Information	Details
Title:	The identification of potential resilient estuary-based enterprises to encourage economic empowerment in South Africa: A toolkit approach
Paper status:	Published
Journal website:	www.ecologyandsociety.org/
Citation:	Bowd, R., Quinn, N., Kotze, D. C., Hay, D. G., & Mander, M. (2012a). The identification of potential resilient estuary-based enterprises to encourage economic empowerment in South Africa: A toolkit approach. <i>Ecology and Society</i> , 17(3): 15 http://www.ecologyandsociety.org/vol17/iss3/art15/
Objective(s):	<p>Develop an Ecosystem Services Framework (ESF), which has scientific and theoretical founding, which enables society to realise the benefits, both social and economic, of responsibly managing natural resources; and ii) helps identify resilient natural-resource based enterprises which could aid poverty alleviation.</p> <p>The developed ESF was required to be evaluated against the four criteria that follow. An ESF toolkit for economic empowerment must:</p> <ul style="list-style-type: none"> • be participative; • provide detailed information on ecosystem services; • consider resilience; and • accommodate complex socio-ecological contexts.
Methods used:	<ul style="list-style-type: none"> • Literature reviews on the following topics: <ul style="list-style-type: none"> ◦ the theory of SESs and the concepts of risk and resilience; and ◦ estuary-related ecosystem services and stakeholders. • Engagement with professionals to identify appropriate case study locations. • Development of an ESF using the findings of the literature review. • Testing of the ESF through workshops which comprised: <ul style="list-style-type: none"> ◦ estuary site visits; and ◦ the completion of pre-programme Excel spreadsheets though structured questioning and discussion amongst different stakeholders. • Assessing the ESF by evaluating it against the four criteria which were guided by constraints identified by Turner and Daily (2007) which hinder SEFs from becoming operational.
Key findings / outcomes of paper:	This paper documents how the theory of the Anderies et al. (2004) framework has been translated into a practical toolkit which can be used by a diversity of stakeholders as a decision-making aid for assessing ecosystem services supply and demand, and associated enterprise opportunities. Thus the toolkit addresses the hiatus between theory and practice by providing an operational decision support system for the practical integration of ecosystem services into decision-making processes. In doing so the approach initiates a process of social learning, considered critical in enhancing resilience, adaptability and transformability in complex SESs.

Research

The Identification of Potential Resilient Estuary-based Enterprises to Encourage Economic Empowerment in South Africa: a Toolkit Approach

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ABSTRACT

It has been argued that ecosystem services can be used as the foundation to provide economic opportunities to empower the disadvantaged. The Ecosystem Services Framework (ESF) approach for poverty alleviation, which balances resource conservation and human resource use, has received much attention in the literature. However, few projects have successfully achieved both conservation and economic objectives. This is partly due to there being a hiatus between theory and practice, due to the absence of tools which help make the transition between conceptual frameworks and theory, to practical integration of ecosystem services into decision-making. To address this hiatus, an existing conceptual framework for analyzing the robustness of social ecological systems was translated into a practical toolkit to help understand the complexity of social ecological systems (SES). The toolkit can be used by a diversity of stakeholders as a decision-making aid for assessing ecosystem services supply and demand and associated enterprise opportunities. The toolkit is participatory and combines both a generic “top-down” scientific approach with a case-specific “bottom-up” approach. It promotes a shared understanding of the utilization of ecosystem services, which is the foundation of identifying resilient enterprises. The toolkit comprises four steps: i) Ecosystem services supply and demand assessment; ii) Roles identification; iii) Enterprise opportunity identification; and vi) Enterprise Risk Assessment, and was tested at two estuary study sites. Implementation of the toolkit requires the populating of pre-programmed Excel worksheets through the holding of workshops which are attended by stakeholders associated with the ecosystems. It was concluded that in order for an enterprise to be resilient, it must be resilient at an external SES level (which the toolkit addresses) and at an internal business functioning level (e.g. social dynamics amongst personnel, skills and literacy levels). Although the toolkit does not address the internal resilience level of an enterprise, it proved helpful in indicating which enterprises show potential resilience given current SES conditions.

KEY WORDS: *Social-ecological systems; stakeholder engagement; participatory tools; ecosystem services; risk assessment*

INTRODUCTION

In 2008 the South African Institute for Race Relations (SAIRR) recognised that the gap between the wealthy and the poor in South Africa was continuing to increase, and that this situation was not sustainable (Hunter et al. 2003, Meth and Dias 2004). Recent studies suggest South Africa's inequality levels are amongst the highest in the world (Fosu 2011) and during the period 1993-2008, income has been increasingly concentrated in the top decile (Leibbrandt et al. 2010). Rural communities experience relatively greater poverty (Leibbrandt et al. 2010), and nowhere is this more the case than the Eastern Cape Province of South Africa, where concern has been expressed, not only in relation to standard poverty metrics (Dzivakwi and Jacobs 2010), but also to people's vulnerability to poverty (Baiyegunhi and Fraser 2010).

It has been argued that ecosystem services can be employed as both a 'common language' for ecosystem-based management (Granek et al. 2009), and as the foundation to providing economic opportunities to empower the disadvantaged (MEA 2005). Although both the wealthy and the poor rely on the functioning of ecosystems (Batabyal and Yoo 1994, Scheffe et al. 2000, MEA 2005), the poor are often more directly reliant on these goods, services and attributes than the affluent. As noted by Tallis et al. (2008:9459), "for the rural poor, at the local level, the status of ecosystem services can make a big difference in their daily lives".

The potential application of the Ecosystem Services Framework (ESF) approach for poverty alleviation, which balances resource conservation and use according to how society values consumptive and non-consumptive services provided by an ecosystem, has received much attention in the literature (Brown et al. 2008, Shackleton et al. 2008, Tallis et al. 2008). The ESF approach is currently the focus of a significant research endeavour known as ESPA (Ecosystem Services for Poverty Alleviation, see <http://www.espa.ac.uk/>). Other initiatives, such as the Natural Capital Project (see <http://www.naturalcapitalproject.org/home04.html>) have also focused on the potential for aligning conservation and economics via the ESF (Turner and Daily 2007).

However, projects that have successfully achieved both conservation and economic objectives are relatively rare. For example, in an analysis of World Bank projects that had the dual aims of poverty alleviation and biodiversity conservation, Tallis et al. (2008) found that only 16% made significant progress on both objectives. Part of the reason for this has been the hiatus between theory and practice. As suggested by Turner and Daily (2007:25), despite this attention in the literature, "an operational decision support system" for implementing an ESF has been "slow to emerge". Daily and Matson (2008:9456) put the challenge more

strongly “radical transformations will be required to move from conceptual frameworks and theory to practical integration of ecosystem services into decision-making, in a way that is credible, replicable, scalable and sustainable”.

This paper attempts to address this challenge by presenting an approach for applying an ESF to assist in the identification of opportunities for economic empowerment at two estuary study sites in the Eastern Cape province, South Africa. In so doing, it also provides an example of how an ESF can be used towards the aim of poverty alleviation.

METHODS

Selection of study sites

Estuaries, in particular, are a useful context in which to develop and test ideas regarding ESFs. Day (1980:198) defines an estuary as a “partially enclosed coastal body of water which is either permanently or periodically open to the sea, and within which there is a mixture of seawater with freshwater derived from land drainage”. Estuaries are ecosystems comprising of a number of different habitats, such as mangroves, tidal flats and reedbeds, which can provide food, building material and protection; are catalysts for residential, commercial, tourism and recreational development; and can ameliorate floods and assimilate waste (Gunderson et al. 2006, Hay 2007, Barbier et al. 2011). Estuaries are therefore complex and dynamic social-ecological systems (SES) (Anderies et al. 2004), where interactions occur between:

- ecological elements (e.g. fish-eating crabs, which eat algae, which grow on mangrove roots);
- ecological and human elements (e.g. humans abstracting freshwater upstream which reduces fish productivity); and
- human elements (e.g. provincial government building roads which allow local communities to visit estuaries).

In South Africa (Turpie and Clark 2007), and globally (Barbier et al. 2011), state that estuaries are clearly valuable economic, environmental and social assets that can provide economic empowerment, including job creation for disadvantaged people living at or near them (Turpie and Clark 2007). Many of the services provided by estuaries are taken for granted and consequently the derived benefits are undervalued. Estuaries are highly dynamic environments which are unpredictable and erratic in nature. Given their high productivity, they are often subject to very high levels of use, and given their location in the lowermost point in the catchment, are often subject to some of the greatest anthropogenic impacts.

Estuaries are also common property resources with poorly defined property rights. This complicates the allocation of opportunities and the benefits that arise from these opportunities. Securing tenure, a vital necessity for most economic developments to succeed, requires a level of sophistication that is currently in short supply in many rural parts of South Africa.

Two estuaries located in the Eastern Cape province of South Africa were chosen to apply the toolkit: the Umngazi estuary, located near to Port St. John (31° 37' 38.43"S, 29 32' 58.44"E), and the Tyolomnqa estuary, located near to East London (32° 58' 56.85"S, 27° 56' 52.70"E"). Both sites currently provide a variety of ecosystem services but differ with respect to their component social systems. The Tyolomnqa estuary's social system is large and complex, and comprises prominent local and provincial governmental bodies, non-governmental agencies and general service users (e.g. local and visiting fishermen). This system is relatively close to the urban centre of East London, and the policing of resource-use activities is high. In contrast, the Umngazi system is rural in nature and is less complex, as there are fewer stakeholders. Although local and provincial governmental bodies operate in the area, their presence is not strong. The dominant stakeholders are the local community, a well-established hotel and tourists.

Criteria for developing the ESF toolkit

The overall aim of the ESF toolkit is to provide a structured mechanism for identifying potential estuary-based enterprises, which take into consideration the dependence of human well-being on natural capital, and which consider resource conservation (Turner and Daily 2007). Turner and Daily (2007:26) identify three constraints in making an ESF approach operational. Firstly there is what they describe as 'information failure', which is the lack of detailed information about the way in which people benefit from ecosystem services, and at a scale that is relevant to decision-makers. The second is 'institutional failure'. This arises as a result of the failure to consider local socio-ecological contexts (including property rights and institutions) and the fact that those who benefit from ecosystem transformation are not the same as the recipients of ecosystem services. Finally 'market failure' arises because of the public-good nature of benefits and as many of the benefits cannot be quantified or be measured in a single currency.

Turner and Daily's (2007) critique has therefore informed the identification of a set of four criteria that could be instrumental in a successful ESF approach. The first criterion is that public participation should be an integral part. This relates strongly to 'information failure' and 'institutional failure' constraints. Secondly, it is evident that one of the fundamental attributes

of an operational ESF should be a mechanism which allows the particular services to be discussed, understood and valued in a common currency. In other words, the ESF should provide a platform for discussion by contributing detailed information on ecosystem services. Thirdly, the toolkit must have the ability to gauge a system's resilience, as the purpose of this study is to have a framework which identifies potential resilient estuary-based enterprises. Finally, the toolkit must contribute to obtaining a thorough understanding of the complex socio-ecological context. This too would help address the 'institutional failure' and the 'market failure' constraints.

An ESF toolkit for economic empowerment must be participative

In recent years stakeholder engagement has moved from being a 'marginal concern' to a 'driving force' (Lynam et al. 2007). Furthermore a dichotomy has been recognised between the commonly used 'top-down' generic scientific tools (which are frequently developed without input from the local stakeholders), and the case-specific customised 'bottom-up' tools (which are generally driven by local needs) (Fall and Fall 2001, Sturtevant et al. 2007). Gunderson et al. (2006) identify five factors for constructive communication to take place: a) the development and maintenance of open communication channels (Berkes et al. 1998, Folke et al. 2005); b) identification of the roles of the different stakeholders through scientific activities or social communication (Fazey et al. 2005); c) the designation of a meeting place at which discussions can take place between the different stakeholders; d) the establishment of trust between the stakeholders; and e) the establishment of leadership, as this is required to integrate social and ecological understanding, and to delegate responsibility to ensure that progress is made. Participation characterised by constructive communication must therefore be a central criterion.

An ESF toolkit for economic empowerment must provide detailed information on ecosystem services

An early challenge in the ecosystem services debate was defining and categorising the nature and scope of these services. For example, Hein et al. (2006) present a generically applicable framework based on earlier contributions (Pearce and Turner 1990, Costanza and Folke 1997, de Groot et al. 2002, MEA 2003). This framework defines three types of services (production, regulation and cultural). Production services refer to goods and services produced in an ecosystem (e.g. food, fuel timber); regulation services result from the capacity of ecosystems to regulate a variety of biological processes (e.g. erosion, storm protection); and cultural services relate to the benefits people obtain from ecosystems through recreation, cognitive development, relaxation, and spiritual reflection. It differs from the MEA (2003) in that it does not differentiate supporting services. Supporting services

represent the ecological processes that underlie the functioning of an ecosystem, and Hein et al. (2006) are of the opinion that the inclusion of supporting services could result in the 'double counting' of services, which would affect the valuation, as they will feature in one of the other three types of services. The Resilience Alliance (2007) modified the Hein et al. (2006) framework by adding 'regeneration services' to the regulation services. This was done to emphasise the importance of services, such as soil fertility maintenance (Resilience Alliance 2007).

In South Africa much work on describing and classifying estuary ecosystem services has been conducted. Turpie and Clark (2007) document estuary associated goods, services and attributes and define 'goods' as harvested resources (such as fish), 'services' as processes that contribute to economic production or save costs (such as water purification) and 'attributes' as relating to the structure and organisation of biodiversity (such as beauty, rarity or diversity) that generate less tangible benefits, such as spiritual, educational, cultural and recreational values.

Based on these contributions a comprehensive list of estuary ecosystem services was developed. The term 'services' has been used to encompass goods, services and attributes, as per Resilience Alliance (2007), Hein et al. (2006) and Bowd et al. (2012). Each of these services is related to the presence of suitable estuary habitat(s) and consequently it was important to identify the full range of estuary habitats. From conducting a brief literature review on the ecological functioning of South African estuaries, it became apparent that ten habitat types could be identified (Branch and Grindley 1979, Allanson 1981, Baird 1999, Colloty et al. 2002), each of which was associated with one or more services (Table 1).

Table 1. Comprehensive list of estuary habitats and associated ecosystem services found in South Africa (Y = yes, N = no)

Ecosystem Services	Estuary Habitats									
	River estuary interface	Mangroves	Reedbeds	Salt marshes	Open water & water column	Intertidal banks	Intertidal flats	Temporarily submerged sediments	Permanently submerged sediments	Estuary mouth
Goods										
Bait harvesting	N	Y	N	Y	Y	Y	Y	Y	N	Y
Fibres	Y	Y	Y	Y	N	Y	N	N	N	N
Food	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Minerals	Y	Y	Y	Y	N	Y	Y	Y	Y	N
Nursery for fish / crustacean species	Y	Y	Y	Y	Y	Y	Y	Y	Y	N
Sediment supply	N	Y	Y	Y	N	Y	Y	Y	Y	Y
Services										
Boat launching and transport	Y	N	N	N	Y	Y	N	N	N	Y
Disease control	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Flood and storm flow attenuation	Y	Y	Y	Y	Y	Y	Y	N	N	Y
Pest control	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Waste assimilation	Y	Y	Y	Y	Y	Y	Y	Y	Y	N
Waste dilution	Y	Y	Y	Y	Y	N	N	N	Y	Y
Wind damage control	N	Y	Y	Y	N	Y	N	N	N	N
Attributes										
Angling	Y	Y	Y	N	Y	Y	Y	Y	Y	Y
Birding	Y	Y	Y	Y	Y	Y	Y	Y	N	Y
Canoeing	Y	Y	Y	N	Y	Y	Y	N	N	Y
Cultural places	Y	Y	Y	Y	Y	Y	Y	Y	N	Y
General recreation	Y	Y	Y	Y	Y	Y	Y	N	N	Y
Knowledge generation and learning sites	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Natural Heritage	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Sailing	N	N	N	N	Y	N	Y	N	N	Y
Settlement	Y	N	N	N	Y	N	N	N	N	N
Visual amenity	Y	Y	Y	Y	Y	Y	Y	N	N	Y
Swimming	Y	N	N	N	Y	Y	Y	N	Y	Y
Skiing	N	N	N	N	Y	N	Y	N	N	N

An ESF toolkit for economic empowerment must consider resilience

As all ecosystem services are subject to the influences of natural and anthropogenic processes that are highly variable, supplies of services are seldom uniform. Whilst some services may seem to be constant over time, others can exhibit wide variations, even over short timescales. Thus every enterprise that is founded on ecosystem services must anticipate changes over time and space as a consequence of both natural and human influences. Some of these influences may be controlled by society (e.g. pollution); however others (e.g. large floods) cannot. The viability of ecosystem-based enterprises will equally be influenced by fluctuations in the demand for services (see Baumgärtner et al. 2011 for an interesting discussion on the relationship between consumer preferences and resilience of ecological-economic systems). These demands may be very variable over time and in space, and furthermore, not all demands are compatible. Neither can they necessarily be accommodated at the same time, and in the same place. This lack of control of interaction places resilience at the forefront of conceptualising, designing, establishing and operating estuary-based enterprises. We define resilient estuary-based enterprises as those that are able to continue profitably under conditions of varying supply of, and demand for, the services upon which they are dependent. Necessarily this needs to be contextualised within the broader debate around resilience, adaptability, and transformability in social-ecological systems (Walker et al. 2004, Folke et al. 2010).

Since the 1970s a variety of definitions and interpretations of resilience have appeared (Pimm 1991, Grimm and Wissel 1997, Neubert and Caswell 1997, Walker et al. 2004). Ecological resilience is generally defined as the amount of disturbance that a system can absorb without a change in its 'state', usually defined by its structure and composition (Carpenter et al. 2001, Walker et al. 2006, Holling 2010). A resilient estuarine system is a system which can continue to provide the necessary services, which are utilised by the different stakeholders, even after times of stress (e.g. ecological conditions allow fish stocks to recover after extensive fishing during the previous season).

An estuary can be impacted upon by both natural events and human actions (which include human interventions which occur in response to natural events (e.g. implementation of bank stabilisation measures)). In order for an estuary to be considered resilient it must retain its state. As an estuary supplies a wide range of services to a variety of stakeholder groups, it is unlikely that at any one time there will be consensus amongst the different stakeholders that an estuary has retained its state, and is thus resilient.

There were a number of reasons why the concept of resilience is seen as being key to the approach. Firstly, resilience has been applied widely to SESs and is increasingly being used to help understand, manage and govern complex SESs (Walker et al. 2002, Anderies et al. 2004, Folke et al. 2004, Ostrom 2007). For example, it has been applied to political ecology and resource management (Berkes et al. 1998, Berkes 1999), as well as to a variety of specific ecosystems which include: rangelands (Anderies 2002, Janssen et al. 2004); lakes and wetlands (Gunderson 2001, Olsson et al. 2004); coral reefs (Hughes et al. 2005); a protected area (Newton 2011) and an evolving urban system (Bures and Kanapaux 2011).

Secondly, resilience theory suggests that the major entities of an SES, and the level at which they interact, are identified through methods that involve constructive communication between experts and stakeholders who understand the SES at different scales and perspectives (Walker et al. 2002, Westley et al. 2002). Thirdly, resilience theory emphasises the need to consider human adaptability (Gunderson and Holling 2002, Walker et al. 2006). Human adaptability is the capacity of humans to manage for resilience; indeed collective capacity to manage resilience ultimately determines the future state of the SES (Walker et al. 2004). Human adaptability is therefore key in assessing the resilience of an enterprise and the SES on which an enterprise is dependent. Transformability has been defined as the “capacity to create a fundamentally new system when ecological, economic or social (including political) conditions make the existing system untenable” (Walker et al. 2004). This includes “introducing new components and new ways of making a living” that define the nature of the SES (Walker et al. 2004), so the concept is particularly relevant in defining resilient estuary-based enterprises.

An ESF toolkit for economic empowerment must accommodate complex socio-ecological contexts

Folke et al. (2010) argue that social-ecological resilience is concerned with the interdependence of people and nature, and furthermore that an ability to effect social change is necessary for SES resilience. The implication of this is that not only do we need to understand the present nature of the SES, but also how this SES might adapt or transform in the future. We show how an existing framework can be used to establish these relationships and use them in a process of social learning. Anderies et al. (2004) present a framework for analysing the robustness of SESs from an institutional perspective. This framework provides a mechanism for disaggregating the entities of a SES and promotes the identification of the relationships between the different entities. The SES is separated into the following four entities: (a) the resource; (b)

the resource users; (c) public infrastructure and (d) public infrastructure providers, and considers two types of disturbance, external and internal (Figure 1). Table 2 provides examples of each of these entities, together with the typical management challenges that characterise them, while Table 3 explores the links between each entity and their associated problems. Table 2 and 3 are taken directly from Anderies et al. (2004). Although the Anderies et al. (2004) approach is based on 'robustness' and not resilience, we do not need to distinguish between the two as we consider robustness and resilience to have the same attributes for the purposes of this study.

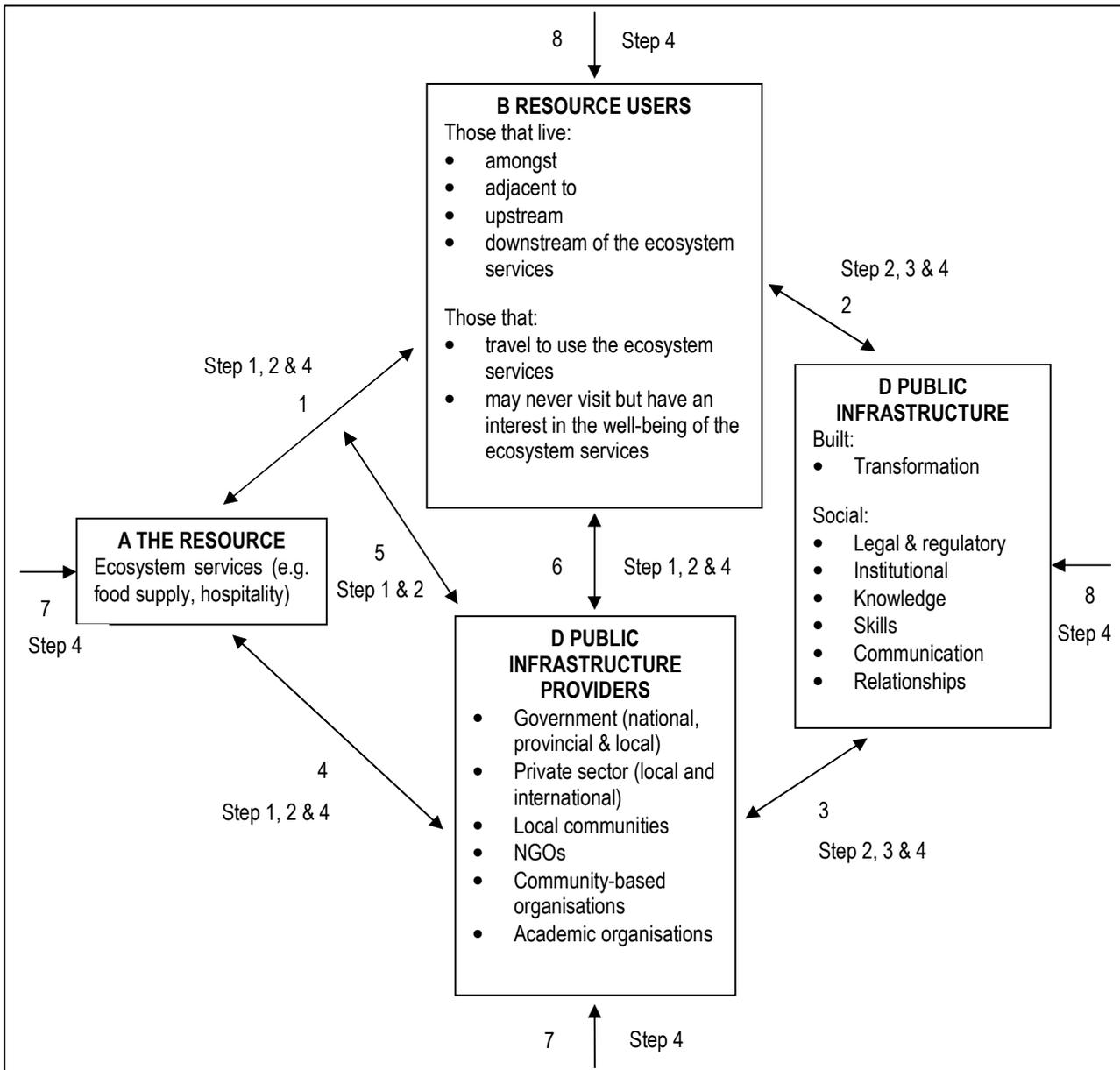


Figure 1. Adaptation of the Anderies et al. (2004) conceptual social-ecological system framework showing (i) examples of how it relates to an estuarine system as presented in R. Bowd, N. W. Quinn, D. C. Kotze, D. G. Hay, and M. Mander (*unpublished manuscript*); and (ii) how the toolkit links with the Anderies et al. (2004) framework in which Step 1 - ecosystem services supply and demand assessment; Step 2 - future estuary roles identification; Step 3 - enterprise opportunity identification; Step 4 - enterprise risk assessment

Table 2. Entities involved in social-ecological systems together with examples and potential problems as identified by Anderies et al. (2004)

Entities	Examples	Potential problems
A. Resource	Water source	Uncertainty
	Fishery	Complexity / uncertainty
B. Resource users	Farmers using irrigation	Stealing water, getting a free ride on maintenance
	Fishers harvesting from inshore fishery	Over harvesting
C. Public infrastructure providers	Executive and council of local users' association	Internal conflict or indecision about which policies to adopt
	Government bureau	Information loss
D. Public infrastructure	Engineering works	Wear out over time
Institutional rules	Memory loss over time, deliberate cheating	-
External environment	Weather, economy, political system	Sudden changes as well as slow changes that are not noticed

Table 3. Links between the different entities within social-ecological systems, together with examples and potential problems as defined by Anderies et al. (2004)

Link	Examples	Potential problems
(1) Between resource and resource users	Availability of water at time of need / availability of fish	Too much or too little water / too many uneconomic fish – too many valued fish
(2) Between users and public infrastructure providers	Voting for providers Contributing resources Recommending policies Monitoring performance of providers	Indeterminacy / lack of participation Free riding Rent seeking Lack of information / free riding
(3) Between public infrastructure providers and public infrastructure	Building initial physical structure Regular maintenance	Overcapitalisation or undercapitalization Disrupting, temporal and spatial patterns of resource use Cost / corruption
(4) Between public infrastructure and resource	Monitoring and enforcing rules Impact of infrastructure on the resource level	Ineffective
(5) Between public infrastructure and resource dynamics	Impact of infrastructure on the feedback structure of resource-harvest dynamics	Ineffective, unintended consequences
(6) Between resource users and public infrastructure	Co-production of infrastructure itself, maintenance of works, monitoring and sanctioning	No incentives / free riding
(7) External forces on resource and infrastructure	Severe weather, earthquake, landslide, new roads	Destroys resource and infrastructure
(8) External forces on social actors	Major changes in political system, migration, commodity prices, and regulation	Conflict, uncertainty, migration, greatly increased demand

Developing the ESF toolkit: Structure

The toolkit comprises four steps which are supported using a pre-programmed Excel worksheet, linked with the four entities of the Anderies et al. (2004) framework (Figure 1). The Excel worksheet and toolkit manual have been published by the South African Water Research Commission (Bowd et al. 2012). This publication presents the practical, stakeholder-informed application of this research and provides useful insight into how the ESF could be further applied.

Step 1: Ecosystem services supply and demand assessment

This step requires that the estuary habitats present are confirmed and their functionality assessed. The functionality, and thus health, of an estuary's habitats is directly related to its ability to supply ecosystem services. In order to identify the estuary habitats, the boundaries of the SES first need to be identified (e.g. areas accessible on foot from the estuary mouth). The functionality of each of the habitats is then calculated, by assessing its condition (0 – 3, three being the best condition), size (area given in ha) and prominence of the ecosystem within the landscape (0 – 3, three being the most prominent). While condition and size are the key determinants of service levels, the landscape context is less important and so is only weighted at 10% of the other two scores in the functionality calculation.

Next, the level of supply of the ecosystem services associated with each of the different habitats is scored (0 – 3, 3 being high, 0 being no supply). The scores are given as if the habitats are pristine. The service supply score is then multiplied by the functionality score, to give a relative service supply level for each service. It is recommended that the issue of seasonal variations in the supply of services is raised before scoring commences. It may be assumed that those services which have a high overall supply level are the services around which enterprises should be based.

Whereas the previous is concerned with the supply of services, the next step focuses on the potential demand for services. Service demand at the local, downstream, provincial, and national and international levels are estimated. Estimated figures of users are shown as orders of magnitude (e.g. 0, 100, 1000). Following this the users of the services are listed, followed by the dependence of each of the different services being scored between 0 (no impact on welfare) and 3 (critical for welfare).

As the toolkit is presented in a pre-programmed Excel worksheet, the following information is automatically calculated for each service: total supply score, total number of beneficiaries, average dependency, total demand summary, and combined total score. These data are then consolidated for use in Step 2.

Step 2: Future estuary roles identification

The endpoint of the previous step is a ranking, in order of priority, of services which currently have high supply and low demand at a local, downstream, provincial, and national and international level. Using the knowledge and common understanding of the status quo gained through implementing Step 1, the desired roles for the estuary and possible conflicting uses (at local, downstream, provincial and national and international levels) are then determined through discussion. Where supply is low (either intrinsically or due to poor ecological condition) but demand is high should be identified as this could indicate potential management actions which in themselves could represent enterprises (e.g. restoration).

Step 3: Enterprise opportunity identification

The worksheet associated with this step provides space to document discussions around current and desired roles of the estuary, and possible conflicting uses. The worksheet provides different types of service use and possible estuary management categories to assist with identifying possible enterprise opportunities.

Step 4: Enterprise risk assessment

This step is supported by two worksheets and is conducted for each enterprise. This step consists of a variety of questions which demonstrate the nature of possible relationships that may operate amongst the four entities of a SES (as identified by Anderies et al. 2004). Also included in this matrix are the external biophysical, social and economic forces that may generate perturbations in a SES. The questions are based on those compiled by R. Bowd, N. W. Quinn, D. C. Kotze, D. G. Hay, and M. Mander (unpublished manuscript) who used the Anderies et al. (2004) framework to develop an analytical framework for understanding complex SES when conducting Environmental Impact Assessments in South Africa (Table 4).

Table 4. Risk Assessment (Source: Bowd et al. 2012)

Relationships	Nature of the risk
Relationship between resources users	
Could some resource users deplete the resource and are they reliant on the resource, thus making it difficult to change patterns of use?	Resource depletion
Are there current conflicts between and / or within the different user groups?	Inability to manage excessive resource utilisation
Is the resource and its available services located within a clearly defined spatial boundary that can exclude users without legal rights?	Cannot enforce the right of exclusive use by owners
Are the people with rights to resource use a clearly defined group separate to those without rights of resource use?	Cannot enforce the right of exclusive use by owners
Does everybody in the community with user rights participate in the resource use?	Unequal incentives for community to manage the resource
Are there good relationships between all the users who have a right of use?	Prohibitive transaction costs in establishing resource management
The infrastructure, economic, social and institutional assets available	
To what extent is the built infrastructure developed and maintained?	Poor quality infrastructure can limit access
Considering current infrastructure, is user safety secure all year round?	Threat to personal security
Does the built infrastructure meet current demand for access (the type, size and quality of infrastructure)?	Unsatisfactory access to the site
What are the levels of skills (education, knowledge, communication, hospitality) amongst the resource users?	Inadequate skills to anticipate and resolve problems
What are the levels of skills (education, knowledge, communication, hospitality) amongst the resource managers / government?	Inadequate skills to anticipate and resolve problems
How adaptable are the resource users to i) changes in the availability of the resource; ii) changes in demand; iii) pursuing other activities to sustain livelihoods etc.?	Poor adaptability to change
What rules of law (local, provincial, national, international) are applicable to the resource users?	Partial application of laws
To what extent are these rules of law enforced?	Uncertainty for investors and users regarding their investments
To what degree are cellular, telephone, email, and fax facilities available to the resource users; and to what degree are these facilities necessary?	Poor communications – no access to market
Resources for management	
To what degree is government contributing to the management of resource users with regards to: i) the resource; ii) research; iii) infrastructure; iv) skills / knowledge; v) security; vi) communication?	Public services not being supplied to management – with risks to resource depletion
Impact of infrastructure on resource levels	
What are the impacts of i) knowledge / skills; ii) infrastructure; iii) security / governance; and vi) communication on the resource?	Depleted resources

Policy implications

What policies are applicable to the resource users and what implications do these policies have on the resource users?

To what extent do these policies give i) adequate protection to the resource; ii) give adequate security (i.e. access, availability) of the resource to the resource users?

Lack of investors

Diminished access to resources

Integrated implementation of developments

Are there conflicts between government actions and / or government infrastructure?

Reduced or limited access to enterprise inputs

Monitoring the state of the asset

To what extent is the state of the resource monitored and who is responsible for this monitoring?

Inadequate knowledge for effective resource management

Is there evidence of monitoring, and if so to what extent, are the findings of any monitoring efforts used to evaluate management, and thus influence future actions (adaptive management)?

Management is not responsive to changes

Co-management of built or natural assets

How adequate is the co-operation between the resource users and government to manage the i) built environment; ii) social / cultural environment; iii) natural environment?

Poor operating environment for enterprise - heightened uncertainty for entrepreneurs

Can upstream resource users, who may influence the ecosystem functioning, and therefore the supply levels of services, be excluded or influenced?

Asset can be run-down – with diminished services availability

Capacity and competency to implement policy

What policies are applicable to public and private infrastructure and to what degree are these policies implemented?

No support for enterprises from government

Inter-government communication

Is there sufficient communication between different government tiers and departments?

High costs to do business

Droughts, floods, changes in supply of resource services

What is the nature of severe biophysical impacts on the resource and what is the significance and frequency of these impacts?

Inability to supply services demanded

Disregard for resource fluctuations

To what degree do resource users plan for fluctuations, and is this planning adequate?

Insufficient revenue to cover costs

Droughts, floods, wash-aways, destroyed communications

To what degree do external shocks damage public infrastructure with regards to: knowledge, skills, aids, natural disasters, over exploitation of resource, establishment or non-maintenance of infrastructure, communication?

Prevention of clients accessing the enterprise site or threats to user safety

To what degree are these external shocks managed / prepared for (i.e. insurance, forward planning)?

Insufficient revenue to cover costs

Poverty and affluence – over-use and exclusion

To what extent does poverty and / or affluence influence / affect over-use and exclusion of the resource?

Can one user group's actions reduce the levels of services available to a different user group?

Do high transaction costs exclude key stakeholders from the decision-making process?

Asset can be run-down, diminished services

Asset can be run-down, diminished services

Unequal incentives to manage the resource

Conflict, crime, uncertainty, changes in demand

Are there social and economic forces, such as conflict, crime (internal and external) and interest rates which can limit the demand by the resource users?

Have the rules of resource use and benefit sharing been understood and agreed to by all people who have rights of use before use commences?

Reduced numbers of clients

Effort can be unrewarded – abandonment of enterprise

Increased use pressures

Are there external social and economic forces (e.g. water provision, housing) creating pressure on available infrastructure that impacts on natural resource-based enterprises?

Asset can be run-down, diminished services

Effectiveness of governance

Does government have capacity / skills to cope with social and economic shocks to resource linked assets (resource, access, infrastructure)?

Are the rules of access and management duties well understood by all resource users?

Prevention of clients accessing the enterprise or threat to personal safety or security

Asset can be run-down, diminished services

The first worksheet requires that the severity and likelihood of each risk is scored (0-3 with 3 being very severe). A risk with a high severity of impact and a high likelihood of occurrence is considered to pose a major risk to enterprise resilience. The severity and likelihood scores are then summed to provide a semi-quantitative value for each risk.

The second worksheet automatically ranks the risks according to the magnitude of risks identified previously. Once ranked, the priority risks are then assessed and mitigating actions identified and noted. If severe risks cannot be mitigated, then the proposed enterprise has a strong possibility of failure.

TESTING THE TOOLKIT

As recommended by Pickett et al. (1999), Scheffer et al. (2000), Anderies et al. (2006) and Sturtevant et al. (2007), a multidisciplinary team was involved in developing and testing the approach, including ecological, economic and social scientists. Criteria 2 and 4 encourage the involvement of a diverse team. The opinions from the different disciplines helped gain a comprehensive and common understanding of the different ecosystem services, and different aspects of the SES.

Criterion 1 highlights the importance of a participative approach; and as such the toolkit is primarily based on stakeholder engagement. Leemans (2000) identifies stakeholder groups at a number of different levels. For the implementing and testing phase we adopted the following:

- Individual, family and municipal stakeholders were grouped as 'local level' stakeholders (knowledge from this group is considered invaluable when obtaining a sound understanding of the dynamics of a SES (Olsson et al. 2004));
- A downstream level of stakeholder was introduced; this group refers to those who utilise services which could be negatively affected by activities upstream. This group is likely to be individuals and families, however in some instances it may include international, national, provincial and municipal level stakeholders;
- Provincial and national level stakeholders, including government departments (e.g. National Department of Environmental Affairs); and
- International level stakeholders, including international conservation non-governmental organisations (e.g. World Wildlife Fund).

Walker (1992) believes that the greater the diversity of stakeholders involved in a process, the

greater the chance of understanding the resilience of a system. This mix of stakeholder groups comprises the social component of the SES, and thus contributes to addressing criteria 3 and 4.

The toolkit was applied at Umngazi over two, two-day workshops, and at Tyolomnqa over one, two-day workshop. A full suite of stakeholders were identified through discussions with key stakeholders in the relevant areas (government departments, established enterprise owners) and review of estuary-related reports commissioned by the South African Water Research Commission. The identified stakeholders were personally invited to the workshop by phone, post or email. At both study sites a wide variety of stakeholders attended and actively participated in the workshops (Table 5).

Table 5. Concise results from testing the toolkit at Umgazi estuary and the Tyolomnqa estuary workshops

Information	Umgazi estuary		Tyolomnqa estuary	
Representatives present:				
National government	Yes	National Environmental Department	No	N/A
Provincial government	Yes	Provincial Development Agency	Yes	Provincial Conservation Department
Local government	Yes	Local Municipality	Yes	Local Municipality
Private business interests	Yes	Hotel representative, horse trail guide	No	N/A
Non-governmental organisations	No	N/A	Yes	Wildlife and Environment Society of South Africa
Community representatives	Yes	Umgazi Community	Yes	Tyolomnqa Community
Tribal authorities	No	N/A	N/A	N/A
Research / academic institutions	Yes	Two South African Universities, Water Research Commission	Yes	South African University, Water Research Commission
Step 1: Possible estuary-based enterprises (where there is high supply and low demand, low supply and high demand or high supply and high demand for services)	Bird watching Restaurant Crayfish factory Craft production Canoe trails Village accommodation (as part of a destination package) Labour intensive government funded estuary rehabilitation programme	Block making Bee keeping Sand mining Horse trails	Seaweed harvesting Residential settlements Fishing Boating Canoeing (races and recreational) Wilderness camp Brick making 4x4 trails	
Steps 2 and 3: Priority enterprises determined through discussion on current, desired and conflicting roles	Canoe trails Village-based tourist accommodation Labour intensive government funded estuary rehabilitation programme	Horse trails	Boating 4X4 trails Wilderness camp	
Step 4: Chosen enterprise for Risk Assessment	Village-based tourist accommodation		Wilderness Camp	
	Main risks	Mitigation	Main risks	Mitigation
	Communication difficulties	Establish internet linkages with the nearby established hotel	Intensity of users is controlled by provincial and national government departments which lack regulating capacity	Improve regulatory capacity of provincial and national government departments. However this is unlikely to occur in the short term
	As tourists like being close to the beach, communities	Sell a package which includes visiting the beach	Poor legislation implementation has resulted in poor water quality standards due to informal	Improve maintenance of waste water treatment works and establish formal sanitation for the informal

located inland
are less likely to
benefit from
tourists

Declining quality
of attractions
due to sand
mining

Improve community
awareness of the importance
of a healthy ecosystem, and
the long-term consequences if
sand mining continue

settlements being located
near to the estuary and the
nearby waste water
treatment works not being
adequately maintained
Access to the estuary is
limited and security is poor

Approximately 50% of the
river has been transformed
and as a result bank
stabilisation for development
has caused habitat
destruction

settlements. However limited
funds are available

Remove illegal fencing along
the estuary and improve
security presence. However
limited funds are available
for these operations
Municipality to take back
control of the banks and
rehabilitate. However limited
funds are available for this
operation

At each study site the first step was to define the boundaries of the SES¹. This helped gain a collective understanding of the SES amongst the different stakeholder (and helped address criterion 4). This was done by the stakeholders visiting the estuarine system and then continuing to discuss the success and failure of past and present estuary-based enterprises, possible reasons for this success or failure, the supply and demand of the estuary services and potential enterprise opportunities. Site visits facilitated a greater understanding of the system being considered, and promoted a shared understanding of the different ecosystem services provided by the estuary (Deconchat et al. 2007). The site visit and discussions contributed to addressing criterion 2.

Following the site visits, workshops for the stakeholders were held where the project team methodically introduced and applied the toolkit. Although the toolkit provided structured questions, discussions around the different questions and between the different stakeholders were encouraged in order to gain a greater understanding of the SES, and especially to enable different stakeholders to understand each other's perspective. This helped address criteria 1, 2 and 4.

In an effort to promote inclusivity at the workshops, when one stakeholder group dominated a response the facilitator would directly ask the other stakeholder groups whether or not they agreed with the dominant stakeholder group's viewpoint. This promoted discussion, ensured all participated and helped gain a shared understanding of a situation. At both sites the provincial level planning authorities were generally more dominant and enthusiastic in comparison to other stakeholders. At Umngazi the provincial level authorities showed a keen interest in the indigenous knowledge communicated by the local community, and frequently asked for the community to expand on information when they did not initially grasp what was being said.

Step 1 of the toolkit, which took place at the beginning of the workshops and which forced the stakeholders to work together to collectively ascribe scores, significantly contributed to the positive interactions which were observed between the stakeholders for the duration of the workshop. These good relations were most valued when populating the risk assessment and when potentially sensitive issues needed to be discussed (e.g. the local community at Umngazi had to explain that there was a lack of service delivery from local government).

Although some discussions were very technical and difficult to be understood by all (e.g. at Umngazi the community members struggled with understanding data presented by a university student researching estuarine benthic organisms), this lack of understanding did not cause

¹ It is recognised that gaining a collective understanding of a systems' boundaries amongst different stakeholders is potentially problematic, however this was explicitly addressed in this case with a joint site visit involving all stakeholders at the commencement of the stakeholder engagement process.

resentment, but was in fact a source of amusement for all when scientific information was explained, which helped connect the stakeholders. At Umngazi this positive response to knowledge sharing was confirmed, when after the workshop the community told the facilitator that the toolkit had “opened their eyes to the importance of the estuary, how it worked, and the opportunities it held”.

Through implementing Step 1 at the Umngazi estuary, a total of 12 possible estuary-based enterprises were identified. Through implementing the subsequent steps, four were identified as priority enterprises (Table 5). The village-based tourist accommodation (as part of a destination package) was selected for the risk assessment as the consensus of the stakeholders was that this enterprise would benefit a greater proportion of the community compared to the canoe and horse trails. In addition, the success of the accommodation enterprise predominantly rested with the community and the management of the well-established and successful hotel, thus its success was semi-controlled by the stakeholders. Although an estuary rehabilitation programme (labour intensive alien plant removal), which the provincial level planning authorities were initially favouring, has the potential to result in a larger cash injection into the community in the short-term, similar programmes have been established in the area and, due to inconsistent implementation, the community was wary of these types of enterprises. Although a number of risks were identified for the accommodation, possible actions to reduce these risks were provided (Table 5).

Through implementing Step 1 at the Tyolomnqa estuary, a total of eight possible estuary-based enterprises were identified. In working through the remaining steps there was consensus between the stakeholders that a wilderness camp would be used in Step 4 (Table 5). A wilderness camp at Tyolomnqa had previously failed, and the attendees were keen to know the reason for its failure, and if any mitigation measures could be implemented to improve its chances of survival if it was resuscitated.

It was concluded that the identified risks were of a magnitude which could not be mitigated or easily controlled without a combination of improved regulatory capacity and the sourcing of alternative non-municipal funds. As the potential for implementing these two mitigation measures could not be accurately assessed with only those in attendance, the wilderness camp was not pursued further.

When the risk assessment concludes that an enterprise does not show potential resilience, the risk assessment can be repeated to assess an alternative enterprise. However, in this instance the identified risks at Tyolomnqa (which included a lack of regulating capacity, poor water quality standards, habitat destruction, limited access and poor security) are likely to affect the supply of the services on which any estuary enterprise is based. The risk assessment highlighted to the provincial planning authority representatives at the workshop, that in order to give an estuary-based enterprise

the greatest chance of survival, some or all of the identified risks should be addressed before any new enterprise is pursued.

The provincial planning authority at Tyolomnqa could see value in the approach and in reflecting on a potential wider application. They were of the opinion that the toolkit could be:

- run for each estuary in the province in order to compare and highlight which estuaries offer the highest service levels, and thus where development should be focused;
- used to match activities to the most appropriate estuary, as implementing the toolkit effectively revealed how different activities were matched to the estuary; and
- used to guide policy making and demonstrate the need for compliance, as the implementation of the toolkit highlighted specific policy needs for the estuary (e.g. development control) and where the greatest specific needs were for compliance (e.g. water quality).

At both sites the use of numerical values as relative measures in the toolkit helped to objectively select which enterprises should be selected for the risk assessment, as the scores were ascribed with consensus from the stakeholders in attendance. Having a broad scope of enterprises which need to be scored helped prevent the stakeholders getting fixated on one particular enterprise. In addition, numerical illustration steered discussions towards obtaining relevant qualitative data, thus time was not lost on irrelevant discussions.

In summary, the workshops identified that there are significant opportunities for the establishment of estuary-based enterprises that could act as catalysts for economic empowerment. However, currently the public service infrastructure providers (primarily local government) are either unwilling or unable to provide the necessary support required to improve the likelihood of an estuary-based enterprise being resilient. It is here where the major risks lie.

The purpose of the toolkit is to help identify potential resilient enterprises. Although all four steps within the toolkit contribute to identifying potential resilient enterprises, it is Step 4 (risk assessment) which gauges the resilience of an enterprise. Thus the implementation of the risk assessment contributed towards addressing criterion 3.

DISCUSSION

In this section we consider application of the toolkit in view of the four criteria which were guided by Turner and Daily's (2007) critique.

An ESF toolkit for economic empowerment must be participative

The first constraint identified by Turner and Daily (2007) was that of 'information failure'. The toolkit addresses this constraint because it is participant-focused and promotes direct communication between the different stakeholders, some of whom are decision-makers. The toolkit combines both a generic 'top-down' scientific approach (as the pre-programmed worksheet and risk assessment are founded on theory and scientific knowledge), with a case-specific 'bottom-up' approach, which is obtained through a diversity of stakeholders actively engaging in discussion and reaching consensus on the scoring of the supply and demand of ecosystems services at a site-specific level. A facilitator is required to collate, interpret and concisely present the information from the workshops, but this nevertheless represents a process aimed at bringing indigenous knowledge and science together to foster social-ecological system resilience (Bohensky and Maru 2011).

This extent of dialogue clearly results in better decisions being made. For example, at the Umngazi study site, the results of implementing the ESF framework indicated that an estuary rehabilitation programme would have created greater economic upliftment compared to the community-based accommodation. However the community was strongly against this type of enterprise as similar initiatives had failed in the past. It is likely that without the participation of the community and the testing of the toolkit, decision-makers would have pursued the estuary rehabilitation programme. Based on the negative reactions of the community, it is likely that this enterprise would not have been supported.

Through applying the toolkit a number of participatory lessons were learnt. These lessons have been tabulated and have been grouped into i) facilitator; ii) stakeholder; and iii) workshop procedure lessons (Table 6). Bohensky and Maru (2011) have recently reviewed the challenges and achievements in bringing indigenous knowledge and science together and a number of 'key lessons' presented in Table 2 of Bohensky and Maru (2011) could also assist the facilitator with implementing the toolkit in the future.

Table 6. Participatory lessons learned from applying the toolkit

Lessons for facilitators

- As application of the toolkit can take considerable time, facilitators must be able to stimulate communication between stakeholders and keep discussion strategic. As implementing the toolkit is intellectually demanding for both facilitators and stakeholders, short sessions and long breaks are recommended.
- Due to a variety of stakeholders participating in the toolkit, it is beneficial for facilitators to have previous experience with implementing participatory tools and communication methods with a range of stakeholder types (Bradshaw and Bekoff 2001, Kinzig 2001).
- As one type of enterprise may be beneficial to one group of stakeholders, but be detrimental to another (e.g. the establishment of village-based accommodation will benefit some community members however the hotel may lose bed nights), facilitators must take into consideration possible hidden agendas (e.g. economic interests) (Kenney 1999).
- Some stakeholders dominate discussions more than others. Thus facilitators should be aware of personal characteristics of the different stakeholders, as these can have a significant influence on the information which populates the toolkit (Jakobsen et al. 2004, Lyman et al. 2007).
- Having a wide variety of stakeholders participating (e.g. national government, community hiking guides) can result in an imbalance of power amongst the stakeholders (McCloskey 1996, Lyman et al. 2007). Only facilitators can address this issue, as the tools by themselves are not able to (Lyman et al. 2007). One method to combat this bias is to introduce quality control methods, such as cross-checking by asking the same questions in a multiple of ways (Lyman et al. 2007).
- Facilitators should be confident and able to inspire confidence amongst the stakeholders.

Lessons for stakeholders

- The accuracy of the data obtained from the toolkit is dependent on the representativeness of the stakeholder groups at the workshops.
- It is imperative that people who are actively involved with currently established local enterprises are involved in the SES. However most successful businessmen are unable to engage in these processes as they are too busy and that is why they are successful.
- Trust must be established between the stakeholders. Trust can only be achieved if i) all stakeholders put their egos aside; ii) workshops have a patient facilitator; and iii) stakeholders are given sufficient time to get to know and understand each other (Deconchat et al. 2007).
- Two workshops were held at Umngazi approximately five months apart. As the toolkit involved stakeholder engagement over a prolonged period of time, problems arose with new stakeholders joining the second workshop, and dominant stakeholders not being present at the second workshop (e.g. provincial government officials transferred between different provinces). These changes led to: i) time needed to be spent on regaining trust between the participants; ii) previous discussions having to be repeated, which was time-consuming; and iii) newcomers not agreeing with consensus views obtained from the previous workshop. To address this, a continuous effort must be made between the stakeholders to ensure collective coherence (Roybin et al. 2001).
- If unexpected or conflicting information is given by a stakeholder, clarification must be sought, as this can highlight incorrect assumptions and provide new insights (Sheil and Liswanti 2007).

Lessons for workshop procedures

- As the success of implementing the toolkit is based on mutual trust, it is important that before conducting the workshop, the facilitator makes clear what the purpose of the toolkit is, and what can be achieved (Sturtevant et al. 2007).
 - All stakeholders should feel included and equally valued, thus the workshops must be conducted so that all those present can understand what is being discussed and, if necessary, methods must be employed to overcome language and literacy barriers. Language must be kept as simple and concise as possible, and concepts should be illustrated through locally relevant examples. If a common language is not possible, translators must be used. When a language barrier is present, the success of the toolkit is reliant on the skills level of the translator.
-

An ESF toolkit for economic empowerment must provide detailed information on ecosystem services

The toolkit provides a systematic process for obtaining both qualitative and semi-quantitative information, and a shared understanding of the way in which stakeholders benefit from ecosystem services. At Umngazi this mutual understanding is likely to help improve the resilience of the community-based accommodation enterprise, as the stakeholders understood why this particular enterprise had been chosen and what services were required for it to be successful. It is likely that with the depth of understanding gained through implementing the toolkit, those in decision-making positions (e.g. government officials) will help to ensure the protection of the ecosystems on which the community-based accommodation relies (e.g. basic infrastructure to service the accommodation – electricity, water, access road).

The second constraint identified by Turner and Daily (2007) was that of ‘institutional failure’. Before the workshop at the Tyolomnqa estuary, the provincial planning authority was of the opinion that there were likely to be many estuary-based enterprise opportunities, due to the estuary being utilised for a wide range of activities and by a relatively high number of people. However, the risk assessment highlighted a wide range of constraints of which the provincial planning authority was previously unaware. This emphasises the value of the toolkit in promoting discussion based on structured consideration of ecosystem services.

The third constraint identified by Turner and Daily (2007) was that of ‘market failure’. Although there is neither a universal currency to value the services provided by the estuary, nor quantification of services in currency terms, the use of relative scoring allowed services to be given nominal values to facilitate comparisons.

An ESF toolkit for economic empowerment must consider resilience

The collated data on the supply and demand of the ecosystem services highlighted to all stakeholders at both study sites that the estuary is a common pool which is utilised by many. As the toolkit promotes a shared understanding of the resource and of resource users, enterprises which do not affect, or have limited impact on the availability of the services used by other resource users, and vice versa, were identifiable. This knowledge is the foundation for identifying resilient enterprises.

The toolkit has demonstrated that it can be used to help identify potential estuary-based enterprises which can function under current ecosystem service supply and demand conditions. However supply and demand are constantly changing and in order for an enterprise to have the greatest chance of being resilient, it must be adaptable. The adaptability of an enterprise (ability of the

enterprise to be managed for resilience) is difficult to gauge without an enterprise first being established. The adaptability of an enterprise is human driven and this highlights a gap in the toolkit. In order for an enterprise to be resilient, it must be resilient at an external SES level (which the toolkit addresses) and at an internal business functioning level (which includes social dynamics amongst personnel, skills and literacy levels). Furthermore, as noted by Coulthard (2012), fundamental questions still remain around the equity of adaption, i.e. how the gains and losses of adaption in a resilient system are distributed within a society, and improved resilience does not necessarily result in improved well-being of people.

Although the toolkit does not address the internal resilience of an enterprise, it does indicate which enterprises show potential resilience, given current SES conditions. Establishing whether or not an enterprise is resilient in terms of external SES conditions must always be done before an enterprise is established, for without external resilience, an internally resilient enterprise will still not succeed. If the internal operation of an enterprise is not resilient, for example if the market demands beach holidays and the holiday package is not being adapted to offer beach visits due to a lack of market knowledge, it is possible to educate personnel to provide this service. However, it is much more challenging to alter external level factors which impact on the supply and demand of ecosystem services, such as providing and maintaining access roads to the beach.

Although the toolkit was aimed at accommodating resilience, it does establish a level of common understanding that would enable a vulnerability assessment to be conducted. For example, one could envisage leading from this application of the toolkit into a subsequent vulnerability assessment along the lines proposed by Ravera et al. (2011). Similarly, Cabell and Oelofse (2012) propose 13 behaviour-based indicators which can be used to assess resilience and capacity for adaptation and transformation. Although developed with agroecosystems in mind the toolkit has obvious extensions to other SESs.

An ESF toolkit for economic empowerment must accommodate complex socio-ecological contexts

The greater the diversity of stakeholders attending and participating at a workshop, the greater the understanding of a complex SES. At both study sites there was a reasonable variety of stakeholders present. Although some stakeholders were more dominant than others, with good facilitation all participants contributed, and this resulted in a greater level of trust, respect and knowledge sharing between stakeholders.

Although the degree to which a stakeholder understood the viewpoint of another stakeholder was not formally evaluated, by the end of the workshop the facilitator was confident that stakeholders had a good understanding of both the ecosystem services utilised by other stakeholder groups, and

the complexities of the SES. Other than directly asking each stakeholder what they had learnt, there is no other practical method for evaluating what information was absorbed by the different stakeholders. Although possible, this questioning would have added additional time to an already lengthy participatory process. Despite this shortcoming, there is little doubt that the process could be categorised as a good example of social learning. Keen et al. (2005:4) define social learning as the “collective action and reflection that occurs among different individuals and groups as the work to improve the management of human and environmental interrelations”. McCarthy et al. (2011) have described a heuristic for describing the epistemological context for social learning within complex SES, and use of this in future applications of the toolkit would improve the quality of the social learning process.

In summary, the participatory approach of the toolkit helped the stakeholders to gain a good understanding of the different perspectives of the other stakeholders, and importantly, the complex interdependencies of the SES. This is an important first step in enhancing resilience, adaptability and transformability. More specifically this mutual understanding would improve the resilience of an enterprise, as it is likely that if the operating of an enterprise negatively impacts upon service delivery for another stakeholder, with greater shared understanding there may be more chance for compromise whereby both stakeholders continue to benefit from services supplied by the estuary. Moore and Westley (2011) have highlighted the importance of networks in relationship building and brokering, and knowledge and resource brokering and how this is fundamental to social innovation. They see this as key in improving human capacity to address challenging problems and improve resilience. In the context of the estuary project, it was clear that we were seeing the incipient formation of a network that, if nurtured, could generate the ‘institutional entrepreneurs’ referred to by Moore and Westley (2011).

Improvement to and further development of the toolkit

The data extracted when implementing the toolkit is primarily derived from discussions amongst the different stakeholders attending the workshop. A shortcoming of the toolkit is that in its present form it does not explicitly encourage the sourcing of existing ecological, demographic, social or market data. The integration of this data into the ESF framework would considerably strengthen the toolkit’s scientific foundations. Such data could include censuses, market analyses (such as B. Reyers and E. Ginsburg, unpublished manuscript) and published biodiversity assessments (such as the National Biodiversity Assessment Database 2011 which shows the habitat areas and ecological health statuses of all South African estuaries) (http://rava.qsens.net/themes/coastal_template/nationalbiodiversity-assessment-2011-estuary-component/2011_NSBApartial01.xlsx/view).

As our findings are based primarily on estuarine SESs, and as ecosystems greatly differ in terms of species composition, service provision, and resilience thresholds (Scheffer et al. 2000), it is not possible to directly transfer this framework to other ecosystems (e.g. wetlands, grasslands, forests). However, given the fact that only Step 1 of the toolkit directly deals with ecosystem services and is tailored specifically to estuaries, the toolkit is likely to be readily adapted for other ecosystem types. The integration of relevant ecological data for other ecosystems is also recommended.

CONCLUSION

In summary, this paper documents how the theory of the Anderies et al. (2004) framework has been translated into a practical toolkit which can be used by a diversity of stakeholders as a decision-making aid for assessing ecosystem services supply and demand, and associated enterprise opportunities. Thus the toolkit addresses the hiatus previously referred to by providing an operational decision support system for the practical integration of ecosystem services into decision-making processes. In doing so, implementation of the toolkit initiates a process of social learning, considered critical in enhancing resilience, adaptability and transformability in complex SESs.

It is impossible to accurately predict if a proposed enterprise will be resilient or not, but the toolkit does, however, provide a structured mechanism for identifying enterprises which have the potential to be resilient. At present the toolkit does not include steps to monitor the impacts of the enterprise on the receiving SES once established, or to assess the internal business functioning level of a particular enterprise. Additional work is required in these areas.

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CHAPTER 4: PAPER 2

Risk and resilience assessment in natural resource-based enterprises: A case study of the Mbongolwane Wetland, northern KwaZulu-Natal, South Africa

Table 4.1. Summary of Paper 2

Information	Details
Title:	Risk and resilience assessment in natural resource-based enterprises: A case study of the Mbongolwane Wetland, northern KwaZulu-Natal, South Africa.
Paper status:	Submitted to <i>World Development</i> (7 March 2015)
Journal website:	www.journals.elsevier.com/world-development/
Citation:	Bowd, R., Quinn, N., & Kotze, D. C. (Unpublished). Risk and resilience assessment in natural resource-based enterprises: A case study of the Mbongolwane Wetland, northern KwaZulu-Natal, South Africa.
Objective(s):	<p>Develop a conceptual framework which informs future resource management interventions which will contribute to the sustainable use of natural resources and improve the livelihood of the poor, through:</p> <ul style="list-style-type: none"> • adapting the Bowd et al. (2012) approach and using it to evaluate the resilience of a natural resource-based enterprise (NRBE) at Mbongolwane; • identifying the risks to the craft group at Mbongolwane (<i>Thuba let elihle</i>) and the wetland system supplying the raw material; • determining whether the adapted toolkit missed any key risks and issues of relevance which were identified from a literature review of other comparable cases; • presenting a SES conceptual framework for craft-related NRBEs, and providing recommendations for achieving resilience; and • reflecting on the underlying impediments to implementing resilience strategies for craft-related NRBEs.
Methods used:	<ul style="list-style-type: none"> • Literature reviews on the following topics: <ul style="list-style-type: none"> ◦ work undertaken at the site over the past decade; and ◦ comparable case studies. • A series of semi-structured interviews over a 28-month period with general community and crafters to obtain detailed understanding of the supply and demand of ecosystem services being utilised, and to gain an understanding of the challenges faced by the craft group and their responses. • A participative workshop with representatives from a local craft agency and the craft group to test the toolkit (missing technical information to populate the risk assessment was obtained from local government officials and interviews with the key informants from the greater community). • A comparison of risks identified through the literature and risks identified through the case study.
Key findings / outcomes of paper:	<p>The Anderies et al. (2004) SES framework proved useful as it led to consideration of social-ecological interactions associated with NRBE at a broad landscape level, however its applicability is limited when applied at an enterprise level. Although some economic risks linked to internal business dynamics were identified, these could be considered socio-economic or ecological-economic. The main advancements made to the Anderies et al. (2004) SES framework are the addition of: 'external impacts on internal dynamics', 'external impacts on demand', 'internal dynamics which impact upon product supply and the creation and meeting of demand' and 'internal forces on demand'. There are four main underlying and interlinked obstacles which hinder achieving resilient craft-related NRBEs: material being sourced from a common pool resource, gender inequality, poverty and low literacy. These obstacles also limit the adaptive capacity of the craft group, and solutions to overcoming these obstacles lie in external assistance.</p>

Risk and resilience assessment in natural resource-based enterprises: A case study of the Mbongolwane Wetland, northern KwaZulu-Natal, South Africa

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Summary - Although there has been a drive to commercialise natural resources with the aim of improving livelihoods and the natural environment, there are key factors which appear to have been overlooked when developing natural resource-based enterprises (NRBEs). A NRBE is located within a complex social-ecological system (SES), which depends on the resource on which it is based being used sustainably. Few studies have considered the impact of the increased use of natural resources on the ecosystem through commercialisation of natural products. The aim of this study is to provide a conceptual framework which informs future resource management interventions which will contribute to the sustainable use of natural resources and improve the livelihoods of the poor. To achieve this aim, the Anderies et al. (2004) SES framework has been applied to a craft group located in rural South Africa, which has used wetland plants to produce commercial conference folders. This study also identifies the underlying obstacles which hinder implementation of strategies to increase resilience. The Anderies et al. (2004) SES framework proved useful in this application as it led to consideration of social-ecological interactions associated with NRBEs at a broad landscape level, however its applicability is limited when applied at an enterprise level. Although some economic risks linked to internal business dynamics were identified, these could be considered socio-economic or ecological-economic. The Anderies et al. (2004) SES framework has been amended to address its shortcoming when applied to a NRBE. The main advancements are the addition of: 'external impacts on internal dynamics', 'external impacts on demand', 'internal dynamics which impact upon product supply and the creation and meeting of demand' and 'internal forces on demand'. Four main underlying and interlinked obstacles which hinder achieving a resilient craft-related NRBE were revealed: material being sourced from a common pool resource, gender inequality, poverty and low literacy. These obstacles are the same obstacles which limit the adaptive capacity of the craft group, and solutions to overcoming these obstacles lie in external assistance.

KEY WORDS

South Africa, social-ecological systems (SES), resilience, risk assessment, wetlands, natural resource-based enterprise

1. INTRODUCTION

In 2008, the South African Institute for Race Relations recognised that the gap between wealthy and poor in South Africa was widening unsustainably (SAIRR 2008). Six years on, although a number of policies have been implemented to facilitate wealth redistribution, they have not resulted in

significantly reduced inequality (Chitiga Mabugu 2014). Both wealthy and poor rely on ecosystems to provide services (Millennium Ecosystem Assessment 2005, Maltby and Acreman 2011) and many enterprises are built directly or indirectly around these services (Scheffer et al. 2000, Tallis et al. 2008, Miller et al. 2010, Robinson 2010, McShane et al. 2011), which are finite, increasingly diminishing and are being compromised through a combination of demand for the services exceeding supply and a lack of management knowledge (Batabyal and Yoo 1994, Scheffer et al. 2000).

Poverty and environmental degradation are causally linked “in a mutually reinforcing downwards spiral” (Breen 2013:35), as those who most need resources are further pressured to extract ecosystem services at levels beyond what can be sustainably delivered (Egoh et al. 2012). Wetland systems, along with their associated goods and services, are a resource that has become increasingly scarce, both within South Africa and worldwide. Kotze et al. (1995) estimate that parts of the Western Cape, Eastern Cape and KwaZulu-Natal have less than 50% of natural wetlands remaining. With increasing climatic hazards such as droughts, wetlands are being used more intensively as a coping strategy for the rural poor in Africa (Wood et al. 2013).

Many more people now live ‘closer to the edge’ in southern Africa compared to the 1990s (Maunder and Wiggins 2007). A combination of increased unemployment, retrenchment and HIV/AIDs (Kgathi et al. 2007) has resulted in increased numbers who are involved or dependent on the natural resource product sector (Rogerson and Sithole 2001, Shackleton et al. 2008). With an increasing population, and low education levels, it is inevitable that natural resources will be increasingly relied upon as a livelihood strategy. Tools which help assess the health and sustainable use of natural resources are therefore needed.

Over the past fifteen years the commercialisation of natural resource products has been promoted as a strategy to help meet the needs of the rural poor (Arnold and Ruiz-Pérez 2001, Cocks and Dold 2004, Shackleton and Shackleton 2004) and embed sustainable natural resource management (Maltby and Acreman 2011). Commercialisation of natural resources in South Africa has generally been driven by external interventions (Marcus 2000, Kotze 2001, Krüger and Verster 2001, INR 2003). Although natural resource products have received attention from some national government departments (e.g. Department of Arts and Culture (DACST 1998), Department of Trade and Industry (Ndabeni 2001)) and local government (Hay 2004), the socio-economic contribution of these products has yet to be fully appreciated by policy makers and practitioners involved with poverty alleviation and micro-enterprise (Rogerson 2000, Shackleton et al. 2000). For example, when enterprise assistance is provided in rural areas, it mainly focuses on agriculture and emerging farmers (Marcus 2000, Shackleton and Shackleton 2004). It has been noted by De Jong et al.

(2000) and Ros-Tonen and Wiersum (2005) that more work is required to understand the complex social context and relationships associated with the commercialisation of natural resource-based products (NRBP), and to address criticisms of its role in poverty alleviation (Wunder 2001, Sunderland et al. 2004, Ros-Tonen and Wiersum 2005).

In the drive to commercialise natural resources and develop natural resource-based enterprises (NRBEs), several factors appear to have been overlooked. For example, many studies have focused on vulnerable people turning to natural resources as a survival strategy in times of need, but there are few studies that measure the impact of the increased use of natural resources on the ecosystem (Shackleton and Shackleton 2012). Kusters et al. (2006), who assessed whether and to what extent the commercial trade of NRBP results in positive or negative effects on livelihoods and the environment, report that the financial benefits of NRBEs are 'unequivocally' positive. However in a few instances commercial production has had a negative social impact and in more than 40% of cases, has had a negative impact on the natural environment. They conclude that "commercial production of non-timber forest products is not likely to reconcile conservation and development objectives. More of the one tends to mean less of the other" (Kusters et al. 2006:16).

The Intergovernmental Panel on Climate Change (2007) identifies three dimensions to vulnerability: a) exposure (the degree of exposure to external shocks (e.g. floods), which are beyond the control of a community); b) sensitivity (the degree to which they are at risk to shocks, and consequent impacts); and c) adaptive capacity (the ability to manage and recover from exposure to these shocks (Shackleton and Shackleton 2012). Building resilience is fundamental to reducing vulnerability and enhancing adaptive capacity (Shackleton and Shackleton 2012). As resilience can be defined as "the capacity of a system to experience shock while retaining essentially the same function, structure and feeds, and therefore the same identity" (Walker et al. 2006:2), the level of adaptive capacity is directly related to the level of resilience of an enterprise.

In the absence of government intervention to alleviate poverty, natural resources will be inevitably relied on in times of hardship, suggesting the need for pragmatic resource management. If NRBEs are to be part of the solution, then they need to be resilient and based on sustainable use of the supporting natural resources. In order to achieve this, there is a need for an analytical approach which brings the sustainable use, and thus the well-being of the ecosystem on which a NRBE is based, to the attention of all those involved (local producers to international purchasers). This study documents the implementation of a toolkit to help achieve this, which was originally developed for identifying resilient estuary related NRBEs (Bowd et al. 2012a, Bowd et al. 2012b), at a wetland case study site, known as Mbongolwane, where a fibre-based crafting enterprise has deteriorated. Although the failure of this NRBE could be considered to reduce pressure on the wetland, there are

potential detrimental impacts as a result of this failure. For example, a lack of use by a large portion of the community could result in reduced policing of the resource (e.g. increased cultivation, over-burning and -grazing, which, relative to craft material harvesting, are highly detrimental to the wetland system). If these activities go uncontrolled, then wetland services are likely to be compromised, and the livelihoods of the poor, who predominantly rely on these services, will deteriorate. This case study illustrates the interwoven socio-economic and environmental impacts of a failing NRBE. It is hoped that implementing the toolkit for a failing enterprise will help inform future interventions, which in turn will contribute to the protection of an important ecosystem.

a) Case study context

The Mbongolwane wetland system is located approximately 30km inland of Eshowe, KwaZulu-Natal, South Africa (GPS 28° 56' 10"S 31° 13' 31"E). Members of a local craft group, established in 1997, known as *Thuba let elihle*, collect material from the wetland system and produce fibre products. *Thuba let elihle* has a designated craft centre where the crafters meet, weave and store products and raw material. When first established, its members were mainly engaged in the production of traditional Zulu sleeping mats, for which there was a long-established local market. These sleeping mats are predominantly made from the sedge *Cyperus latifolius* (known locally as *iKhwane*), which grows in abundance at the Mbongolwane wetland.

In 2000 a Land Care Project was established at Mbongolwane, which explored the possibility of producing commercial crafts from abundant wetland fibre. One suggestion was the production of conference folders from *C. latifolius*, and members of the Land Care Project team assisted with successfully identifying a market for this product. The Land Care Project intended phasing out their assistance after building the group's self-reliance and adaptive capacity and linking the group with multiple buyers, but unfortunately significant problems occurred. During 2004 a craft agency, based in Eshowe and known as *Inina*, approached *Thuba let elihle* to become a member of their agency, which, at the time, acted as the marketing agent for ten other craft groups located in the outlying areas of Eshowe. *Inina* commissioned *Thuba let elihle* to produce the conference folders. An individual producer can make two conference folders per day, which gives a net return of \$10 per day (Breen 2013). During 2004, at the peak of sales, *Thuba let elihle* had 110 members and a collective annual income of more than \$28 000. This equated to a member earning an average of \$255 per annum. With the cost of a large 40 kg sack of maize meal costing \$12, less than two days of production was sufficient to provide basic nutrition for a month for a family of five (Breen 2013). This high net return was achieved because the basic raw material was free and no retailers were involved (Breen 2013). Considering the average annual household income in KwaZulu-Natal in 2000 was \$337.80 (SSA 2002), the income derived from the conference folder market was significant.

During 2007 a buyer, who had a small internet-based business which mainly focused on the selling of high quality African craft items, commissioned *Thuba let elihle* to make a consignment of conference folders for a large government conference, and this constituted the last bulk order for conference folders. So although *Thuba let elihle* was an economically successful operation for a number of years, demand for *Thuba let elihle*'s conference folders declined after 2007, and by 2011 there were no orders. In 2013 orders for a new type of product – *izicephu*, which are small mats – were placed with *Thuba let elihle*, however the preferred material for this product has limited availability at Mbongolwane. This, together with a now reduced numbers of crafters, meant that *Thuba let elihle* was unable to fulfill this order. The craft group effectively disbanded as a commercial entity in 2011, and has since not been able to recover, raising questions around the resilience of the institution as a NRBE.

b) Natural resource-based enterprise as a social-ecological system

Natural resource-based enterprises occur within complex social-ecological systems (SES). Over the past two decades, there has been much discussion of methods to understand and disaggregate SESs surrounding poverty alleviation (Grieg-Gran et al. 2005, Pagiola et al. 2005, Bulte et al. 2008, Pagiola et al. 2008, Wunder 2008, Jourdain et al. 2009, Milder et al. 2010, Muradian et al. 2010, Pattanayak et al. 2010, Binder et al. 2013, Defeo et al. 2013, Dorward 2014). However much of this work has had a strong theoretical base and has rarely been practically applied (Daily and Matson 2008, Turner and Daily 2008, Bowd et al. 2012b).

In an attempt to bridge theory and practice, Bowd et al. (2012a) document the development and testing of a toolkit for the identification of resilient estuary-based enterprises as a means of socio-economic empowerment for disadvantaged communities in South Africa. Although the focus was to identify estuary-based enterprises, an additional goal was to demonstrate the economic value of natural resources and, in turn, promote the wise use and sustainable management of natural ecosystems (Christiansen 1999, Arnold and Ruiz-Pérez 2001, Kotze 2001). The approach is based on the earlier work of Anderies et al. (2004) and Ostrom (2007, 2009). Contreras (2010) also uses the Anderies et al. (2004) conceptual approach to help understand rural craft in Colombia as a system which interacts with its ecological and social environment, and which depends on these interactions in order to develop adaptive strategies to cope with change.

c) Aim of the study

We aim to provide a conceptual framework which informs future resource management interventions through addressing four objectives. Firstly to adapt the Bowd et al. (2012a) approach and use it to evaluate the resilience of a NRBE at Mbongolwane. Secondly, to identify the risks to *Thuba let elihle* and the wetland system supplying the raw material. Thirdly, to determine whether

the adapted toolkit missed any key risks and issues of relevance which were identified from a literature review of other comparable cases. Finally, using the lessons learned from the case study, and supporting literature, present a SES conceptual framework for craft related NRBEs, and provide recommendations for achieving resilience. We also reflect on the underlying impediments to implementing resilience strategies, resolution of which is critical to the establishment of sustainable NRBEs.

2. METHODS

Three sets of methods underpin this study. Firstly a literature review, secondly a series of semi-structured interviews over a 28-month period, and finally a participative workshop and subsequent consultations aimed at generating the inputs to the Bowd et al. (2012a) framework. The literature review focused on work undertaken at the site over the past decade, and was aimed at compiling a comprehensive list of risks commonly associated with craft-related NRBEs, and gaining a better understanding of drivers of successes and failures of these enterprises.

The primary components of a SES are best identified through methods which involve constructive communication between experts and stakeholders who understand the SES (Walker et al. 2002, Westley et al. 2002). Stakeholder engagement has more recently gone from being a 'marginal concern' to a 'driving force' (Lynam et al. 2007), and it has become apparent that case-specific customized 'bottom-up' tools, which are generally driven by local needs (Fall and Fall 2001, Sturtevant et al. 2007), are more successfully implemented compared to the commonly used 'top-down' generic scientific tools, which are frequently developed without input from local stakeholders (Raymond and Cleary 2013). For these reasons, the Bowd et al. (2012a) toolkit combines quantitative and qualitative information gathering via a participative stakeholder engagement process.

A fundamental aspect of the toolkit is compilation of an ecosystem services inventory, which is then used to identify relevant stakeholders separated into four groups: i) local level stakeholders (e.g. individual, family and municipal); ii) provincial and national level stakeholders; iii) international stakeholders (e.g. global conservation groups); and iv) downstream stakeholders (those who utilise services which could be negatively affected by activities upstream). Implementing the toolkit comprises four steps (Figure 1), and is supported by a pre-programmed Excel worksheet.

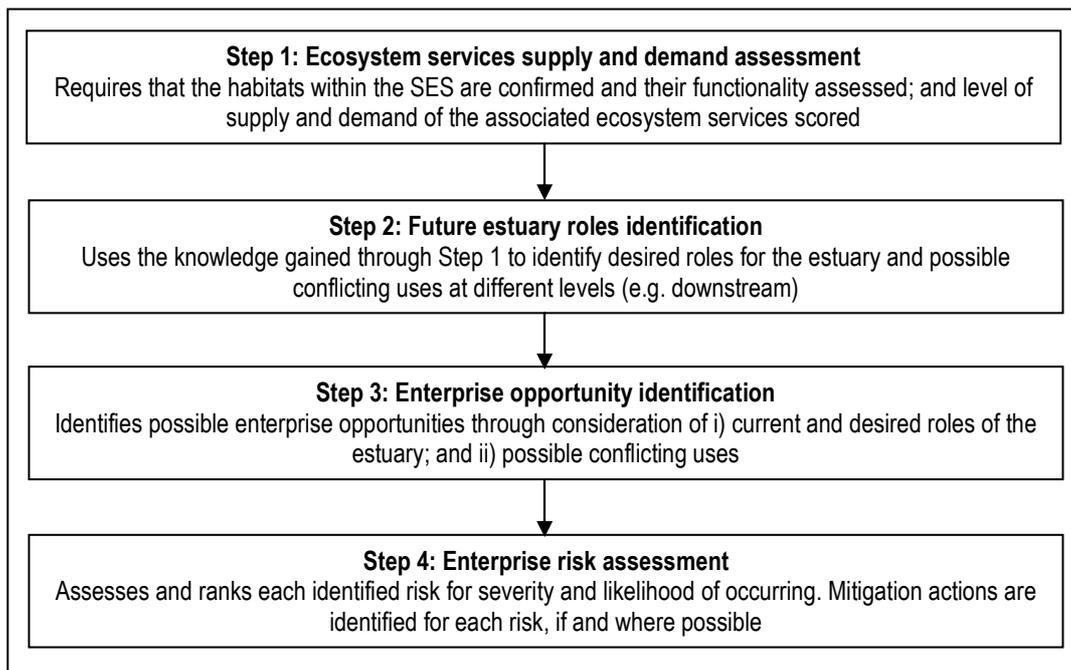


Figure 1. The four steps of the Bowd et al. (2012a) toolkit

Semi-structured focus group interviews were conducted at Mbongolwane with the general community and crafters from *Thuba let elihle* on May 22, 2007, December 4-6, 2007 and September 17, 2009. The purpose of these interviews was firstly to obtain a detailed understanding of the supply and demand of the wetland ecosystem services being utilised, and secondly to gain an understanding of the shocks and challenges faced by *Thuba let elihle* membership and their responses. Interviews were conducted over 28 months, enabling the researchers to gain a good understanding of key issues and trends that occurred over a period of time, rather than being overly influenced by issues considered important at any one time.

Ecosystem services supply and demand were assessed as described in Bowd et al. (2012a) (Step 1 in Figure 1), although amendments to the toolkit's habitat and estuarine services inventory were made so it was applicable to an inland wetland. This requires that habitats are identified and scored in terms of supply of ecosystem services. The ecosystem service demands at the local, downstream, provincial and national level are then estimated by order of magnitude (e.g. 0, 10, 100, 1000 users). The users of the services are subsequently listed, following which the dependence of each on the different services is scored between zero (no impact on welfare) and three (critical for welfare).

An enterprise risk assessment, as documented in Bowd et al. (2012b), was then undertaken (Step 4 in Figure 1), which provided an integrated overview of potential risks to the enterprise, and

appropriate interventions to address the identified risks. This analysis required the severity and likelihood of each risk to be scored (0-3, three being very severe / likely to occur). A risk with a high severity of impact and a high likelihood of occurrence is considered to pose a major risk to enterprise resilience, so the severity and likelihood scores are multiplied to provide a semi-quantitative value for each risk. When complete, the pre-programmed spreadsheet automatically ranks the risks according to their magnitude. Following this, risks are ranked and a list of associated mitigatory actions is compiled (Bowd et al. 2012a). As steps 2 and 3 of Figure 1 are designed for screening proposed alternative enterprises, they were not implemented in this study, which focuses rather on one established enterprise.

The methods above are necessarily participatory, and were implemented at a workshop of representatives from both *Inina* Craft Agency and the *Thuba let elihle* at Eshowe on September 22, 2009. Due to the limited literacy level of the participants, not all questions were asked during the workshop. However, where necessary, missing technical information (such as 'impact of infrastructure on resource levels') to populate the risk assessment was subsequently obtained through discussions with local government officials and interviews with the key informants from the greater community.

Using the results of the risk assessment, those which were classified as 'high' risks were tabulated and an explanation of each is given. Following this, the risks identified through the literature were compared to the risks identified through the case study to establish whether the risk assessment omitted any key considerations.

3. RESULTS

a) Risk assessment

The adapted risk assessment is presented in Table 1. During its implementation, participants were comfortable using their knowledge to assign scores to the different ecosystem services supplied by the wetland, despite fairly low levels of formal education and no prior experience in participating in exercises of this nature. Participants engaged freely with each other in discussing the basis of their scores and to reach a consensus view. Although the ecosystem services supply and demand inventory is not the main focus of the toolkit when applying it to an established enterprise, it did stimulate dialogue between the participants and helped to build a common understanding of the wetland system and its relative importance in supplying a range of different ecosystem services.

Table 1. Established wetland-based enterprise risk assessment showing data obtained from the test site. A=Severity of impact on enterprise (score 0 to 3, 3=most severe); B=Likelihood of occurrence to enterprise (score 0 to 3, 3=most likely to occur); and C=Risk to enterprise (severity x likelihood)

Questions	Results obtained from the test site	A	B	C	Examples of actions to mitigate the risk
Relationship between resource users and the resource					
Could the enterprise user group deplete the resource?	Unlikely as the abundance of <i>Cyperus latifolius</i> is very high in relation to the quantity harvested. <i>C. latifolius</i> is resilient to harvesting and re-grows rapidly after being cut (Kotze et al. 2002; Traynor et al. 2010; Kotze and Traynor 2011). <i>Juncus kraussii</i> is in short supply and it is unlikely that the availability of this material will support demand.	3	2	6	<i>Thuba let elihle</i> to develop products using <i>C. latifolius</i> , rather than products requiring the considerably less abundant species (e.g. <i>J. kraussii</i>) (Kotze and Traynor 2011).
Relationship between resource users					
Are there conflicts between the enterprise user group and other user groups?	Main conflict is when grazing cattle trample <i>C. latifolius</i> . Although <i>C. latifolius</i> is always available, the most accessible areas are also the areas where the cattle prefer to graze. Cattle grazing is a major threat to <i>J. kraussii</i> .	3	3	9	Cattle owners to communicate with <i>Thuba let elihle</i> regarding when and where grazing will occur, to allow harvesters time to collect raw material.
If yes, are the other user groups reliant on the resource?	Cattle benefit from grazing in the wetland, particularly during the late winter/early spring when grazing outside of the wetland is limited, especially in dry years.				Cattle to be kept away from <i>J. kraussii</i> .
Can one user group's actions reduce the levels of services available to the enterprise user group?	Heavy grazing and thus trampling shortly before or during harvesting could potentially impact on the availability of <i>C. latifolius</i> . Burning to promote plant growth for cattle grazing temporarily reduces the availability of harvestable material. However, material can be collected from elsewhere and burning may improve the quality of craft material.	2	2	4	Restrict the movement of cattle in the wetland prior to and during harvesting times. Harvesters to be given sufficient time to collect craft material prior to seasonal burns.
Can the enterprise user group influence upstream users who may influence the ecosystem functioning and therefore the supply level of services?	An Environmental Impact Assessment (EIA) would be required if an upstream development was proposed which had potential to impact on the quantity and quality of water in the wetland (and thus on the availability of harvestable material). Although the EIA would consider the impact of the development on the harvesters, the influence of the crafters would depend on the inclusivity and quality of the EIA process.	1	1	1	If an upstream development is proposed, <i>Thuba let elihle</i> must ensure that they make their interests known to those conducting the EIA.
Relationship between public infrastructure and the resource					
Is the wetland and its available services located within a clearly defined spatial boundary that can exclude users without legal rights?	Harvestable material is within a defined spatial boundary. Outsider harvesters have come to collect craft material from the Mbongolwane system for many years. Outsiders are required to have a stamped letter from the Local Traditional Authority.	1	1	1	Local Traditional Authority has considered charging outsiders to collect material. It is likely that this charging system will be implementable.
What are the impacts of i) knowledge / skills; ii) infrastructure; iii) security / governance; and vi) communication on the resource?	Traditional knowledge and beliefs held by the crafters and rules of the Traditional Authority discourages harvesting during the growing season, thereby limiting potential impacts on the resource. The well maintained roads and craft centre (to a lesser degree) allow the crafters to obtain and store material and distribute their products. Well maintained roads results in material, which is in abundance, being extracted from the wetland.	2	3	6	<i>C. latifolius</i> should remain the preferred choice for craft products. <i>J. kraussii</i> products must not be pursued. The craft centre must be maintained. Strict control over harvesting times must continue to be enforced.
Relationship between public infrastructure and resource users					
Are the people with rights to use the	To some degree. Outsiders are required to obtain a stamped letter from the	2	2	4	Outside harvesters should be charged by the number of

resource a clearly defined group separate to those without rights of resource use?	Traditional Authority prior to harvesting. This practice is not always respected. The implementation of a proposed charging system will further define rights to the resource.				bundles collected to guard against wasteful harvesting.
Does everybody in the community with user rights participate in the resource use?	In a survey of 50 households living near the wetland, 70% of households were found to use craft plants in the wetland (Kotze et al. 2002).	1	2	2	N/A
Are there any positive relationships between the user groups who have a right to use the resource?	Although there is conflict between cattle owners and crafters, many cattle owners know people who produce craft and have some degree of understanding of the importance of the material.	2	3	6	Crafters must make the cattle owners more aware of the financial contribution crafting makes to the household. This awareness must be made to anyone involved in an activity which might have a detrimental impact on the availability and quality of material.
Considering current infrastructure, is the safety of the enterprise user group secure all year round?	Roads to collect material and distribute products are accessible all year. The craft centre can be locked and is secure. As crafters are paid in cash, thieves could rob the crafters, payment point and/or those travelling with the funds to be distributed. To date no attempted robbery has taken place.	1	2	2	Care must be taken when collecting and distributing payments. Those withdrawing and carrying large sums of money must not travel alone.
Does the infrastructure meet current demand for access (the type, size and quality of infrastructure)?	Communication is limited between crafters and clients due to: i) no established means of compensating individuals for use of personal cell phones for craft group business ; ii) language barriers; iii) low literacy level and a lack of marketing skills.	3	3	9	Strengthen mechanisms for compensating members who incur costs for craft group. Introduce literacy courses.
What are the levels of skills (education, knowledge, communication) amongst the enterprise user group?	Crafters have low literacy skills. Their business and marketing skills are also very limited. There are inadequate linkages to organisations that can provide skills training and mentoring. There is good local knowledge of the resource (e.g. the best and worst times of the year to harvest) and factors potentially impacting negatively on the resource (e.g. livestock grazing).	2	2	4	Introduce business skills courses.
How adaptable is the enterprise user group to i) changes in the availability of the resource; ii) changes in demand; iii) pursuing other activities to sustain livelihoods, vi) competition from other enterprises etc.?	Craft group has demonstrated adaptability by producing a product which is made from an abundant material in the wetland, and stockpiling raw material to ensure that further orders can be met. When a drop in product demand occurred, crafters shifted to other income generating activities (e.g. vegetable gardening). When product demand increased, other family members become responsible for tending to vegetables. When demand for the groups 'keystone' product, the conference folder, dramatically declined, due to competition from another craft group, <i>Thuba let elihle</i> were unable to adapt by developing a new product.	3	2	6	Through linking with craft agencies who have access to email and information on market demands, develop other products.
What rules of law (local, provincial, national, international) are applicable to the enterprise resource users?	At Mbongolwane it is taboo to collect <i>C. latifolius</i> before the end of April (summer). If harvesting occurs there is the belief that a storm and a seven-headed serpent will emerge from the wetland. The end of summer is when the plants naturally die back, and harvesting before this time minimises the impact of harvesting on the wetland (Kotze and Traynor 2011).	1	3	3	Crafters to be educated on the ecological reasons as to why harvesting should not take place before April.
To what extent are these rules of law enforced?	The rule is mostly respected. However if a large order is received outside of harvesting season then crafters who have not accumulated sufficient raw material are known to collect. This occurrence is limited as the material harvested outside of the	1	3	3	Crafters to be educated on the ecological reasons as to why harvesting should not take place before April.

	harvesting season is generally not suitable for weaving.				
Who principally controls the wetland?	Crafters believe the Traditional Authority controls the wetland; however there is evidence of self-regulation between the crafters (e.g. crafters are not supportive of harvesting before April).	1	2	2	Crafters must ensure the Traditional Authority is aware of the contribution <i>Thuba let elihle</i> makes to the community.
What policies are applicable to the resource users and what implications do these policies have on the resource users?	Government policy encourages micro-enterprises, especially those which can uplift the rural poor, most notably women who are considered the most disadvantaged group. Government provides grants to those unemployed, disabled, retired or caring for children.	3	1	3	Crafters must ensure that they are registered to receive all applicable government grants. These grants are increasingly important during times of few or no orders.
To what extent do these policies give adequate security (i.e. access, availability) of the resource for the resource users?	Government grants and assistance with micro-enterprises do not give direct protection to the resource, however the younger generation appear to be far less interested in craft as they can survive on the grants. Fewer crafters in the future may reduce the impact of crafting on the wetland (which is currently minimal), however if there is no reliance on the health of the system to provide craft material, there is potential for detrimental activities on the wetland to go unnoticed.	2	2	4	Crafting amongst the younger generation should be encouraged. Government agencies who help establish micro-enterprises should educate the younger generation on how to and the benefits of establishing resource-based micro-enterprises.
Do high transaction costs exclude key stakeholders from the decision making process?	Conflict between crafters and cattle grazers has required mediation from the Traditional Authority. However, the Traditional Authority requires payment before they will enter into conflict resolution.	1	2	2	Crafters to ensure that financial provision is made for conflict resolution.
Relationship between public infrastructures					
What infrastructure is available and to what extent is it developed and maintained?	Craft centre provides a place to store the product and material, and for crafters to weave and attend meetings. The centre is generally well maintained, however products have been damaged once by a leaking roof.	2	1	2	Craft centre to continue to be maintained through re-investing a portion of the group's profits.
What policies are applicable to public and private infrastructure and to what degree are these policies implemented?	Government seeks to provide access to basic services (e.g. good local road network, and water stand pipes). The road has assisted with material collection and product distribution. Stand pipes have reduced the need for women to spend time collecting water, thus providing more time for lucrative activities, such as craft production.	1	2	2	Government to ensure that road and water infrastructure is maintained.
Relationship between public infrastructure providers and the resource					
To what extent is the state of the resource monitored and who is responsible?	Wetland system is not formally monitored, however it has been the focus of university research projects, and the local conservation department has extension officers who have visited the wetland.	3	2	6	Formal monitoring should takes place, especially if <i>J. kraussii</i> , or any other plant with limited availability, is used.
To what degree is government contributing to resource user management with regard to the resource?	Government provides grants to those who are eligible. Without these grants greater cultivation and grazing (as well as block making etc) would be taking place. These activities are likely to have a detrimental impact on the wetland.	1	2	2	Government to promote awareness on the importance of, what activities are harmful to and how wetlands should be managed.
To what degree is local governance, including traditional leaders, contributing to the management of resource users with regards to the resource.	The introduction of outsider harvesters being charged is proposed, however this has yet to be implemented. The Traditional Authority has previously mediated between harvesters and cattle grazers.	2	2	4	Traditional Authority to be educated on the importance of the wetland system, and to ensure that management decisions are in the interests of the health of the wetland system, and not on the self gain for one group of users.

Relationship between public infrastructure providers and resource users

To what degree is government contributing to the management of resource users with regards to: i) research; ii) infrastructure; iii) skills / knowledge; iv) security; v) communication? Government contributed to supporting sustainable use of the wetland through a Land Care project from 2000 to 2004. 2 2 4 Government to be approached to assist with restricting cattle in the wetland during sensitive times of the year. This could take the form of educating the farmers and providing fencing.

How adequate is the cooperation between the enterprise resource user group and the government to manage the i) built environment; ii) social / cultural environment; iii) natural environment? There is limited direct co-corporation between *Thuba let elihle* and Government. Previously the majority of external assistance has come from private sector. However the largest conference bag order came from a government department. 2 3 6 *Thuba let elihle* to request assistance, in the form of small enterprise skills training, from the relevant government departments.

Relationship between public infrastructure providers and public infrastructure

What are the levels of skills (education, knowledge, communication) amongst the resource managers / government? Government has some skilled personnel, however government presence in the community is very limited. 3 2 6 *Thuba let elihle* to request assistance from relevant government departments on natural resource-based management.

Is there evidence, and if so to what extent, are the findings of any monitoring efforts used to evaluate management, and thus influence future actions (adaptive management)? A formal monitoring system is not in place, however crafters have shown self regulation, through the reporting of harvesters reported to the Traditional Authority when harvesting has taken place outside of harvesting times. 1 3 3 Community to be encouraged to report those seen harvesting outside of harvesting times.

Relationship between public infrastructure providers

Is there sufficient communication between different government tiers and departments? No, communication is insufficient (e.g. the department responsible for environmental protection and the department responsible for local economic development do not communicate). 2 2 4 Government departments to work together to assist developing the skills and knowledge of all wetland user groups. Skills development to include marketing, product development, literacy, wetland management.

Relationship between external biophysical forces and the resource

What is the nature of severe biophysical impacts on the resource and what is the significance and frequency of these impacts? Although the region experienced an eight year drought, the supply of *C. latifolius* was not significantly affected. Floods are infrequent, however when they do occur, not all of the *C. latifolius* is usually rendered unacceptable for harvesting. 1 3 3 Craft group to continue to stockpile material for use following flood events.

Relationship between external biophysical forces and resource users

To what degree does the enterprise user group plan for fluctuations and is this planning adequate? As *C. latifolius* is available even during extreme weather conditions, little planning takes place, other than the craft group stockpiling material to meet orders which are placed when harvesting is not permitted. Although *C. latifolius* is currently plentiful, 3 2 6 *Thuba let elihle* to be proactive against the impacts of increased grazing and flood events on material availability. *Thuba let elihle* to raise issue with cattle owners before it occurs.

increased grazing pressures and/or increased flood frequency may result in *C. latifolius* not being so readily available.

Relationship between external biophysical forces and public infrastructure

To what degree do external shocks damage public infrastructure with regards to: knowledge, skills, floods, over exploitation of resource, establishment or non-maintenance of roads, communication?	Flood events have caused roads to be inaccessible, the department of transport undertake the necessary repairs.	3	1	3	Should a publicly provided service be interrupted (e.g. failure of cell phone communication due to storm damage, road wash-aways), these services must be reinstated as soon as possible.
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Relationship between external biophysical forces and public infrastructure providers

To what degree are these external shocks managed/prepared for (i.e. insurance, forward planning)?	During times of low product demand crafters plant garden vegetables; however it is not known if planting occurs when no orders have been placed for one month or twelve months. Due to low literacy levels or possible unawareness of external shocks, it is unlikely that the crafters are prepared for any major external shocks.	3	3	9	<i>Thuba let elihle</i> to be educated on the possibility of external shocks, and what preventative methods can be implemented to reduce the impacts of the shocks. Education can either come from government or a private entity.
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Relationship between external social and economic forces and the resource

To what extent does poverty, gender and/or affluence influence/affect over use and exclusion of the resource?	As <i>Thuba let elihle</i> is dominated by women (99% of crafters are women), and cattle grazing is controlled by men, the consensus was that the women felt that negotiating separate harvesting and grazing areas was futile, as men dominate decision-making and overrule the women in the community.	2	3	6	As the cattle owners may have a wife or daughter who bring money into the household from the selling of crafts (based on Kotze et al. 2002 who stated that 70% of households were found to use craft plants in the wetland), <i>Thuba let elihle</i> must attempt to negotiate separate grazing and harvesting areas before increased grazing or flood events occur.
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Relationship between external social and economic forces and resource users

Are there any internal social and economic forces, such as conflict, which can impact on the demand for wetland services by the enterprise user group?	There was internal conflict between members of <i>Thuba let elihle</i> . Some members were not supportive of the appointed treasurer. Some members felt it unfair that one particular member was always chosen to communicate with potential clients.	3	3	9	Craft group, with external assistance, requires education on internal conflict resolution and business management.
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Are there any external social and economic forces (e.g. interest rates, crime, competition, customers taking credit), which can impact on the demand for wetland services by the enterprise user group?	The success of <i>Thuba let elihle</i> has significantly declined in recent years due to a lack of market awareness and a rival craft group having access to the preferred conference bag material. Although this decline has resulted in reduced demand for wetland material, there is concern that if fewer crafters are involved in craft production there will be less reliance on the health of the system. A consequence of this is that there is potential for detrimental wetland activities to go unnoticed.	3	3	9	Craft group, with external assistance, to become more aware of current market demands (e.g. access to internet and attending workshops and conventions), and to identify products which are better suited to <i>C. latifolius</i> than conference bags.
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Relationship between external social and economic forces and public infrastructure

Have the rules of resource use and benefit sharing been agreed to by all people who have rights of use before use commences?	No. There is no formal understanding of the benefits obtained from the wetland services amongst the different users groups.	3	3	9	<i>Thuba let elihle</i> , with external assistance, to educate those that use (e.g. cattle owners) and manage (Traditional Authority) the wetland system on the importance of the harvested material.
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<p>Are there external social and economic forces (e.g. water provision, housing) creating pressure on the availability of infrastructure which impacts on the enterprises?</p>	<p>Increased unemployment, due to worldwide recession, has resulted in the unemployed returning to their rural homes. Increased rural population increases the pressure on services in the rural area. Reversed urbanisation can lead to increased cultivation and grazing pressures to meet food demand. These activities are likely to impact on the availability of harvestable craft material.</p>	<p>3 1 3</p>	<p>Health of the wetland system to be periodically monitored. To some degree this has been done (e.g. Kotze et al. 2002), but no formal programme exists.</p>
<p><i>Relationship between external social and economic forces and public infrastructure providers</i></p>			
<p>Does government/local governance have capacity/skills to cope with social and economic shocks to the enterprise (resource, access, infrastructure)?</p>	<p>Consensus was that the government would not directly come to the aid of the enterprise, due to its small size. Indirectly the government has assisted with providing social grants to allow those in the community to survive during times of no income. Traditional Authority is not in an economic position to assist the enterprise to cope with economic shocks. However, due to relatively high regard for traditional leadership in the community, the Traditional Authority may be able to provide assistance with social shocks.</p>	<p>1 3 3</p>	<p>Crafters to build awareness of the importance of the enterprise amongst government departments and the Traditional Authority, to pave the way for asking for assistance in times of economic shock.</p>

b) Ranking of risks

Thuba let elihle and the wetland system it relies on, have experienced a number of shocks of varying intensities. According to Bowd et al. (2012b) only high risks (those which scored over 6) are ascribed mitigation measures. However, through applying the toolkit at Mbongolwane it became apparent that amongst the intermediately scoring risks (i.e. a score of 4) there were important risks that were being overlooked, such as the movement of cattle in the wetland, especially if the cumulative impacts of these intermediate risks were considered in an enterprise. As there is potential for an accumulation of these intermediate risks to be greater than a single high risk, all risks that scored over 4 were classified as high risks (Table 2).

Table 2. Summary of high risks (those that scored > 4 in the risk assessment) to *Thuba let elihle* and the wetland system supplying the raw material

Risk	Explanation
Risks which reduce the availability of craft material	
<p>Cattle grazing, and as a consequence, tramped craft material and seasonal burns, temporarily reduces the availability of craft material.</p> <p>Flooding and droughts caused by climatic events.</p>	<p>Thus far the abundance of raw materials has been very high relative to the demand for craft production, as livestock generally only damage a portion of this resource, so crafters have been able to locate undamaged areas. Although indicating their intention to engage livestock owners, it appears that crafters will only do so when undamaged areas become too scarce to meet their demands for craft. There is the possibility that the crafters will leave it too late to act, resulting in insufficient supply of raw material.</p> <p>Although floods were identified as a risk, there are areas of the wetland where raw material is not damaged. Similarly, although the quality of the resource on the drier margins of the <i>C. latifolius</i> was negatively affected by drought, extensive areas currently still remain wet enough during droughts for <i>C. latifolius</i> to grow to acceptable length and quality for weaving. However, with future climate scenarios predicting an increase in variability of rainfall, and a decrease of up to 25% in available water resources over the next few decades (IPCC 2007, Shackleton and Shackleton 2012), South Africa is predicted to become hotter and drier with increased annual rainfall (Hope 2009).</p>
<p>Reduced water in wetland as a consequence of activities in the catchment.</p> <p>Crafting material being collected by those living outside of the area.</p> <p>No official monitoring protocol.</p>	<p>Although based on past experiences the supply of <i>C. latifolius</i> is very resilient to drought, if water use in the upstream catchment is increased (e.g. by the planting of timber or sugar cane) this may disrupt the supply of <i>C. latifolius</i>.</p> <p>The introduction of charging outside harvesters may result in over-harvesting as people may want to get value for money when collecting material, however the impact of this is dependent on the fee structure (e.g. per visit, per bundle).</p> <p>The availability of raw material could be depleting, as there is no official protocol for monitoring the health of the wetland, or for monitoring the availability of the raw material which grows in the wetland.</p>
Risks which reduce access to craft material	
<p>Craft material being sourced from a common pool resource which is controlled by a male-dominated society.</p> <p>Crafters are generally poorer members of society who have limited social standing and are not consulted in decision-making.</p>	<p>Those in authoritative positions (e.g. representatives from agricultural departments, Traditional Authorities) are either unaware of or are dismissive (due to inequality between the sexes) of the contributions (financial, emotional etc.) crafting has to households in the community.</p> <p>Frequently decisions are made in the interests of the wealthier members of society, as these people generally have the most influence over decision-makers, or are the actual decision-makers themselves.</p>
Risks which reduce demand for the product	
<p>Competing craft group took <i>Thuba let elihle</i>'s market share.</p> <p>Product no longer being regarded as a novelty.</p> <p>Only inferior craft material is available to make products which are in demand.</p> <p>Insufficient active marketing.</p>	<p>During 2007 a "rival" craft group started producing conference folders made from <i>Cyperus involucratus (iNduma)</i> which is better suited to the making of conference folders and which does not grow at Mbongolwane. Consequently the rival product became generally more favoured than those produced by <i>Thuba let elihle</i>. Although <i>C. latifolius</i> is not ideally suited to the making of conference folders, due to its lack of durability in comparison to other wetland plants, notably <i>Juncus kraussii (iNcema)</i> (Van Wyk and Gericke 2000), it was selected as it was far more widely available at the wetland in comparison to the other wetland plant species. As the use of <i>C. latifolius</i> for the production of conference folders was not optimal, this created a risk with the product. <i>Thuba let elihle</i> had made conference folders for a number of large government conferences. As the majority of these conferences are held annually, organisers look to vary corporate gifts.</p> <p>The current demand is for 'dainty' woven craft products which are produced using material which does not occur, or is in short supply at Mbongolwane.</p> <p>Without external assistance, <i>Thuba let elihle</i> does not have the ability to actively market as the group has low literacy and a lack of skills and knowledge in this area.</p>
Internal business dynamics	
<p>Crafters have a low level of literacy.</p>	<p>As a consequence of low literacy levels, the crafters have limited business knowledge and product development and marketing skills. They are generally</p>

As crafters rely on the income to meet basic needs, making provision for outlay costs is difficult.	not fully proficient in the speaking, reading and writing of English. Although lapses in the maintenance of the craft centre have resulted in craft material and products being damaged, when <i>Thuba let elihle</i> was functioning well, an agreed upon percentage of earnings was designated for maintenance and running costs. Due to limited funds now being available, it is not possible to repair the centre.
Miscommunication between craft members, and craft members and clients.	There is a lack of funds to pay for outlay costs (the purchase of material which is needed for some products, e.g. twine). Miscommunication between these parties has resulted in production deadlines being missed and payments being delayed. In one instance, conference folders for one order were redirected to another order, because their deadline was sooner, and because there was no accurate counting of products made. With orders still not being able to be fulfilled (for <i>izicephu</i>), adequate planning and time management are areas where the crafters need to improve, because "even with 'fake' deadlines we still couldn't meet the deadlines".
Internal stealing of craft group funds Reduced numbers of crafters.	In response to this the guilty members were excluded from the craft group. This can be attributed to: i) the younger generation not being interested in becoming involved in a resource-based enterprise, as government grants provide sufficient money to survive; ii) previous members finding an income to sustain their livelihoods elsewhere; iii) the older generation who predominantly were involved in craft dying out, and the younger generation being more interested in "office jobs and waitressing as it doesn't damage your hands".

c) Comparison of literature review-based risks and toolkit assessed risks

The findings from the case study and literature review reveal that there are social, economic and ecological risks associated with a craft NRBE (Table 3). Most, but not all, of the literature review-based risks were noted in the risk assessment. Those absent were predominantly economic risks which were related to the internal business dynamics of an enterprise. The two omitted social risks were also related to internal business dynamics. There were two risks identified through the toolkit which were not encountered in the literature review; a lack of a wetland health monitoring protocol, and conflicts between the different crafters.

Table 3. Comparison between risks commonly associated with natural resource-based enterprises identified in the literature review and those identified in the case study

Risks identified in natural resource-based enterprise literature	Adequately addressed in case study
Social environmental risk	
Access to communication and transport infrastructure (Taylor et al. 1996, Shackleton 2005)	yes
Lack of literacy, skills and training (Shackleton 2005, Makhado 2004)	yes
Access to market (and as a consequence the market has limited knowledge of product) (Kusters et al. 2006, Shackleton 2005)	yes
Lack of policy to support NRBE (Shackleton 2005)	yes
Unsympathetic attitude of those controlling material, and thus insecure access to material (Shackleton 2005)	yes
Competition and reduced market share due to oversupply (Shackleton 2005)	yes
Being responsible for tasks which you do not specialise in (Breen 2013)	yes
Developing skills which are very different to current skills set (Breen 2013)	yes
Women not being involved in decision making (Shackleton and Shackleton 2012)	yes
Lengthy decision-making processes (Breen 2013)	no
Low volume of products (Taylor et al. 1996)	yes
Poor quality control (Taylor et al. 1996)	no
Poor handling and storage of products and material (Taylor et al. 1996)	yes
Economic environmental risk	
Lack of demand (Shackleton 2005)	yes
Buyers using credit (Shackleton 2005)	yes
Transport costs associated with both raw material and finished product (Shackleton 2005)	no
Cost of raw material and additional material (Shackleton 2005)	no
Poor return for effort (Shackleton 2005)	no
Middleman profits; crafters are not fully rewarded for their efforts (as a consequence poverty is prolonged) (Taylor et al. 1996)	no
Lack of start-up capital (Kusters et al. 2006, Shackleton and Shackleton 2012)	no
Ecological environmental risk	
Shortage and seasonal variation of raw material (Taylor et al. 1996, Shackleton 2005, Shackleton and Shackleton 2012)	yes
Damage to raw material (Taylor et al. 1996, Shackleton 2005)	yes
Burning (planned) (Taylor et al. 1996, Contreras 2010)	yes
Floods (Taylor et al. 1996, Contreras 2010)	yes
Droughts and unplanned fires (Taylor et al. 1996, Contreras 2010)	yes
Climate change and a reduction in quality of raw material (Taylor et al. 1996, Contreras 2010, Shackleton et al. 2010)	yes

d) A SES conceptual framework for craft related NRBEs

The Anderies et al. (2004) SES conceptual framework has been amended to include internal business dynamics (Figure 2). The accompanying Table 4 defines the components and interlinkages within the resultant SES conceptual framework and includes ten internal dynamics which impact upon product supply and the creation and meeting of product demand.

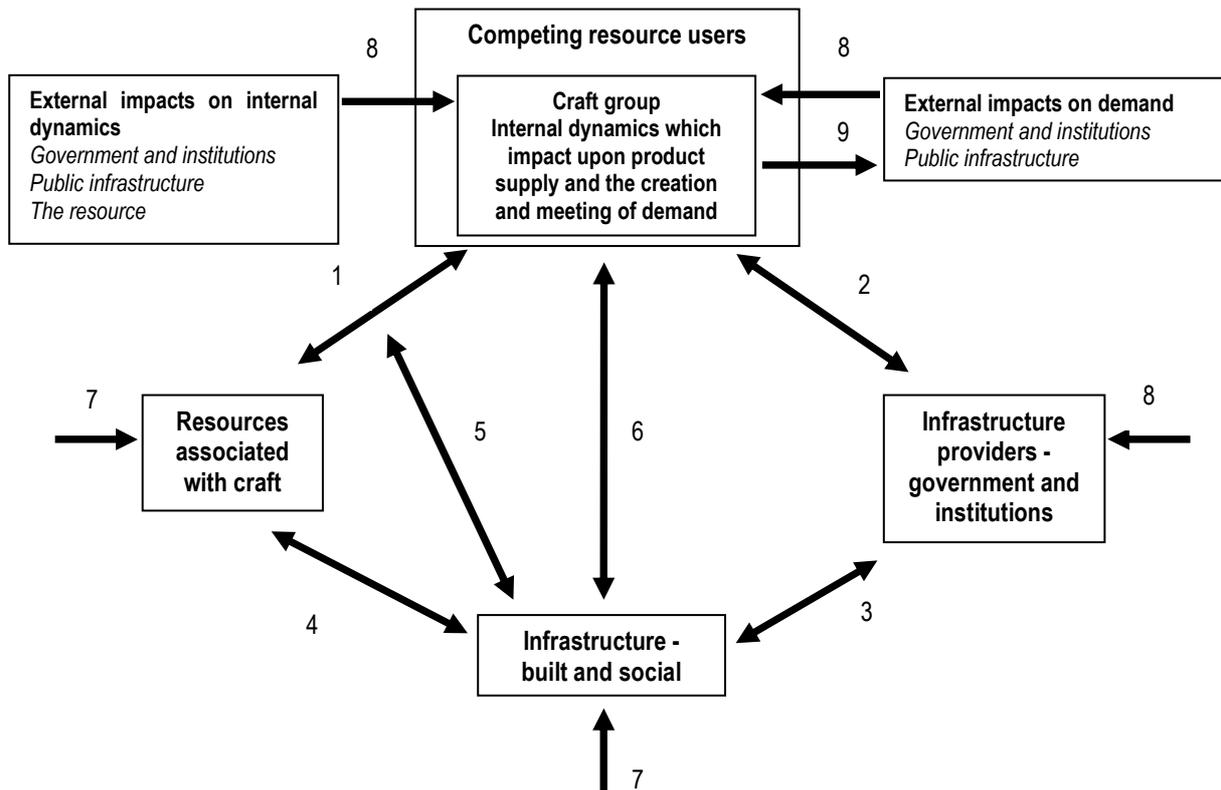


Figure 2. Amended Anderies et al. (2004) social-ecological system conceptual framework for craft related natural resource-based enterprises

Table 4. Interlinkages and components within a craft related natural resource-based enterprise social-ecological system, adapted from Anderies et al. (2004), Contreras (2010), Bowd et al. (2012)

Component / linkage	Example / explanation / risk
Competing resource users	Those that live: amongst, adjacent to, upstream, downstream of the ecosystem service(s), and who: travel to use the resource, may never visit but have an interest in the well-being of the resource
Craft group Internal dynamics which impact upon product supply and the creation and meeting of demand	<p>Members of the craft group</p> <p>Ability to:</p> <ol style="list-style-type: none"> 1. Communicate amongst the crafters (e.g. conflict resolution, provision for maintenance costs, prompt decision-making processes, organise material and product production) and between the crafters and the market (e.g. language barrier) 2. Develop new skills and be responsible for tasks which one is not specialised in 3. Plan for future reduction in the availability of material 4. Develop high demand products with acceptable returns for effort, and obtain appropriate material 5. Handle and store products and material 6. Maintain high levels of quality control 7. Access start-up capital, outlay costs (e.g. purchase of suitable material) and surplus funds during lean times 8. Overcome gender inequality to secure access to material 9. Obtain assistance from external support 10. Attract crafters to meet orders during times of high demand
External impacts on internal dynamics	<p>Government and institutions have resulted in:</p> <ul style="list-style-type: none"> • Poor literacy levels • Poor skills development and training • Retaining cultural ties and traditions <p>Public infrastructure</p> <ul style="list-style-type: none"> • Roads • Transport • Telecommunication <p>The resource</p> <ul style="list-style-type: none"> • Lack of suitable material to meet product demand (e.g. as a consequence of climate change, competing resource users, ownership and management of resource)
External impacts on demand	<p>Government and institutions</p> <ul style="list-style-type: none"> • Market unable to communicate with crafters due to crafters having poor literacy levels, skills development and training. This results in: <ul style="list-style-type: none"> ○ Ignorance of competition ○ Reduced market share due to over supply ○ Unawareness of ever changing market demands ○ Demand exceeding production volumes ○ Middlemen profiting at the expense of crafters • Changes in policy (e.g. environmental awareness and monitoring of wetlands may result in an increase or decrease in demand for wetland

	<ul style="list-style-type: none"> • products) • Changes in political environment (e.g. leader not liked by international community thus the boycotting of products from certain countries) • Buyers using credit • Financial crisis
Resources associated to craft Infrastructure – built and social	<p>Public infrastructure</p> <ul style="list-style-type: none"> • Due to a lack of or high cost of public infrastructure: <ul style="list-style-type: none"> ○ Cost of product not competitive due to high transport costs ○ No / limited communication due to high cost or limited availability <p>Raw material used to make products</p> <p>Built: transformation</p> <p>Social: legal & regulatory, institutional, knowledge, skills, communication, relationships</p> <p>Government (national, provincial & local), private sector (local and international), local communities, NGOs, community-based organisations, academic organisations</p> <p>Competition between the craft group and other raw material users</p> <p>Legislation which favors craft group activities over other resource user activities and vice versa</p> <p>The provision, monitoring and maintenance of infrastructure by those responsible for providing infrastructure</p>
Infrastructure providers – government and institutions	
(1) Between resource and resource users	
(2) Between users and infrastructure providers	
(3) Between infrastructure providers and infrastructure	
(4) Between infrastructure and resource	
(5) Between infrastructure and resource dynamics	
(6) Between resource users and infrastructure	
(7) External biophysical forces on resource and infrastructure	
(8) External forces on resource users and infrastructure providers	
(9) Internal forces on demand	

e) Recommendations to achieve a resilient NRBE

Recommendations towards establishing and operating a resilient NRBE, which were identified through the literature review and case study, have been divided into social, economic and ecological recommendations (Table 5).

Table 5. Summary of recommendations to achieve a resilient NRBE

Social

- A strong institutional arrangement must be in place to enforce control (De Jong et al. 2000, Sunderland et al. 2004, Shackleton 2005)
- Decision-making around resource management must involve competing land users (Buck et al. 2014) and must build on local knowledge, as well as external scientific knowledge, in order to gain an accurate understanding of resource dynamics (Wood and Thawe 2013)
- Recognition that financial reward from craft is not the only contribution made to livelihoods. Social benefits also play a role in livelihood upliftment (Breen 2013)
- Promote social learning which involves interactions between competing users. Social learning has two possible outcomes: a) a change in understanding and behaviour amongst those involved; and b) the knock-on effect of changing the behaviour of those in the wider community (Reed et al. 2010). Thus, it is important to identify how people learn best and change their practices through learning methods (Shackleton and Shackleton 2012)
- Reflect on likely future scenarios and take these into account in management (e.g. how climate change could affect the availability of the resource (Breen 2013)
- Keep open channels of communication between those in authoritative positions who have control on the natural resource, and the main competitors for the resource (Breen 2013)
- Be aware of the need for quality and standards to be set high at the onset, to deter competition and keep the national and international market loyal and confident in the product
- Be aware of the groups' limitations and, as far as possible, ensure that those designated responsible for tasks are suitably qualified
- Ensure that continual training occurs
- Know the limitations of the group and do not over-stretch both the resource and the crafters by promising more than what can be delivered
- A holistic approach, which considers: i) the ignorance of market forces, and development agencies of the rural people (their needs, aspirations and traditional resource management practices); ii) the resource based, its size and characteristics; and iii) the ownership of the resource (Taylor et al. 1996) must be adopted
- Use of a diversity of species, production of innovative products (Taylor et al. 1996) and trade with a variety of markets (Shackleton 2005)

Economic

- Government, conservation and development organisations involved with NRBEs to be made aware of the trade-offs, as more socio-economic benefits can mean less ecological benefits and vice versa. This awareness helps formulate realistic objectives (Kusters et al. 2006)
- Be aware of buyers using credit and middleman excessively benefiting from the crafters' hard work. However the crafters are in a vulnerable position if their work is not in high demand
- Determine what percentages of earnings need to be reinvested for maintenance and day-to-day running costs
- Institutional development and economic rewards to retain the interests of those involved in the enterprise (Wood and Thawe 2013, Shackleton and Shackleton 2012)

Ecological

- Appropriate and sustainable harvesting procedures must be employed (Shackleton 2005)
 - Continual monitoring of the health and availability of the resource
 - Others uses/developments (both within the wetland and in its upstream catchment) potentially impacting upon the resource need to be controlled
-

4. DISCUSSION

Numerous risks associated with *Thuba let elihle* and the wetland system supplying the raw material were identified and high risks could be grouped under four categories: those which reduce the availability of material to make the product; those which reduce access to the material; those which reduce the demand for the product and those associated with internal business dynamics. Of the sixteen high risks identified, three were purely ecological, nine were purely social, three were social-economic and one was ecological-economic (Table 6). There were no purely economic risks identified. This was not entirely unexpected as the SES conceptual framework is not directly concerned with economic impacts. Although the grouping 'internal business dynamics' shows that the SES conceptual framework led to the identification of internal business risks, these risks are all linked to social aspects within a SES.

Of the sixteen high risks identified, nine were broad landscape-level and seven were enterprise-level risks which were related to internal business dynamics. Anderies et al. (2004) require the identification of a system's boundary; identified as the physical boundary within the landscape upon which the social environment depends (Resilience Alliance 2007). As Anderies et al. (2004) focus on landscape-level interactions, the identification of so many enterprise-level risks is unexpected. Remembering, however, that Anderies et al. (2004) emphasise that SESs function as a nested, hierarchical structure, with processes occurring within different subsystems at different rates and scales (Gunderson and Holling 2002, Walker et al. 2002), perhaps the presence of enterprise-level risks is not so unexpected. The seven enterprise-level risks are: competition from another craft group, insufficient active marketing, product no longer being regarded as a novelty, low literacy, no surplus funds for outlay costs, miscommunication amongst the crafters and clients and the stealing of funds. These risks are as a consequence of crafters having low literacy and having to turn to craft as a survival strategy due to poverty.

There was no tendency for high risks to be associated with any particular interlinkage or component within the Anderies et al. (2004) SES framework. Although enterprise-level risk did emerge from applying the Anderies et al. (2004) SES framework, these risks do not seem to fit with any of the particular interlinkages or components. They are probably best placed within the 'competing resource users' component, as the craft group is one of these.

Table 6. High risks identified in the case study, grouped into social, economic and ecological risks

Risk grouping	Social	Economic	Ecological
Risks which reduce the availability of material	<ul style="list-style-type: none"> • Trampled and burnt material due to cattle grazing • Competition from outside harvesters 	<ul style="list-style-type: none"> • Reduced water available in catchment due to economic activity 	<ul style="list-style-type: none"> • Flooding and drought • No monitoring protocol
Risks which reduce access to the material	<ul style="list-style-type: none"> • Material being sourced from a common-pool resource <ul style="list-style-type: none"> • Poorer members of society with limited social standing to participate in decision-making 		
Risks which reduce the demand for the product	<ul style="list-style-type: none"> • Competing craft group took market share • Product no longer novel • Insufficient active marketing 		<ul style="list-style-type: none"> • Only inferior material to make high demand product
Risks associated with internal business dynamics	<ul style="list-style-type: none"> • Low level of literacy <ul style="list-style-type: none"> • No surplus funds for outlay costs • Miscommunication amongst crafters and client <ul style="list-style-type: none"> • Stealing of group funds • Reduced numbers of crafters 		

When comparing the risks from the literature review to the risks linked to the case study, the risk assessment revealed that no ecological risks were missed, however there were two social and five economic risks which were not identified through application of the toolkit. Possible explanations for the omission of these risks are provided in Table 7.

Table 7. Possible explanations for the omission of certain risks when implementing the risk assessment

Social environmental risk	
1. Lengthy decision-making processes	As the craft group was instructed and overseen by the wholesalers, their need to make decisions was minimal
2. Poor quality control	The Land Care Project facilitated a process where skilled crafters helped less skilled crafters attain the necessary quality and the group appointed a few very skilled crafters to carry out their quality control within the group. If a folder was not of sufficient quality, it was rejected and the crafter would not get paid, so quality did not emerge as an issue
Economic environmental risk	
1. Transport costs associated with both raw material and finished product	Wholesalers were responsible for the transportation of the finished products, and the supply of raw material is accessible on foot
2. Cost of raw material and additional material	Additional material required to make the folders (e.g. twine and logo badge) were given to the crafters
3. Poor return for effort	Conference folders are a high price product, thus crafters do not mind "working until 2am to meet deadlines"
4. Middlemen profiting at the expense of the crafters	There were no middlemen involved with the buying of the product, only wholesalers
5. Lack of start-up capital	The initial venture was government funded

However, a broader reason for the toolkit not identifying these risks is the fact that they are directly related to internal business dynamics. As the framework on which the questions are based is focused on ecological and social sciences (Binder et al. 2013), it is not unexpected that issues surrounding internal enterprise dynamics were not profiled. This reveals a potential gap in SES theory when applied to NRBEs.

Two identified risks were not noted in the literature review: a lack of a wetland health monitoring protocol, which is an ecological risk, and conflicts between the different crafters (e.g. the stealing of funds), which is considered a social risk. Anderies et al. (2004) promote the consideration of monitoring through assessing the relationship between 'public infrastructure' (rules and regulations) and 'public infrastructure provider' (those responsible for enforcing these rules and regulations), which is interlinkage '3'. Anderies et al. (2004) illustrate that there are a variety of resource users who can compete for a resource, by referring to 'resource users' as a plural. However, there is no specific prompt to consider inter-user conflicts. This probably arises because the Anderies et al. (2004) SES conceptual framework is intended for application at a broad landscape level, rather than an enterprise level.

Although it has failed to identify risks associated with the internal business dynamics and economics of NRBEs, the Anderies et al. (2004) SES conceptual framework has nevertheless provided an effective means to identify social and ecological risks at a landscape level. In response to this shortcoming, we propose the following amendments, reflected in Figure 2:

- Combining the Anderies et al. (2004) 'infrastructure providers' and the Contreras (2010) 'government and institution' into a single component called 'infrastructure providers – government and institutions' to emphasise that 'infrastructure providers' can be both government and non-government types of institutions.
- The component 'infrastructure' renamed 'infrastructure – built and social', to increase awareness that 'infrastructure' does not solely mean physical structures.
- 'Public' has been removed from 'infrastructure' to avoid the exclusion of private entities and infrastructure.
- The 'resource' has been expanded to 'resources associated with craft' to make the framework more craft-specific and to exclude the consideration of non-craft related resources.
- 'Competing' has been added to 'resource users' to promote awareness that other entities could reduce the availability of the resource on which the NRBE is based.
- 'Craft group' has been placed in its own box within the 'competing resource users', because the craft group is one of the 'competing resource users', and is the focus of the SES.
- External forces on 'competing resource users', namely the craft group, and has been split into two: i) external impacts on internal dynamics; and ii) external impacts on demand. Both these external impacts impact upon the internal dynamics of a NRBE which, in turn, impact upon product supply and creating and meeting demand for a NRBP. External impacts can be from: i) 'Infrastructure providers – government and institutions' and ii) 'Infrastructure – built and social'. The 'resource' has been added to 'external impacts on internal dynamic' as state and availability of the 'resource' impacts on the internal functioning of the craft group.
- A ninth interlinkage, 'internal forces on demand', has been added, as this facilitates the consideration of how the internal dynamics of the NRBE impacts upon the demand for products.

Our findings illustrate that the SES for a NRBE, at a landscape level, is highly complex, but also that the dynamics within an NRBE are just as complex. Being resilient to shocks within the internal workings of an enterprise is as important as being resilient to shocks at a landscape level. In fact, the degree to which an enterprise is resilient to external shocks is highly likely to

be influenced by the level of internal resilience of an enterprise. Of key importance when assessing the resilience to internal shocks is the motivation, attitudes and commitment of personnel (Shackleton 2005).

This study isolates four underlying and interlinking obstacles which impede achieving a resilient NRBE: material being sourced from a common pool resource, gender inequality, poverty and low literacy (Figure 3).

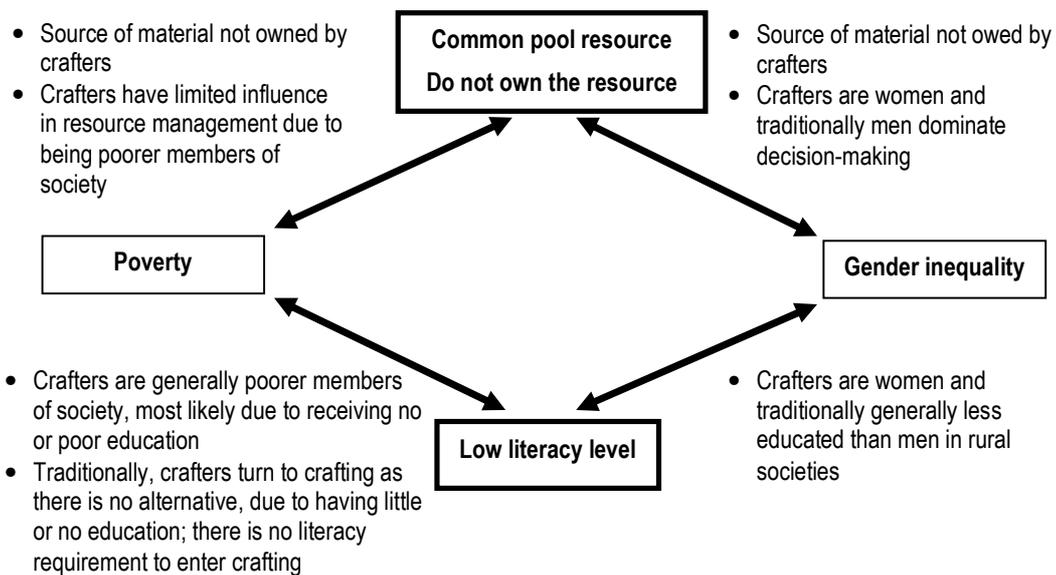


Figure 3. Main obstacles which hinder achieving resilient craft related natural resource-based enterprises

The wetland is regarded as a common-pool resource for which access and use are generally regulated by a community-based institution; this is a unique aspect of NRBEs in comparison to usual businesses (Breen 2013). The nature of the regulation is usually dependent on whether the benefits are realised internally or externally. When a resource is benefiting the community (internal benefits), the regulations surrounding its use are generally informal but well understood by all. When benefits are recognised externally, the regulations are generally more formal (Breen 2013). In the case of Mbongolwane the need for outside harvesters to have a letter from the chief, and the proposed introduction of a charging system for these people, reflects the findings of Breen (2013). One response to the toolkit was that it “opened their minds” to the importance of the wetland, and crafters realised that controls needed to be in place so the wetland could be managed for conservation purposes “something we have not thought about as

important before". Without the external intervention of this research, the crafters would not have realised the importance of wetland functioning, to the extent they now do.

The principle behind common pool resources is that while the state owns the resource on behalf of the community, the community has the right to manage its use, which includes determining who may and may not use the resource (Breen 2013). If the resource was portioned up and privately held, then shocks are likely to affect those crafters who own the portions which fall within the affected areas. However, as the resource is accessible to the community (apart from the areas which have been given to people for cultivation), and the wetland is large enough to cope with shocks (such as cattle grazing, floods, droughts and burning), crafters are easily able to move to undamaged areas, as these environmental shocks seldom affect the entire wetland uniformly. Although in this instance the use of a common pool resource is beneficial to the crafters, Taylor et al. (1996) believe that this arrangement leaves the resource open to exploitation. They suggest that if people are given ownership of a resource, they are more likely to protect it, which will in turn lead to increased resilience (Shackleton and Shackleton 2012). Although it would not be beneficial for individual crafters to own portions of the wetland, there could be merit in the community taking greater ownership of the entire wetland.

Although the use of a common pool resource benefits the crafters, there are associated negative implications. Frequently when a common pool resource is used by a NRBE there is the expectation that it will benefit the community as a whole (Kusters et al. 2006, Breen 2013). If this does not occur, there is often disinterest from those who manage the resource. The resource is managed by a Tribal Authority, who requires payment if involved in dispute resolution (e.g. conflicting land uses). The crafters said that "the previous chief knew about this project, however the new chief, his son, does not know. He has only been to the wetland once. The leaders are not good". This gives the impression that the managing institution, which is patriarchal, is not concerned with the female-run enterprise. Even though a women's position in a household is strengthened when they engage in economic activity (Kusters et al. 2006), the role of women in decision-making and managing the resource is very limited at Mbongolwane. The women claimed that the wetland was not owned by them, and that "we do not have the right to tell the cattle to get out of the wetland". This suggests that the women have this opinion because cattle are predominantly owned by men. Pereira et al. (2006) and Shackleton et al. (2008) noted that the proportional contribution to livelihoods from natural resources was several times higher for female-headed households in comparison to wealthier ones. Many of the

crafters were from women-headed households (in many cases the crafters were solely responsible for the upbringing of grandchildren without husbands or children to assist). Although these women received social grants (pension and orphan), these grants were not sufficient for survival: “crafting supplements our pension”. According to Steyn (2013) there is evidence that the poor usually do not benefit from improved resources (e.g. availability of improved grazing as a result of prohibiting cultivation in wetlands), but instead bear most of the costs (e.g. increase in eutrophication and thus reduced water quality as a result of increased cattle movement in the wetland). They suggest that this is due to the poor not being well represented in the decision-making so that resource use restrictions are not defined in the interests of the poor, but rather in the interest of the better-off. Our research echoes the findings of Steyn (2013) as a combination of gender inequality and the craft enterprise attracting the poor as a survival strategy, has resulted in crafters not ‘having a voice’ in the management of the wetland.

The wetland appears to be managed in the interests of the cattle farmers with 45% of the wetland area being regularly used for grazing (Breen 2013). Although livestock do not contribute greatly to the local economy (Breen 2013), it is apparent that the interests of the cattle owners, who are regarded as wealthier members of the community, take priority.

Women turn to crafting as a ‘safety net’ at a time in their lives when living costs increase (as a result of a death of a breadwinner (Shackleton and Shackleton 2012), or due to the costs associated with caring for children) and when there is no alternative source of income, or when they are no longer able to do more lucrative work because they have to care for the young and the sick. Turning to natural resources as a ‘safety-net’ can mean: i) increased use of a resource already used as part of their livelihood; ii) use of a resource which is not usually used; and temporary use of a resource which may develop into a permanent livelihood strategy (Shackleton and Shackleton 2004). Crafting at Mbongolwane is not generally permanent: crafters here also seem to turn to this source of income in times of need. Crafting was considered appealing as there were no outlay costs, other than a sickle and a frame, and women could weave in the evenings (when children had gone to bed, or ‘after a day in the garden’). Although the consensus was that the young were not interested in craft, which the crafters frowned upon, and that crafting was ‘dying out’ because of this lack of interest from the younger generation, we speculate that the young today may well turn to crafting when the need arises (e.g. they have children and the sick to look after, or when there is no alternative income).

There are a number of possible explanations for the gender imbalance in crafters at Mbongolwane. One could be that crafting is used as a livelihood strategy by the poorest members of society and these members are likely to be those with no or limited formal education. As the level of illiteracy is far higher for women compared to men in rural Africa, men are more likely to be able to find an alternative and more lucrative income compared to crafting. Another explanation could be because craft weaving is traditionally a women's activity in Zulu culture. A point for further work could be a comparative study between men and women operated NRBEs, to determine the extent to which gender inequality, as opposed to other factors, impedes NRBEs.

Thuba let elihle was formed with external assistance, and those involved did not necessarily have 'business savvy'. Had this been so, they may have already been involved with more lucrative work, and would not be looking to craft to meet their basic needs. Although the initial training and subsequent withdrawal of the external assistance was planned and considered appropriate, in practice it has not worked.

The only solution to overcoming the underlying obstacles is to reintroduce external public and / or private assistance to address each impediment. We suggest that, given the severity and deep-rooted nature of these obstacles, external assistance will be required for the foreseeable future, if not for the lifetime of the enterprise. Dixon et al. (2013) also argue that common pool resources are often unable to function effectively without external support, such as that provided by government or non-government organisations (NGOs).

As external assistance is unlikely to be available in perpetuity, the livelihoods of the crafters will be dependent on their adaptive capacity, which includes their ability to develop a collective identity and to take collective action. Although the crafters demonstrated adaptive capacity by turning to planting of vegetable gardens in times of no orders, shifting where the resource is harvested in response to the temporary impacts of floods and fires, the training of their husbands to make conference folders in an effort to meet deadlines and improving their financial controls when group funds were stolen, their adaptive capacity to cope with and to prepare for shocks is hindered by gender inequality, low literacy, poverty and being dependent on a resource which they do not own or control its management.

5. CONCLUSION

Anderies et al. (2004) provided a strong foundation on which to develop a craft-related SES conceptual framework, enabling a broad understanding of the social and ecological risks associated with a NRBE at a landscape level. Although Anderies et al. (2004) has its origins in the political and ecological sciences (Binder et al. 2013), a number of economic (enterprise level) risks associated with internal business dynamics were nevertheless identified.

The applicability of the Anderies et al. (2004) SES framework to craft-based enterprises has been improved through refining nomenclature and extending interlinkages, including internal dynamics which impact upon product supply and the meeting of demand. This is important because being resilient to shocks at an enterprise level is as important as being resilient to shocks at a landscape level, as the degree to which an enterprise is resilient to external shocks will be influenced by the level of internal resilience of an enterprise.

It can be concluded that the inherently resilient resource of *C. latifolius* at Mbongolwane can contribute to reconciling conservation and development objectives. However, given the level of skills and lack of control of the common pool resource by the crafters, due to poverty and gender inequality, the contribution of the enterprise to development will depend strongly on outside assistance (such as from government departments, non-governmental organisations or private entities).

A limitation of this study is that data were collected from a single enterprise operating at a single location. It is recommended that further research is undertaken for a variety of NRBEs (e.g. wood carving, broom making), at locations which represent a diversity of SESs (e.g. resource being extracted from a protected area or commercially owned land (multi-national timber company)).

6. ACKNOWLEDGMENT

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CHAPTER 5: PAPER 3

Towards an analytical framework for understanding complex social ecological systems when conducting Environmental Impact Assessments in South Africa

Table 5.1. Summary of Paper 3

Information	Details
Title:	Towards an analytical framework for understanding complex social ecological systems when conducting Environmental Impact Assessments in South Africa
Paper status:	Published
Journal website:	www.ecologyandsociety.org/
Citation:	Bowd, R., Quinn, N., & Kotze, D. C. (2015). Towards an analytical framework for understanding complex social ecological systems when conducting Environmental Impact Assessments in South Africa. <i>Ecology and Society</i> , 20(1): 41 http://www.ecologyandsociety.org/vol20/iss1/art41/
Objective(s):	<p>Develop a systematic framework for EIA practice in South Africa, which encourages public participation, and which helps understand and interpret the interrelationships and interdependences within the SES a proposed development could impact upon. The developed framework was required to be evaluated against the following four criteria:</p> <ul style="list-style-type: none"> • Using Binder et al. (2013) assess whether the framework helps understand the interrelationships and interdependencies within a SES. • Evaluate its ability to provide a means of effectively communicating impacts. • Evaluate its ability to promote an integrated, comprehensive and detailed understanding of the impacts. • Given that the framework was developed using work surrounding estuaries and natural resource-based enterprises, assess its transferability to a different type of development and environment.
Methods used:	<ul style="list-style-type: none"> • Literature review to identify the inadequacies of tools used globally in EIA practice, and identify the shortcomings of EIA practice in South Africa. • Development of a framework using estuary case study example (Papers 1 and 2). • Evaluation of the framework using the set of four criteria.
Key findings / outcomes of paper:	<p>The framework:</p> <ul style="list-style-type: none"> • promotes the consideration of all six aspects of the environment, with equal attention given to the social and ecological systems, and provides a mechanism to identify and understand interlinkages between the components of a SES at a range of social scales. • encourages an Environmental Assessment practitioner (EAP) to understand the environmental implications of a development at a broad, systemic scale initially, but then allows the EAP to focus on the specific issues that may impact upon the supply of ecosystem services. • helps identify the ancillary infrastructure requirements and those who may be responsible for its supply and maintenance. This is frequently a cause of failure in development. • provides a platform for discussing, understanding and communicating impacts between and among stakeholders, thereby fostering social learning and effective public participation in EIA. • is transferable to different types of development. • in comparison to a conventional matrix, helps describe and explore potential interrelationships in a more useful way.

Research

Towards an analytical framework for understanding complex social ecological systems when conducting Environmental Impact Assessments in South Africa

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ABSTRACT

Consideration of biophysical impacts has historically dominated environmental impact assessment (EIA) practice. Despite the emergence of social impact assessment, the consideration of socio-economic impacts in EIA is variable, as is the extent of their integration in EIA findings. There is growing recognition for the need to move EIA practice towards sustainability assessment, characterised by comprehensiveness (scope of impacts), integration (of biophysical and socio-economic impacts) and a greater strategic focus. This is particularly the case in developing regions and in countries like South Africa which have statutory requirements for the full consideration of socio-economic impacts in EIA. We suggest that EIA practice could benefit from incorporating evolving theory around social-ecological systems (SES) as an effective way of moving towards sustainability assessment. As far as we are aware this study constitutes the first attempt to apply and formalise SES constructs to EIA practice within a regulated procedure. Our framework goes beyond conventional scoping approaches reliant on checklists and matrices by requiring the EIA practitioner to co-create a conceptual model of the current and future social-ecological system with the impacted communities. This means social and biophysical impacts are assessed integratively and that communities participate meaningfully in the EIA process, thereby helping address two of the most common shortfalls of EIA practice. The framework was applied in two case studies, establishment of community-based accommodation linked to existing tourism infrastructure (Eastern Cape, South Africa), and a proposed wine estate (KwaZulu-Natal, South Africa). The framework revealed impacts which would not be considered in a biophysically-oriented EIA and helped identify development synergies and institutional and governance needs that are equally likely to have been overlooked. We suggest the framework has value as a counterpoint to established approaches and could contribute to improving the quality of EIAs in respect of the complex SESs that characterise the developing world.

KEY WORDS: *Ecosystem services; Environmental Impact Assessment (EIA); Framework; Participation; Social-ecological system (SES); Sustainability assessment*

INTRODUCTION

Environmental Impact Assessment (EIA) is recognised globally as a principal tool in environmental management and is entrenched in domestic and international law (Ortolano and Shepherd 1995, Morgan 2012). Fundamental to EIA practice is consideration of the interrelationships between the social, economic and biophysical aspects of a project (IAIA 1999), and early principles for the design and development of effective EIA processes (Fuller 1999:57) acknowledged that their scope should extend to “all aspects of a proposal, including cumulative effects, interrelated socio-economic, cultural and health factors and sustainability implications”. In practice however, EIAs have dealt predominantly with biophysical impacts, leading Social Impact Assessment (SIA) to be described as the ‘poor relation’ and ‘orphan’ of the EIA process in the US and UK (Glasson and Heaney 1993, Burdge 2002, Chadwick 2002). The resulting debate stimulated development of International Principles for Social Impact Assessment (SIA) (Vanclay 2003:6) acknowledging that good practice in SIA “accepts that social, economic and biophysical impacts are inherently and inextricably interconnected”. Although SIA has since emerged as a specialised area within EIA, compared to “biophysical issues, SIA usually has a minor role” (Esteves et al. 2012), and consideration of socio-economic impacts in EIA globally is variable and often very weak (Glasson et al. 2012). Where they are assessed, there is a tendency to focus on positive, measurable and direct economic impacts (Fisher 2011), whilst consideration of socio-cultural impacts is marginal (Glasson et al. 2012). In the case of South Africa, du Pisani and Sandham (2006:707) suggest that SIA practice is “neglected” and “not yet on a sound footing”, and can still be considered the ‘orphan’ of EIA (Hildebrandt and Sandham 2014:20). Whilst there is clearly an ongoing debate regarding the relationship between SIA and EIA, we take the view that assessment of socio-economic impacts is integral to EIA and therefore the domain of the EIA practitioner is the social-ecological system potentially impacted by a development proposal.

Social-ecological systems (SESs) can be viewed as a nested hierarchy of geographical, physical, biological, social, economic and cultural subsystems that interact interdependently, and at different temporal and spatial scales, and wherein some of the interdependent relationships with humans are mediated through interactions with ecological units (Walker et al. 2002, Anderies et al. 2004, Ostrom 2009). They are, therefore, complex and multidimensional, and despite often forming the subject matter of environmental assessments, are often considered from a reductionist/rationalist perspective in EIAs (Lawrence 2000, Cashmore 2004, Bond and Morrison-Saunders 2011). Pope et al. (2013) acknowledge emerging opportunities for

EIA practice lie in the further incorporation of concepts such as system dynamics, resilience and ecosystem services into impact assessment. This paper seeks to contribute to this debate and we suggest that EIA practice could benefit from incorporating evolving theory in the SES and complex systems literature, in particular, Anderies et al. (2004), Ostrom (2007, 2009), and Binder et al. (2013). We modify and extend these approaches and link them to an ecosystem services framework in proposing a methodology that can be used to characterise SESs and their susceptibility to impacts.

In the section that follows we firstly review international expectations in relation to the consideration of SESs in EIA, before discussing the particular requirements of South African legislation. The conceptual basis for the approach is then presented, following which we describe its preliminary application to a proposed estuary development. As we wished to examine transferability of the approach we also report on its application to a proposed mixed-use, rural agricultural project.

As far as we are aware this study constitutes the first attempt to apply and formalise SES constructs to EIA practice within a regulated procedure. Our framework goes beyond conventional scoping approaches, reliant on checklists and matrices, by requiring the EIA practitioner to co-create a conceptual model of the current and future social-ecological system with the impacted communities. This means social and biophysical impacts are assessed integratively and that communities participate meaningfully in the EIA process, thereby addressing two of the most common shortfalls of EIA practice. Recent EIA reviews call for EIA practice to include ecosystem services thinking and also to move towards more complete 'sustainability assessment' (Morrison-Saunders and Retief 2012). Our framework provides a mechanism for doing so.

SESs and environmental assessment practice

Given the patchwork evolution of EIA processes globally, it is not surprising that there is significant variation in the extent to which social impacts are explicitly acknowledged and assessed. In the USA for example, the scope of impacts covered by the National Environmental Policy Act (NEPA) is relatively broad (e.g. changes in land-use patterns, conflicts with land-use plans/policies, impacts on historical and cultural quality and socio-economic and environmental justice). Implicitly therefore, investigation of coupled social-ecological systems is intended. In contrast, biophysical (including architectural and archaeological) impacts are emphasised in the

European Directive, but social and economic impacts are not specifically included (Wood 2003), and consequently consideration of socio-economic impacts in Europe has had a lower profile (Glasson et al. 2012). Despite holistic consideration of impacts being implied in US policy, the biophysical bias of early EIA is cited as a reason for the development of SIA in the late 1970s and early 1980s (Taylor et al. 2004).

For some time however, SIA has been regarded as secondary to EIA (Glasson and Heaney 1993, Burdge 2002, Chadwick 2002) and recent reviews suggest that there is still some way to go in relation to the effective integration of social and biophysical impacts (Fisher 2011, Hildebrandt and Sandham 2014). Pope et al. (2013:1) refer to “an apparently ever-increasing number of distinct and specialized forms of practice”, and that the “plethora of specialist branches is generating a somewhat confusing picture and a lack of clarity regarding how the pieces of the impact assessment jigsaw puzzle fit together”. It could be argued that this diversification of practice, in part, reflects practitioners’ struggle in effectively dealing with SESs. At the very least, “the prevalence of these other forms of impact assessment suggest inadequacies (perceived at least in some quarters) in EIA practice, and a need to balance ex ante assessment” (Bond et al. 2012:53).

Sustainability assessment has been referred to as the “third generation” of impact assessment after EIA and SEA (Bond et al. 2012:53) and Morrison-Saunders and Retief (2012:35) acknowledge the “increasing demand internationally that EIA should move more towards sustainability assessment”. Why this is relevant is that of all the practice areas, sustainability assessment would presumably require most explicit consideration of social-ecological systems since one of its core principles is “socio-ecological system integrity” (Gibson 2006).

Hacking and Guthrie (2008) present a framework that conceptualises environmental impact assessment practice as a three-dimensional space along three axes of ‘integratedness’, ‘strategicness’ and ‘comprehensiveness’ (see Figure 1 for definitions). This framework is important in that it helps resolve some semantic issues associated with the proliferation of terminology and practice, and also provides a trajectory for moving from traditional biophysical EIA to a more comprehensive, integrated and strategic ‘sustainability assessment’. The need for the latter in South Africa has recently been emphasised (Morrison-Saunders and Retief 2012), and we adapt the Hacking and Guthrie framework (Figure 1) to illustrate the difference between present and desired practice in South Africa.

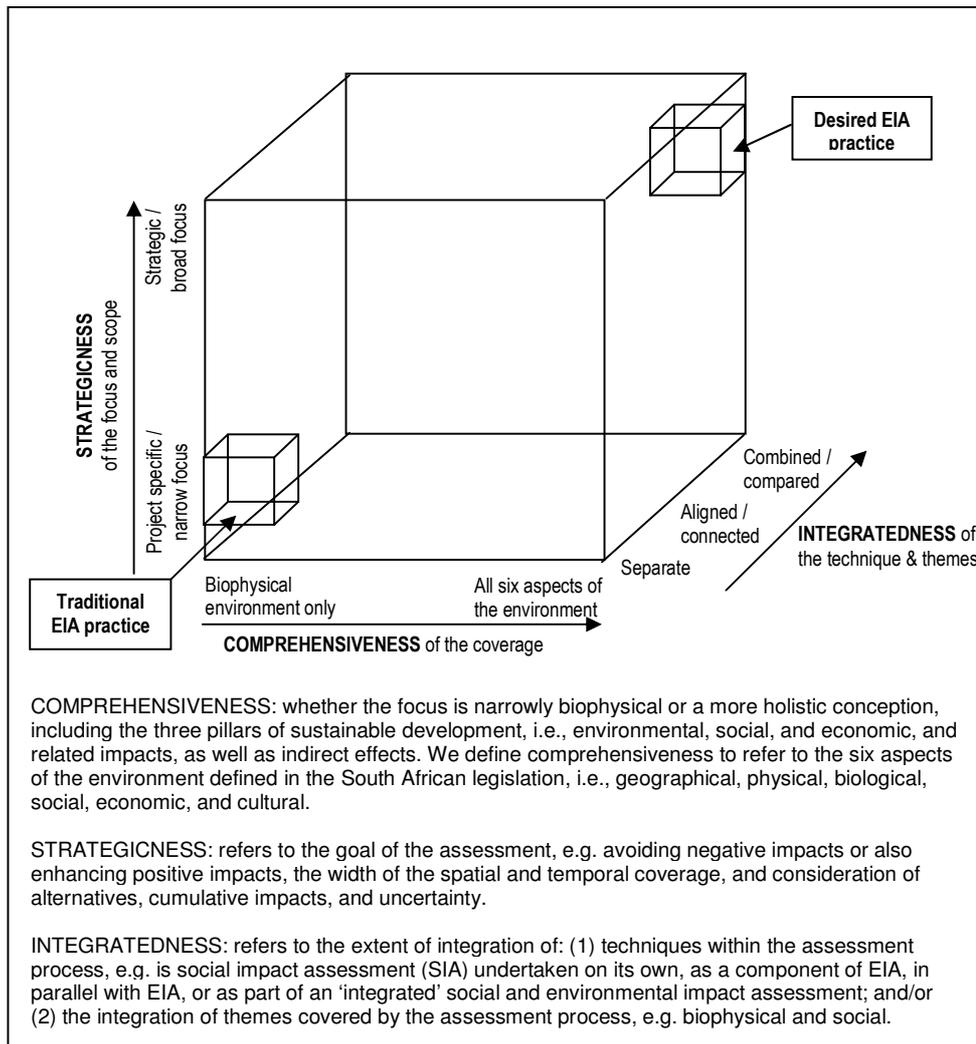


Figure 1. The difference between current and desired EIA practice in South Africa (adapted from Hacking and Guthrie (2008))

In the case of South Africa, it is clear that 'comprehensiveness' is intended in the environmental assessment legislation (du Pisani and Sandham 2006). Thus regulations of the National Environmental Management Act (Act 107 of 1998) (NEMA) require that an EIA must include assessment of the six different components of the environment (geographical (spatial), physical, biological, social, economic and cultural). Somewhat uniquely for environmental legislation, NEMA includes a set of principles requiring that "the social, economic and environmental impact of activities must be considered, assessed and evaluated and decisions must be appropriate in the light of such consideration and assessment". Morrison-Saunders and Retief (2012) have suggested that relative to the Gibson (2006) principles for sustainability assessment (and where

social and ecological are firmly combined), NEMA arguably tends to treat the social, economic and environmental components separately. Nevertheless, the complex nature of these systems is recognised in NEMA, “environmental management must be integrated, acknowledging that all elements of the environment are linked and interrelated, and it must take into account effects of decisions on all aspects of the environment and all people in the environment”. Clearly there is an explicit legal requirement for the EIA process in South Africa to include integrated assessment of social impacts (du Pisani and Sandham 2006), and by implication, address the complexities of SESs.

The final axis of Figure 1 relates to the strategic focus. Whilst this refers to whether the assessment adopts a ‘project-only’ focus or a more regional focus, it also relates to consideration of cumulative and secondary impacts, often only obvious if the scope of the assessment is broader. This axis is perhaps the most challenging, requiring a balance between obtaining sufficient detail which allows for an increased strategic focus, without wasting unnecessary resources on obtaining unnecessary detail. In principle, the initial ‘scoping’ phase of an EIA is intended to identify the potentially important impacts from issues of less direct relevance (Glasson et al. 2012). The subsequent and detailed EIA phase then investigates these impacts and attempts to quantify them and then assess their significance. Inadequate scoping can clearly lead to impacts not being identified, or alternatively not being addressed at the correct level of detail. Stirzaker et al. (2010:600) propose the concept of “requisite simplicity” to help negotiate complex problems, defining it as “an attempt to discard some detail, while retaining conceptual clarity and scientific rigor, and which helps us move to a new position where we can benefit from new knowledge”. The scoping process in EIA should therefore be attempting to identify these requisite simplicities. This is also important because the financial implications of regulatory EIA compliance, relative to development needs, are strongly politicised, particularly in countries such as South Africa (Morrison-Saunders and Retief 2012).

There is the expectation therefore, that EIA practice would be located more towards the top right corner of the Hacking and Guthrie (2008) framework (Figure 1), rather than the origin where traditional biophysical EIA is located. Morrison-Saunders and Retief (2012:37) have reviewed the South African EIA legislation in relation to sustainability principles and concluded that South Africa has a “strong and explicit sustainability mandate” and therefore the debate on the integration of sustainability into EIA should address “effectiveness of practice” rather than the legal mandate, highlighting the need for practitioners to innovate and embed sustainability

thinking into their practice. We suggest our framework would help practitioners achieve this.

EIA policy and practice in South Africa – bridging the SES hiatus

In reality there is a significant hiatus between policy and practice as EIAs in South Africa frequently do not fully consider all environmental aspects (Hacking and Guthrie 2008, Sandham and Pretorius 2008, Kidd and Retief 2009, Morrison-Saunders and Retief 2012). Nor do EIAs generally take into consideration the linkages between the different environmental aspects. An example of a linkage could be how the social environment (e.g. crafters who use estuary resources to make goods to sell) will be impacted upon by changes to the ecological environment (e.g. a loss of crafting material) as a consequence of a proposed development (e.g. the damming of a watercourse to create a dam to irrigate new pastures). Morrison-Saunders and Retief (2012) highlight that these 'indirect costs', often relating to ecosystem services and impacts on quality of life, pose difficulties in quantification and often extend over long timescales. Despite these being fundamental questions in any sustainability-focused EIA, they are therefore often poorly resolved, and may lead to poor decisions. In South Africa (and in other developing countries), examples include the construction of community halls and craft markets, which remain unused due to their unsuitable location or function, and as a result of inadequate assessment before commissioning (Riddell 2007). We suggest that development failures such as these are symptomatic of a failure to understand complex SESs.

There are at least two reasons for this hiatus in practice. Firstly, in South Africa, EIAs are conducted by Environmental Assessment Practitioners (EAPs), many of whom enter EIA practice with a natural sciences academic background (du Pisani and Sandham 2006, Hildebrandt and Sandham 2014). This has led to ecologically-focused EIAs, which generally consider biophysical aspects in isolation, without taking into account socio-economic impacts, or the linkages between the different aspects (du Pisani and Sandham 2006). When social or economic impacts are included in these assessments, they are often appended to the report, and are not integrated into the actual impact assessment (Burdge 2003, Barbour 2007, Hildebrandt and Sandham 2014).

Secondly, we argue that there is a lack of a systematic framework in which complex SESs can be described, understood and investigated in an integrated manner during an EIA. Conventional approaches to scoping include checklists and matrices, and although these are useful and widely used (Canter 2008, Glasson et al. 2012), we argue in the following section that they have

recognised shortcomings. Without a framework that is oriented towards holistic understanding of an SES, it is, for example, difficult to predict the consequence of land use change on the flow of ecosystem services and sometimes even more difficult to communicate these impacts to affected communities. Clearly an approach which helps map out interrelationships and interdependencies in SESs, whilst also providing a means of assessing and communicating impacts, would be of significant value in helping improve practice in South Africa and other developing countries.

A final area of acknowledged weakness in EIA practice globally is that of meaningful public participation (Esteves et al. 2012, Morgan 2012, Pope et al. 2013). This is especially the case in South Africa where du Pisani and Sandham (2006:719) described it as having “serious shortcomings” and that it should be redesigned to be more effective and “truly participative”, although recent improvement is recognised (Hildebrant and Sandham 2014).

CONCEPTUAL BASIS FOR THE FRAMEWORK

Current tools – matrix and network approaches

Tools for identifying impacts range from simple checklists, through to matrices, networks and quantitative methods (Morris and Therivel 2009, Glasson et al. 2012). These are intended to provide a more structured way of identifying impacts, as opposed to an ad hoc approach (Barrow 1997). Of these, matrices are probably the most well-known for attempting to capture more complex relationships (Canter 1996). Rudimentary matrices are two-dimensional charts showing components of the development on one axis and components of the environment on the other. More sophisticated “magnitude matrices” attempt to quantify this through a subjective assessment of components of the impact (e.g. magnitude, significance or time frame) (Glasson et al. 2012). Of these the Leopold Matrix (Leopold et al. 1971), and the Peterson Matrix (Peterson et al. 1974) are the most widely used.

The qualitative Leopold Matrix consists of 100 columns representing the various activities (e.g. construction, water supply) associated with a project, and 88 rows representing the various environmental components to be considered. Environmental factors are divided into three groups: physical conditions (e.g. soil); biological conditions (e.g. fauna); and social and cultural conditions (e.g. land use). The matrix is completed to indicate the magnitude (from -10 to +10) and the importance (from 1 to 10) of the impact of each activity on each environmental factor (Leopold 1971, FAO-UN 1996, Glasson et al. 2012, Kassim and Williamson 2005).

The Peterson Matrix (Peterson et al. 1974) is an extension of the concept and is a weighted impact interaction matrix (Noble 2009). This consists of three component matrices: (i) project impact against environmental components, (ii) impacts of environmental change on the human environment and (iii) the relative importance of the human components. The approach uses the multiplication properties of matrices to find the effect of the casual elements on the human environment, while the resulting product is weighed according to the significance of the human impact (Noble 2009, Akintunde and Olajide 2011).

The Sorensen Network (Sorensen 1971) was the first network-approach developed for use with EIAs (Turnbull 1992, Glasson et al. 2012), and is probably the best-known approach for investigating higher order impacts (Modak and Biswas 1999), although originally developed to help planners reconcile conflicting land uses in California (Glasson et al. 2012). Six environmental components (water, climate, geophysical conditions, biotas, access conditions and aesthetics) are recognised and its implementation begins with the practitioner identifying potential causes of environmental change associated with a proposed development, using a matrix format (Glasson et al. 2012). The first change in the environment is called an initial 'condition' change (e.g. residential development). This initial 'condition' change will affect other environmental components, termed 'consequent' conditions (e.g. increased erosion due to cleared vegetation on development footprint) (Turnbull 1992).

Although these approaches are demonstrably relevant in EIA practice, they have limitations (Bojórquez-Tapia et al. 1998), and we suggest, particularly in respect of their inability to deal with highly integrated and complex SESs (Table 1). So what can SES theory offer EIA? The first point relates to the value of conceptualising, and then formally describing, a SES in relation to its structural properties. The second point is that once a conceptual model is formalised, this enables a more structured and systematic process of examining the interactions between components and helps define the key issues and focus subsequent investigations.

Table 1. Limitations of the Leopold Matrix, Peterson Matrix and the Sorensen Network when dealing with complex SESs

General limitation	Specific comments
Lack of transferability	Leopold Matrix requires amendments for every project, and can be too detailed for some projects and not precise enough for others (FAO-UN 1996, Barrow 1997, Glasson et al. 2005)
Time consuming, thus expensive	Leopold Matrix includes 8800 possible interactions, and two entries per interaction (176 000 items must be taken into account in decision-making) (FAO-UN 1996, Wood 1999, Kassim and Williamson 2005)
Physical-biological environment bias	67 of the 88 environmental characteristics in the Leopold Matrix are biased towards the physical-biological environment (Kassim and Williamson 2005)
Difficulties in applying to Socio-economic Impact Assessments	Sorensen Network is “reputedly difficult to apply...to socio-economic impact assessment” (Barrow 1997:145)
Concerns that key issues, particularly human, may be overlooked	Leopold Matrix does not include a mechanism for focusing attention on the most critical human issues (Kassim and Williamson 2005). Likewise, the Sorensen Network presents over-simplification of a situation, which may result in key impacts being overlooked As there a high number of variables to consider with both Matrices and Network, it is difficult to get an overview of the impacts (Barrow 1997, Noble 2009)
Discrimination between a system’s current and future state	As results are summarised on a single diagram, interactions may be perceived to have taken place by the reader (Kassim and Williamson 2005) In matrix approaches there is a tendency for the structure of the system to be determined by the form of the matrix used There is substantial opportunity for double counting with the Leopold Matrix (Kassim and Williamson 2005)
Utility in public participation	Conventional matrix approaches are not aimed at identifying stakeholders (Kassim and Williamson 2005). The Leopold Matrix “does not facilitate public involvement” (Barrow 1997:140)
Scoring poses subjectivity questions and has higher knowledge requirements	The scoring, and thus the outcome of the EIA, is entirely based on the subjective judgment of the scorers, as the tools do not provide explicit criteria for assigning numerical values to the weighting (Glasson et al. 2005, Kassim and Williamson 2005) Network approaches demand “greater knowledge and expertise for their effective use” (Wood 1999:78)
Accommodating qualitative and quantitative data	Although the Leopold Matrix accommodates both quantitative and qualitative data, it does not discriminate between them (Munn 1979, Kassim and Williamson 2005) Accuracy of the tools is limited by the adequacy of the data available, and the level of knowledge of the practitioner (Glasson et al. 2005)
Accommodating quantification of impacts and their significance	Sorensen Network identifies impacts but does not establish their magnitude or significance or extent of change (Barrow 1997) Matrix approaches do not incorporate details of the methodology/technology used to predict impacts (Glasson et al. 2005)
Dealing with uncertainty and impact likelihood	No provision for indicating uncertainties resulting from inadequate data or knowledge in both the matrix and network approaches – all predictions are treated as if certain to occur (Kassim and Williamson 2005) Matrix approaches do not specify the probability of an impact occurring (Glasson et al. 2005) Neither cater for indicating environmental variability, including the possibility of extreme, unacceptable hazards, nor are the associated impact probabilities indicated (Kassim and Williamson 2005)

Accommodating indirect, temporary and long-term impacts	<p>Matrix approaches are unable to identify significant indirect, secondary or cumulative impacts (Wood 1999)</p> <p>Although the Sorensen Network can identify indirect impacts, it is restricted to third and lower order impacts (Modak and Biswas 1999)</p> <p>Matrix approaches and the Sorensen Network (Ogola 2007) are unable to identify and handle temporary aspects</p> <p>Leopold Matrix does not distinguish between immediate and long-term impacts (Kassim and Williamson 2005)</p> <p>Matrix approaches do not relate environmental components to one another, so the complex interactions between the different components that lead to indirect impacts are not assessed (Glasson et al. 2005)</p>
Consideration of alternatives	<p>Users may sum the numerical values to produce a composite value to compare with that of other developments or alternatives, but since the matrices do not assign weighting to different impacts to reflect their relative importance, it would not be possible to compare the impacts associated with different developments or alternatives (Glasson et al. 2005)</p>
Accommodating mitigation and monitoring measures	<p>The magnitude of the predications with the matrix approaches are not related explicitly to the 'with-action' and 'without-action' future states (Kassim and Williamson 2005)</p> <p>Matrix approaches have no capability for making recommendations on inspection procedures to be followed after completion of a project (Kassim and Williamson 2005)</p>

Methodological approach

Anderies et al. (2004) present a framework for disaggregating the components of a SES in a way which promotes the identification of critical linkages, and importantly, the potential vulnerabilities of SESs to disturbances. The latter makes this approach particularly appropriate in the context of impact assessment. The system is represented as comprising four components: (i) the resource system; (ii) the resource users; (iii) public infrastructure and (iv) public infrastructure providers (Figure 2). This approach is strongly conceptually related to the SES framework of Ostrom (2007, 2009) where the SES is described in terms of (i) resource system, (ii) resource units, (iii) users and (iv) governance system. In a recent comparison of frameworks for analysing SESs, Binder et al. (2013) highlight Ostrom's (2007, 2009) as being of particular value in that it was the only framework giving equal depth to social and ecological systems. In using Anderies et al. (2004) rather than Ostrom (2007, 2009) we retain this benefit while also emphasising the "infrastructural" dimension that is common to almost all EIA projects.

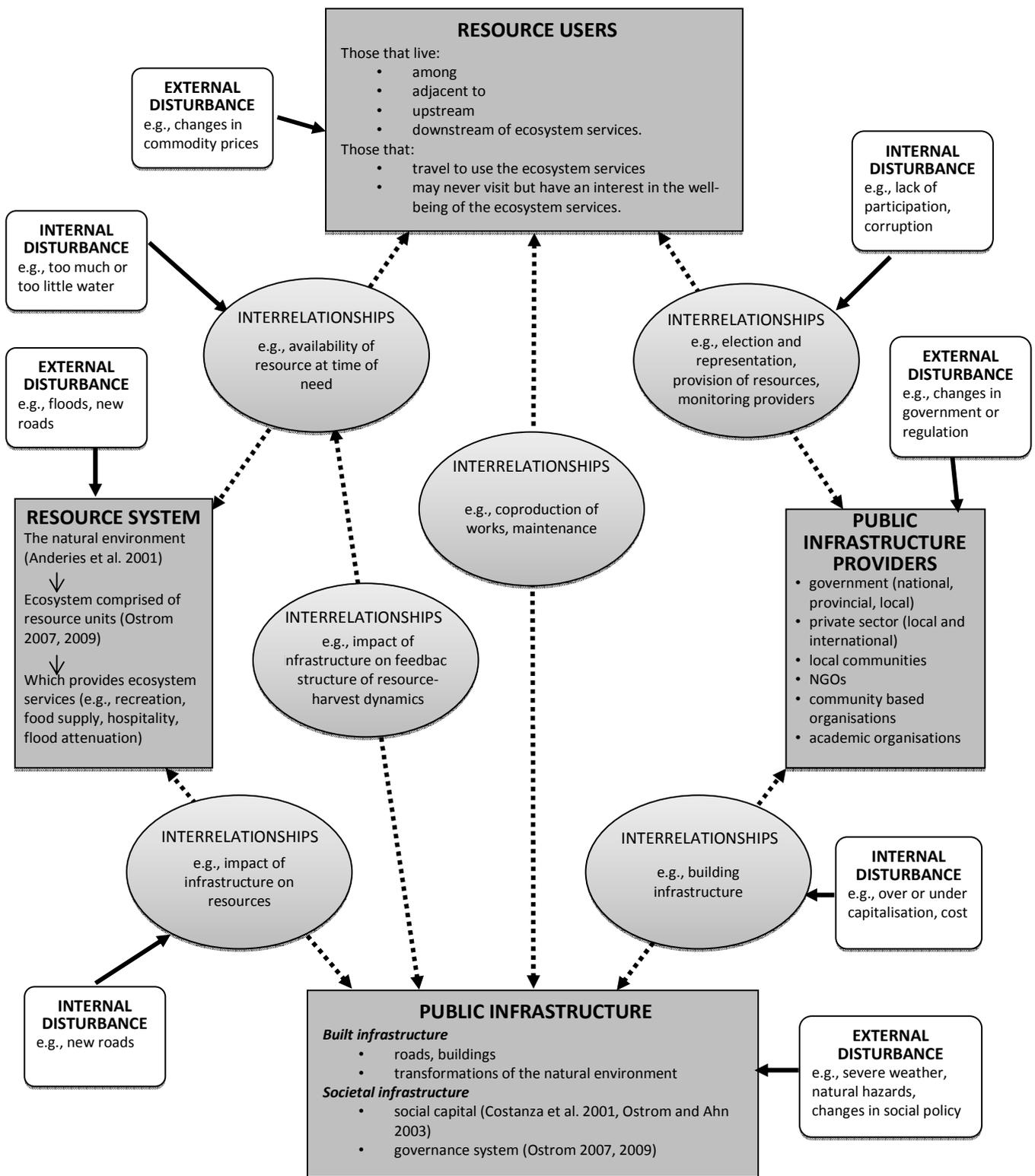


Figure 2. Adaptation of the Anderies et al. (2004) framework

Anderies et al. (2004) define 'resource system as the geographical, biological and natural physical environment. We define the resource system more specifically as an ecosystem (or ecosystems) comprising particular habitats (analogous to the 'resource system' plus the 'resource units' defined by Ostrom (2007, 2009) and delivering a suite of ecosystem services. The users are those that might be directly dependent on these ecosystem services (i.e. fisherman) or those further afield but who nevertheless derive benefit.

Public infrastructure refers to both built infrastructure (e.g. roads, buildings), and also social infrastructure – meaning the social networks and rules used by those governing, managing, and using the system, as well as those factors that affect monitoring and enforcement of those rules, otherwise referred to as 'social capital' (Costanza et al. 2001, Ostrom and Ahn 2003) and 'governance system' in the Ostrom (2007, 2009) framework. Having defined a conceptual model of the system, it is then possible to consider impacts to the system. These may be external disturbances to any or all the four components of the system, whilst internal disturbances are interactions between one or more of the components. Figure 2 provides examples of these and illustrates the value of both representing the structure of the SES and using interrelationships to reveal potential issues, impacts and problems.

We have further refined the approach of Anderies et al. (2004) by defining the resource system in ecosystem services terms. This is important as it both provides a basis for quantification, and retains the interdependencies between ecosystems and the socio-economic environment. Incorporation of ecosystem services into EIA is acknowledged as an "emerging opportunity" in EIA theory and practice (Pope et al. 2013), and while Baker et al. (2013) concur, they also argue for further practical application to help foster debate and incorporation into practice. The final aspect of our contribution is that we have integrated this process with the South African EIA procedure; the result is what we will refer to as the Social-Ecological-System Environmental Assessment (SES-EA) Framework (Figure 3).

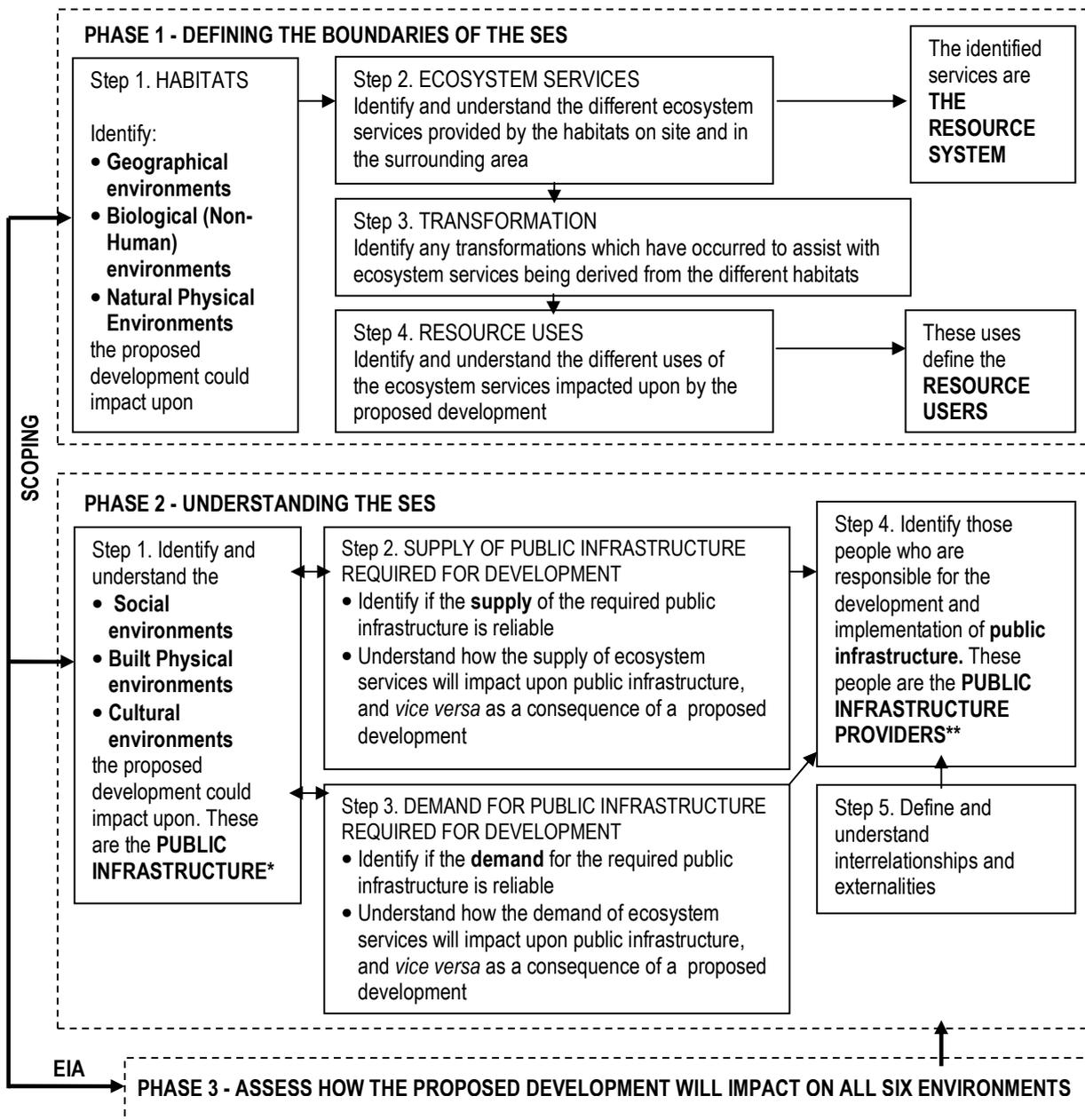


Figure 3. The SES-EA Framework (refer to Figure 2 for estuarine examples of the resource system, resource users, public infrastructure and public infrastructure providers). *Any transformations identified in Phase 1, step 3 must be included. ** Identify whether the public infrastructure providers are resource users

Methodology

In the following section we develop and apply the SES-EA Framework to proposed accommodation development in a rural estuary setting in the Eastern Cape province (South Africa). The estuary is a tourist destination because it is relatively unspoilt and offers a variety of recreational activities. This development would require EIA authorisation, and therefore its use in this context provided some insight into its potential utility as an EIA tool. The estuary is also important to local people who use it directly in maintaining their livelihoods (Bowd et al. 2012). Following development and application of the method in this case study, we test the transferability and utility of the SES-EA Framework in a proposed wine estate development in the KwaZulu-Natal Midlands of South Africa.

Application of the framework requires a participative approach to co-produce understanding. For the estuarine project, workshops were held with stakeholders (resource users and public infrastructure providers) on 28-29 October 2008 and 17-18 March 2009. For the wine estate project, public meetings were held on 16 July 2009 and 30 July 2010 for all interested and affected parties.

DEVELOPMENT AND APPLICATION OF THE SES-EA FRAMEWORK

The SES-EA Framework comprises three phases (Figure 3) which relate both to the generic EIA process (Glasson et al. 2012), but also to the statutory South African EIA procedure. The first phase aims to both define the resource system and the resource users; this constitutes the boundary of the SES. The second phase is aimed at developing an understanding of the SES, in particular the complex set of interrelationships, and the potential issues and impacts associated with the proposal. Because the six aspects of the environment are explicitly included in the conceptual model of the SES, this means they must necessarily be considered from the start.

Phase 1: Defining the boundaries of the SES

The identification of the boundaries of a SES requires the consideration of the 'resource system' (the geographical (spatial), biological and natural physical environment) and the 'resource users' (the social systems (stakeholders) deriving benefits from the resource system) (Anderies et al. 2004). Boundaries are determined by both identifying the different habitats within the resource system (Step 1) and the ecosystem services supplied by these habitats (Step 2).

For the estuary case study, ecological habitats included mangroves, reedbeds, salt marshes and water surface. In addition, the estuary basin (the area of the landscape which drains directly into the estuary) featured grasslands, forests and streams. Adjacent coastal habitats (e.g. beaches) can also be viewed as an integral part of the estuary's ecological system. Estuary-linked ecosystem services supplied by the different habitats included food provision, hospitality, recreation and flood attenuation (Bowd et al. 2012). In order to enable these services to be derived from the habitats of the ecological system, transformations (e.g. bridges, roads, buildings, harvesting nets and ploughed fields) need to have occurred. Step 3 thus focuses on identifying the transformations that have occurred (or need to occur) in order to establish or maintain the desired supply of ecosystem services.

The final step is identification of the different users of these ecosystem services, and in particular those who may be impacted by a proposal. Resource users can originate from a wide range of locations, and can influence and/or are influenced by the ecosystem services supplied by the system. For example, local residents, tourists, neighbouring communities, farmers, fishermen and non-governmental organisations (Bowd et al. 2012). We identify six proximity-based categories of 'resource user' (Figure 2).

Phase 2: Understanding the SES

The objective of the first step in this phase is to identify and understand the public infrastructure, that is to say the built physical environment (including the transformations already identified) as well as the social and cultural environment. Public infrastructure enables a 'resources user' to use a 'resource', and consists of all social and economic capital associated with a SES, and can come in a variety of different forms. For our case study we identify seven different categories of infrastructure (Table 2).

Table 2. The seven different types of public infrastructure with examples from an estuarine case study which considers the establishment of a community-based accommodation facility which is linked to a currently established hotel

Type of public infrastructure	Description of each type
Transformation infrastructure	All man-made alterations to a landscape, including roads, bridges and other infrastructure
Legal and regulatory infrastructure Institutional infrastructure	Laws in the form of Acts, regulations, policy documents and customary regulations Private / business structures (e.g. for trade between different businesses) Social structures (e.g. traditional practices relating to the use of natural resources) Government / political structures (e.g. structures to define powers and responsibilities)
Knowledge infrastructure	Indigenous / cultural knowledge (e.g. knowledge concerning the local uses of different natural resources) Scientific / technical knowledge (e.g. that relating to the condition of ecosystems)
Skills infrastructure	The skills of those involved in each type of infrastructure
Communication infrastructure	Transportation, e.g. via vehicle. Telephonic / digital communication
Relationship infrastructure	The relationship amongst and between all the different types of infrastructures

The second and third steps in this phase relate to the supply and demand of public infrastructure respectively. Firstly, one examines whether the supply of public infrastructure is reliable and how this might be impacted by the proposed development and vice versa. Secondly, one needs to consider the demand for public infrastructure. In other words what public infrastructure is needed to maintain the current supply of ecosystem services, but also in relation to the proposed development. In our view, approaching things from this perspective is useful in the identification of alternatives, a key requirement of most EIA systems internationally.

Step 4 identifies those who are responsible for the development and implementation of 'public infrastructure, the 'public infrastructure providers'. The list of different public infrastructure types (Table 2) can be used to help identify the different groups of public infrastructure providers. It is also useful to refer to the list of 'resource users', as these can be the same people. In this way, additional relevant stakeholders are identified, again an essential part of scoping in most EIA systems.

In identifying the resource system, the resource users, the public infrastructure and the public infrastructure providers, the practitioner has developed an integrated conceptual model of the SES. This model includes the key actors (stakeholders) and identifies the critical resources underpinning their interaction. The final step in this phase is to systematically explore these interrelations by way of a structured SES-matrix (Table 3), representing the interlinkages shown in Figure 2.

Table 3. SES-matrix showing the linkages between the four main components of an SES, and how biophysical, social and economic forces relate to the four different components. Estuarine examples of the linkages have also been provided. The ‘resource’ has been omitted as a row, since the resource is generally impacted upon by external impacts, and this is addressed by the addition of ‘biophysical forces’ as an additional row

	Resource system	Resource user	Public infrastructure	Public infrastructure provider
Resource user	The resource supplies ecosystem services to the resource users. Over-exploitation of these services will detrimentally impact the resource system	Resource users can have neutral, positive and / or negative relationships with each other over use of the resource system (e.g. communities remove alien trees for fire wood and thus help reduce alien vegetation)	Used by the resource users, and can have both positive and negative impacts on its users (e.g. a tourist enterprise may not succeed if the access road is frequently impassable)	Generally provide public infrastructure to meet the needs of resource users (e.g. a municipality may build a bridge to allow access to an inaccessible place)
Public infrastructure	The condition of a resource system is impacted by available public infrastructure (e.g. the tarring of a road could have a negative impact on an estuary, as it could facilitate access, resulting in intensive fishing)	Resource user activities and allocation of resources are influenced by the availability of public infrastructure (e.g. the implementation of Black Economic Empowerment legislation creates preferential access, and thus opportunities, for historically-disadvantaged individuals)	The implementation of one type of public infrastructure may detract from another type (e.g. a public parking lot established adjacent to an exclusive lodge may negatively impact on an exclusive lodge)	Potential new public infrastructure is often influenced by the currently available infrastructure (e.g. a hotel chain may be more likely to establish a new hotel if a tarred road is previously established)
Internal disturbances Public infrastructure provider	The resource system can both benefit and be detrimentally impacted upon by public infrastructure providers (e.g. a hotel could monitor the water quality of an estuary and take rectification action if required. However it might be the hotel which is polluting)	Public infrastructure providers do not always meet the needs of all resource users. Conflict can arise between what the resource users and public infrastructure providers want	The implementation of public infrastructure is reliant on the capacity and competency of the public infrastructure providers (e.g. there may be good policy on solid waste disposal, but if the municipality is not able to implement it, solid waste will remain a problem)	Public infrastructure providers can work together and against one another. An example of the latter, is when one department is promoting economic growth using infrastructural development and another department is promoting conservation
External disturbances Biophysical forces (Biological, non-human and natural physical forces)	Natural resources are impacted upon by external biophysical forces. These include droughts and floods. These events can change the quantity of ecosystem services	Resource users can be negatively impacted upon if they have not considered fluctuations in the supply of ecosystem services	Biophysical forces can influence public infrastructure (e.g. natural disasters can cause wash-aways and destroy communications, limiting access to enterprises and causing financial losses)	Public infrastructure providers can be prepared or ill-prepared for unexpected biophysical forces (e.g. Roads Department may have financial provisions for road repairs after major flood events, knowing that flooding was likely)

External social and economic forces (Social, economic and cultural forces)	External social and economic forces can alter the resource base (e.g. poor people may over use fish stocks, or affluent people may displace poor users, such as a fishing concession excluding local fishermen from previously used sites)	External social and economic forces can influence resource users. Conflict, crime and uncertainty can influence changes in demand for local services (e.g. dangerous driving on access routes could discourage tourists from visiting)	External social and economic forces can have both positive and negative impacts on public infrastructure (e.g. if a new road is established, it is likely to result in increased accessibility. This could result in increased tourist facilities which could cause ground and surface water pollution if their sewage systems are not maintained)	Delivery is reliant on social and economic forces. Public infrastructure providers must meet performance requirements (e.g. a municipality must demonstrate sound fiscal management to attract foreign investors, who could provide investment for the area)
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Table 3 demonstrates the nature of the possible relationships that may be operating amongst the four components of the system, together with estuarine examples. Also included in this matrix are the external biophysical, social and economic forces that may generate perturbations in the local system. The SES-matrix must be interpreted by how the components along the columns are impacted upon by the components in the rows.

Phase 3: Impact assessment

Whereas Phases 1 and 2 typically represent scoping, Phase 3 corresponds to the traditional impact assessment stage (definition and significance of impacts), during which other EIA tools, such as the Rapid Impact Assessment Matrix (RIAM) (Pastakia and Jensen 1998) and Cumulative Effects Assessment (CEA) (Smit and Spaling 1995) could be used. Incorporation of ecosystem services into EIA procedure is being emphasised in the literature (Baker et al. 2013, Partidario and Gomes 2013), and because our definition of the resource system is in relation to the ecosystem services provided, this could constitute a basis for achieving this.

TRANSFERABILITY OF THE SES-EA FRAMEWORK

To test transferability, the Framework was applied to an agricultural site in rural KwaZulu-Natal, located 12km from the nearest major town and 25km from a major city. The KwaZulu-Natal Midlands is known for its tourist route, whereby numerous popular enterprises have become established (e.g. leather work, gourmet foods and tourist accommodation). There are a number of current and proposed townships (government housing for the poor) within a 5km radius of the development site. Only 30% of the local population are employed, predominantly in agriculture and tourism. The development site is 50ha in extent and currently comprises a farmhouse and 300m² of commercial land-use (restaurant and tourist shops). The site has been transformed through a combination of past and current farming and associated retail operations. Surrounding land-use is predominantly agricultural, consisting of wattle plantations, grazing and seasonal

vegetables.

The development proposal comprises the establishment of a residential wine estate consisting of: 20 high-income residential units; expansion of an existing commercial node to 3 000m²; expansion of vines from 5ha to 35ha; establishment of a winery; and upgrading of existing infrastructure (e.g. internal road network, water and electricity supply). It is therefore a mixed-use (residential/agri-business) proposal.

Table 4 shows the results of implementing the SES-EA Framework for the development, arranged in relation to the stages of the SES-EA process. The results show how the ecosystem services provided by the habitats (e.g. enhancing the water quality of runoff flowing through the on-site wetland system) can impact on the SES (e.g. the runoff feeds into the main water supply dam for the area). The framework aided in the identification of past transformations within the SES which could negatively impact (e.g. adjacent poultry farm has the potential to emit nuisance odours) or positively impact (e.g. good electricity supply) on the proposed development. Beyond what is likely to have been achieved with a normal scoping assessment, the framework aided in building, together with stakeholders, an overall conceptual understanding of the site, its linkages within the broader landscape, and its provision of ecosystem services under current and future scenarios. A further benefit was the identification of required infrastructure (e.g. water provision, local road network, effluent disposal), and identification of who may be responsible for its supply and maintenance. In addition, the framework helped gain an understanding of the relevant resource users (e.g. tourists, local farmers) and highlighted potential conflicts associated with the establishment of the proposed development (e.g. concerning sense of place).

As was the case with the estuary case study, one identified potential impact was accelerated deterioration of the local road networks. In response to this, the framework helped identify that discussion with the Roads Department was required to ensure continued maintenance of the local road network. Any additional costs could therefore be contextualised in relation to longer term increases in economic activity and therefore a funding base to support road development and maintenance. This highlights the important aspect of secondary and cumulative impacts, which are not easily accommodated within conventional matrix-only type approaches.

In applying the framework it became evident that the only controversial aspect of the proposal

was the residential development component, since the agricultural aspect (winery and vines) and commercial node were in keeping with the area and also complied with government planning policy (job creation and improving agriculture in agricultural areas). A number of stakeholders, most notably surrounding affluent land owners, were strongly against the residential development on grounds of potential impact on the sense of place. However, application of the framework also showed that revenues generated from the sale of the residential units was required to fund the agricultural and commercial components, without which the development would not occur. A trade-off could then be articulated between a potential negative change in sense of place and the positive impacts of the development as a whole. In the estuary case study, the SES-EA Framework similarly enabled the identification of trade-offs between tourism and sand-winning and enabled stakeholders to engage in an informed discussion of these issues. In both cases, this would be an unlikely outcome using traditional EIA approaches.

Table 4. The results of applying the SES-EA Framework to a development proposal for establishment of a residential wine estate in the KwaZulu-Natal Midlands, South Africa

Phase 1: Defining the Boundaries of the SES	
Step 1. Habitat	Maize dominates the site (65%), also vines (10%), <i>Acacia mearnsii</i> (Black Wattle) and <i>Eucalyptus grandis</i> (Blue Gum) (10%), <i>Pennisetum clandestinum</i> (Kukuyu grass) (10%), hardened surface (paving, concrete, roofing) (3%) and aquatic habitats (wetland, 5 000m ³ dam and stream) (2%) A natural aquifer traverses the site from east to west
Step 2. Ecosystem services The Resource System	The stream and aquifer contribute supply to a dam, which is the main water source for a major city located 25km south of the development site. The wetland system helps clean the stream water which has elevated nutrient levels due to intensive grazing up-stream Birdlife use the freshly cultivated maize lands for seasonal foraging The soils, despite having low percolation, are used to grow vines and maize, they provide good grazing land, and are suitable for construction
Step 3. Transformation	A poultry facility on an adjacent property A borehole on the property extracts ground water from the aquifer and feeds the dam on-site, thereby increasing the connection between groundwater and surface water The site has suitable soils and topography for vines The soil type is not ideally suited to maize; however a maize company plants and fertilises the site for advertising purposes, due to its location on the tourist route The farmhouse and tourism-linked commercial operations have associated gardens, access roads, parking areas and septic tank and soakaway systems
Step 4. Resource uses	If stormwater and effluent is not managed correctly, the stream, wetland system and aquifer could become polluted (and in turn pollute the dams on and off site) Fertiliser application can increase nutrient load and sedimentation in the stream and wetland system. Although vines require fertiliser, a minimal amount is used in comparison to maize, thus the removal of the maize could potentially reduce nutrient inputs to the stream and wetland Maize supports a greater diversity of birdlife in comparison to vines, especially when the maize land is fallow. However indigenous gardens around the residential units can provide suitable foraging habitat for a wider variety of birdlife all year round. An increased number of people have the potential to disturb birdlife The application of vine biocides could have detrimental health implications for the health of the residents
Resource users	Down-stream beef and dairy farmers who use the stream to water their cattle Up-stream farmers who use the wetland to improve run-off quality Residents and visitors who appreciate the area for its sense of place On-site commercial shop owners and restaurant and farmhouse owner (same person) Birders / local conservation group Down-stream water users who use the main water supply dam (e.g. inhabitants of the major city) Maize company who leases the land to grow maize for advertising purposes

Phase 2: Understanding the SES

Step 1. Identifying and understanding the Public Infrastructure	<p>Surrounding neighbours (farmers, enterprise owners and tourists) who enjoy the area's agricultural sense of place are likely to oppose a 20 unit residential development which has the potential to change the local sense of place. However, enterprise owners and tourists will benefit from the winery and increased commercial area</p> <p>There is a nearby township (<5km) whose community has limited formal education and ~70% unemployment</p> <p>Wine making is labour intensive. Those seeking employment would be supportive of this development</p> <p>Birders and conservation groups are likely to be against all development which could cause pollution and have a negative impact on wildlife</p> <p>Municipal water and sewage reticulation is not available. The municipality does not have the funds to connect the site to either service</p> <p>The area has a reliable electricity connection and there is a good public road network</p> <p>The development will reduce unemployment which may reduce crime; however criminals may be attracted to an affluent development</p> <p>The poultry farmer may be apprehensive about receiving odour complaints from the new residence and tourists</p> <p>The maize company will no longer be able to use the site to advertise</p> <p>The development will help meet the demand for high-income homes in the area, and the additional commercial development will contribute to attracting tourists</p> <p>The additional vines and wine processing facility will promote local tourism, and be a catalyst to other landowners who wish to diversify into another type of agriculture</p>
Step 2. Supply of Public Infrastructure	<p>There is no municipal sewage reticulation and the soils on site have poor percolation rates. If effluent is not properly managed, it could have a detrimental impact on the aquatic habitats and the aquifer</p> <p>Municipal water is not available. The yield of the borehole on site is not sufficient for the proposed development; however if supplemented from a borehole on an adjacent property, there will be sufficient water available</p> <p>There is sufficient and reliable power for the proposed development</p> <p>The local public road network is generally well maintained</p>
Step 3. Demand of Public Infrastructure	<p>There is local demand for drinking water. If the development impacts on the functioning of soil filtration or wetland system, this could have a negative impact on water supply</p> <p>The development is located within a water stressed catchment. Thus additional pressure on ground water could reduce the availability of water for local agricultural activities</p> <p>Increased overhead power lines have the potential to increase bird fatalities</p> <p>Increased road usage, as a result of the development, will accelerate road deterioration</p>
Step 4. Public Infrastructure Providers	<p>Developer to provide waste water treatment plant. The plant must treat effluent to agricultural standards, and infrastructure must be established to enable the treated effluent to be used for agriculture (e.g. irrigation onto vines)</p> <p>Developer to provide water from borehole on property and adjacent property owner to agree to servitudes over borehole</p> <p>Developer to extend power lines and local Electricity Company to provide power. Power lines must be placed underground to avoid bird fatalities</p> <p>The Roads Department is responsible for road maintenance</p> <p>Developer is responsible for the majority of the public infrastructure, thus the developer will ensure that there are sufficient</p>

Step 5. Understanding the economic environment	funds for the required public infrastructure before commencing with the development The profit from the units will fund the i) expansion of the commercial operation; ii) additional 30ha of vines; and iii) wine processing facility. Developer must obtain a written undertaking from the Electricity Company to supply electricity, and the Roads Department to maintain the local road network
Phase 3: Assess how the proposed development will impact on all Six Environments	
Economic	Large capital investment into the area through the establishment of 20 high-income residential units. The large capital injection will come into the local economy through job creation, increased visitor numbers (and thus spending), increased municipal rates and introduction of a new agri-industry to the area The maize company will no longer advertise on the site which may result in reduced profits. However, given the agricultural nature of the area it is likely that the maize company will be able to identify another suitable site in the area to advertise
Cultural	There are no cultural sites on or near to the development site
Built physical	The development will increase the built physical environment, by way of additional structures and service infrastructure. The development may impact on road quality
Natural	The development will have limited impact on natural vegetation as the site is already highly transformed
Social	Employment associated with the development will improve the living standards of the local community Although poultry-associated odours could deter potential residents, chicks are removed at one day old, and this practice does not produce nuisance odours The development could result in other local properties growing vines, as there would be a local wine processing facility to process their crop The residential infrastructure will negatively impact those surrounding neighbours who enjoy the agricultural sense of place
Biological	If the development impacts on the functioning of the soil filtration or wetland system, this could have a negative impact on the main water supply for the area Maize removal could decrease the availability of foraging habitat for birds, however the establishment of indigenous gardens around the residential units may provide suitable foraging habitat for birdlife all year round. This may benefit conservation groups
Geographical	Thirty hectares of vines will be established, and platforms will be cut for the establishment of 20 residential units and the expansion of the commercial facility

DISCUSSION

Earlier we acknowledged the need for EIA practice to move towards ‘sustainability analysis’, represented in Figure 1 by increased strategic focus, comprehensiveness, and integration (Hacking and Guthrie 2008). Comprehensiveness means considering all aspects of the environment, whilst integration refers to the complex interrelationships and interdependencies that define social-ecological systems. Clearly the extent to which the proposed framework enables understanding of these complexities is an important consideration in evaluating its utility and value in helping shift EIA practice towards sustainability assessment. A second weakness of EIA practice acknowledged earlier related to the effectiveness of public participation, and these two themes will be explored in this section.

Does it help understanding of the interrelationships and interdependencies within a SES?

To address this question we have used the five criteria proposed by Binder et al. (2013) for evaluating the effectiveness of SES conceptual frameworks (Table 5).

Table 5. Evaluation of the degree to which the SES-EA framework meets the requirements of EIAs in a South African legislative and policy context, using Binder et al. (2013)

Key attributes of frameworks for analysing SESs	Requirements for EIAs in a South African legislative and policy context	Degree to which the SES-EA framework meets the requirements
Conceptualisation of the social system in terms of the inclusion of hierarchical levels and dynamics	<ul style="list-style-type: none"> • Micro to macro scale • Social dynamics should be explicitly considered 	High: <ul style="list-style-type: none"> • Micro to macro scale explicitly included • Several key elements of social dynamics explicitly included
Conceptualisation of the ecological system in terms of the inclusion of hierarchical levels and dynamics	<ul style="list-style-type: none"> • Micro to macro scale • Ecological dynamics should be explicitly considered 	Moderately high: <ul style="list-style-type: none"> • Micro to macro scale explicitly included, but the internal dynamics of the ecological system are not explicitly considered
Conceptualisation of the interaction between the social and the ecological systems	<ul style="list-style-type: none"> • Should consider effects in both directions 	High: <ul style="list-style-type: none"> • Effects in both directions are considered
Degree to which the social and ecological systems are treated in equal depth	<ul style="list-style-type: none"> • Should provide the option to treat the social and ecological systems in equal depth 	High: <ul style="list-style-type: none"> • Both systems are treated in almost equal depth
Ecocentric vs. Anthropocentric	<ul style="list-style-type: none"> • Should not be overly anthropocentric or overly ecocentric 	Moderate: <ul style="list-style-type: none"> • The ecological system is considered in terms of its utility for humans, thus the framework is biased towards anthropocentric impacts

Orientation: analysis-oriented vs. action-oriented frameworks	<ul style="list-style-type: none"> • An action-oriented framework is required 	High: <ul style="list-style-type: none"> • Identification of what action needs to be taken, and by whom
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Criterion 1: Conceptualisation of the social system and its dynamics

This criterion firstly refers to the diversity of social (hierarchical) levels of the system (e.g. individual, group, society) that is represented, and secondly, to the level of interaction across these levels (macro – influence of governance system on individuals – vs micro – individual decision making and learning changes governance). The social system conceptualised within the SES-EA Framework comprises individual resource users, communities and public infrastructure providers (provincial and national government departments and their agents) and therefore accommodates all social levels. In relation to the degree of interaction, Binder et al. (2013) suggest better representation arises in a system where individual behaviour can influence the social structure and vice versa. The nature and scope of the development project will determine the combination of level and degree of interaction, but most projects will extend from the level of the individual through to society at large and the framework permits the conceptualisation of both the synchronic and diachronic duality between the ‘micro’ and ‘macro’ referred to by Binder et al. (2013). For example, as part of the co-production workshop, an individual (micro level) could propose a mitigation measure that would alleviate an impact, which in turn is incorporated as part of the conditions for project approval and thereby becomes part of the formal governance system (macro level).

Criterion 2: Conceptualisation of the ecological system and its dynamics

In this criterion Binder et al. (2013) consider the conceptualisation of the ecological system in relation to the two opposing paradigms; the anthropocentric versus the ecocentric. The SES-EA Framework conceptualises the dynamics of an ecological system from an anthropocentric perspective: the ecological system is regarded as a provider of services that increases human well-being (Binder et al. 2013). This is at least consistent with the South African definition of sustainable development, which is “unashamedly anthropocentric” (Morrison-Saunders and Retief 2012:38). The boundaries of a SES are initially identified through the identification of ecological system boundaries. However the ecological system boundaries are based on whether or not a proposed development will or is likely to impact upon this ecological system. The scale of the ecological system being assessed is related to the physical impacts of the proposed ‘human’ development. However, the SES-EA does not facilitate consideration of the dynamics between the different ecological elements within a SES, but rather only the dynamics

of the ecological system that are relevant to human well-being.

Criterion 3: Conceptualisation of the interaction between the social and the ecological systems

Here Binder et al. (2013) refer to whether the ecological system influences the social system ($E \rightarrow S$), human activities affect the ecological system or ecosystem services ($S \rightarrow E$), or whether the framework permits evaluation of reciprocity between the social and ecological systems, as indicated by the bi-directional arrow ($E \leftrightarrow S$). The SES-EA Framework conceptualises the interactions between the social and the ecological systems as how a proposed development will affect the ecological system by way of reducing the services the ecological system can provide to the social system. However, the framework does not explicitly promote the consideration of how a development may impact on or between ecological subsystems. Furthermore, both social and ecological systems are dynamic and will change over time. The framework helps define the present SES, and so promotes the consideration of impacts on the current state rather than future social or ecological states of the system.

Criterion 4: Degree to which the social and ecological systems are treated in equal depth

Binder et al. (2013) consider this to be an important criterion when choosing a framework. Of the 10 frameworks they investigated, only one was considered to meet this criterion; that of Ostrom (2007, 2009). The conceptual link between the latter, the approach of Anderies et al. (2004) and the SES-EA Framework is referred to earlier. The SES-EA Framework places social and economic impacts at the same level of importance as the commonly considered biological (non-human) and natural physical environments, and views this as a coupled system. This also helps overcome the identified physical-biological bias of conventional matrix approaches.

Criterion 5: Orientation: analysis-oriented frameworks versus action-oriented frameworks

Binder et al. (2013) distinguish between 'analysis-oriented' frameworks which are more suited to framing research questions and 'action-oriented' frameworks that are aimed at interventions. The SES-EA Framework is an action-based framework which provides a methodological approach to obtaining and understanding what information is required to be taken, and from whom.

Application of the SES-EA Framework in each of the case studies illustrates the value of attempting to formally describe and define the associated SES. Creating a conceptual model in this way helps build a more holistic understanding of the complex interrelationships between the

four structural elements (Figure 2). Once the conceptual model is defined completely, the interlinkages between components provide the basis for defining the interrelationships in the SES-matrix (Table 5). The SES-matrix is therefore specific to, and appropriate for, the project. This overcomes one of the major weaknesses of conventional matrix approaches of being either too detailed for some projects or not precise enough for others (FAO-UN 1996, Glasson et al. 2012).

In summary, the SES-EA Framework supports the identification and understanding of i) a variety of different levels of the social system; ii) a variety of different levels of the ecological system; and the iii) interrelationships between these two systems. Importantly it gives equal emphasis to both the ecological and social systems.

Does it provide a means of effectively communicating impacts?

Public participation is an essential component of any EIA process, and more so in South African EIA legislation (Government Gazette 33306, GNR 543) where public participation must be meaningful, with a further requirement to address impediments to participation. For example Regulation 54 2e requires that the EAP gives notice of a proposed development “using reasonable alternative methods... where a person is desiring of but unable to participate in the process due to (i) illiteracy; (ii) disability; or (iii) any other disadvantage”.

The advantage of using the SES-EA Framework is that the process of conceptualising the SES helps identify the beneficiaries of ecosystem services. Stakeholders are therefore identified more directly, rather than by relying on conventional advertising, which limits participation to the literate. Similarly, through identifying the ‘public infrastructure providers’, additional stakeholders can be identified. Identifying stakeholders whilst developing an understanding of the coupled socio-ecological system makes it far less likely that key stakeholders would be missed.

Recent reviews of EIA practice highlight the challenges around the critical role of public participation in EIA, calling for “cultural change” and recognition of the “importance of different forms of social and organizational learning through participatory approaches” (Morgan 2012:10). For example, Pope et al. (2013:5) suggest trends “towards more deliberative and empowering forms of engagement have been slow” and also recognise the need to recast public participation as a process of social learning and transformation. One of the ways in which Stirzaker et al. (2010:605) suggest requisite simplicities can be identified is by developing “empathy for other

knowledge forms such as culture and experience and spending time learning together”.

We suggest that the participatory methodology at the heart of the approach goes well beyond traditional EIA practice and makes an important contribution in addressing these challenges. Both case studies used participatory workshops to better understand the associated SES and the likely implications and impacts of development proposals, and a variety of stakeholders including community and local government representatives participated in this process. Stakeholders identified ecosystem services important to them, and learnt about the extent and nature of the ecosystems that sustain them. Other stakeholders could recognise the importance of resources to other participants and how their activities might impact on these resources. Application of the framework allowed the complexities and interrelationships to be exposed with all parties contributing and sharing; new understanding of the system was thus co-created. Once an understanding of the system is in place, it is much easier for stakeholders to describe and understand impacts to the system. Furthermore because impacts are related directly to ecosystems services which are important to them, potential impacts can be perceived more readily.

Does it promote an integrated, comprehensive and detailed understanding of the impacts?

South African EIA regulations require that an EIA must provide a description of the “manner in which the geographical, physical, biological, social, economic and cultural aspects of the environment may be affected by the proposed activity” (Sub-section 2d of regulation 22 and 31 of GNR 543). Step 1 of Phase 1 of the SES-EA Framework requires identification of the geographical, biological and natural physical environments a proposed development will impact upon. Step 1 of Phase 2 of the framework requires identification of the social, built physical and cultural environments a proposed development will impact upon. Implementing the framework in this sequential and systematic way therefore ensures that all aspects of the environment are addressed.

For example, the approach enabled identification of the potential secondary negative visual impact a sand-winning operation might have on location desirability from an ecotourism perspective. This is unlikely to have been identified in a conventional EIA process focused on the biophysical impacts associated with establishing the accommodation facility. Sand-winning was also considered to have a likely secondary impact on the quality of roads, as large trucks would need to utilise the local road network. In this case study the framework facilitated a more

comprehensive understanding of the direct and indirect impacts associated with the proposed development, which in turn enabled the identification of potential mitigation measures, essential for sustainability of the project and the resource.

One possible mitigation measure identified was for the sand-winning operation to be moved to an alternative site, away from the view of the accommodation. However, consideration of the SES in more detail revealed that the sand-winning operation was subsidising road maintenance, normally the sole responsibility of the local authority. The implication of this is that future local government participation would be essential to the success of the development, as they would need to be responsible for maintaining the access road on which the development would be dependent.

Although relatively straightforward, what this case study illustrates is the benefit of having a mechanism to depict complex interdependencies in a SES and is therefore an effective means to explore the advantages and disadvantages of proposals with stakeholders. In this respect the SES-EA Framework proved a useful adjunct to conventional EIA tools.

Response of statutory agencies to the framework was encouraging. In the case of the estuary project there was a cross-section of statutory bodies from which to canvas opinion. In the case of the residential wine estate we reviewed application of the framework with representatives of key government departments (including the Department of Water Affairs, Ezemvelo KwaZulu-Natal Wildlife, local and district municipality representatives), as well as the environmental officer responsible for assessing the EIA and authorising the project. This official indicated that use of the approach had clearly (i) enabled the potential impacts associated with the development to be systemically considered and logically understood; and (ii) instilled a greater level of confidence in the information presented in the EIA, in comparison to an 'ordinary' EIA, as it was much clearer that the impacts of the development were considered holistically and thoroughly, and not in isolation. Although these views are anecdotal and qualitative, they nevertheless suggest that the approach has merit and that further testing and evaluation would be beneficial, particularly in relation to the call by Weaver et al. (2008:97) to push "the sustainability vectors on every EIA an individual works on".

Limitations

The core SES conceptualisation of the framework takes an anthropocentric view, and although

it considers ecosystems broadly, the emphasis is on ecosystem services directly relevant to human well-being, raising the possibility that some biophysical impacts might be overlooked. Similarly as the focus is between the social and biophysical, interactions between components of ecosystems may not be considered. This resonates with the broader debate concerning the relationship between EIA and SIA and the merits of complete integration; some have concerns that biophysical concerns will be 'diluted' (Smith and Sheate 2001; Hacking and Guthrie 2008) or that biophysical impacts will receive less attention due to further resource and time constraints imposed by considering socio-economic impact concurrently (Scrase and Sheate 2002). Our response would be that the framework is not intended to replace what biophysical assessment would ordinarily be done in an EIA, it is an additional mechanism for exploring interdependencies between the social and biophysical.

Assessment of ecosystem services is a relatively new field and EIA practitioners may not have adequate knowledge and skill in this area. Our approach relies on basic rather than expert knowledge in this field, but the implication is nevertheless that the broader team should include this expertise and that EIA practitioners should seek out training in this important and developing area.

One area of EIA practice that is acknowledged as being weak internationally is that of cumulative impact assessment (Morgan 2012, Pope et al. 2013). In South Africa there is the expectation that cumulative impacts will be assessed; sub-sections 2i of Regulation 22 and 21 of Regulation 31 require a description and assessment of the significance of any environmental impact, including cumulative impacts, which may occur as a result of the undertaking of the activity. Matrix approaches are acknowledged to have limited value in identifying cumulative impacts, particularly at higher orders (Table 1). Although the SES-EA Framework would probably provide a strong foundation for considering cumulative impacts, this would need to be a subsequent activity supported by other approaches.

The SES conceptualisation is based on the initial work of Anderies et al. (2004) and Ostrom (2007, 2009). We are aware there has been an evolving discussion of this framework which has recently been formalised further (McGinnis and Ostrom 2014). Although the fundamental principle is the same, our approach would doubtless benefit from extension via these most recent developments.

CONCLUSIONS

We have shown that the process of systematically defining the SES helps describe and explore potential interrelationships in a more useful way than conventional matrix approaches. The process helps identify stakeholders who are beneficiaries of ecosystem services, but also those responsible for providing infrastructure to maintain the supply of ecosystem services, thereby promoting more complete public participation. Co-production of the SES also provides a platform for discussing, understanding and communicating impacts between and among stakeholders, thereby fostering social learning and effective public participation in EIA.

We suggest that our SES-EA Framework addresses the three criteria proposed by Hacking and Guthrie (2008) (Figure 1). 'Comprehensiveness' is achieved by promoting the consideration of all six aspects of the environment, with equal attention given to the social and ecological systems, and 'integratedness' is addressed by providing a mechanism to identify and understand interlinkages between the components of a SES at a range of social scales. The Framework addresses 'strategicness' by encouraging an EAP to understand the environmental implications of a development at a broad, systemic scale initially, but then, in accordance with the approach of requisite simplicity (Stirzaker et al. 2010), allows the EAP to focus more closely on the specific issues that may impact upon the supply of ecosystem services. An additional advantage is that the approach helps identify the ancillary infrastructure requirements and those who may be responsible for its supply and maintenance. This is frequently a cause of failure in development projects because the project has been decided in isolation.

We are also encouraged by the potential in the approach recognised by statutory agencies, but acknowledge that further application and evaluation is required. The Framework is not intended as a completely stand-alone approach or a replacement for matrix or network approaches; it is an adjunct to existing methods which may have particular relevance in the case of complex SESs. More work is required to develop new tools or link existing methods to abstract the data, information and understanding required to implement each step, particularly in relation to the quantification of impacts.

In the interim we propose that it could be used in South Africa and other developing countries by EAPs, and in the review of EIAs, and as a counterpoint to more traditional approaches. We hope that application in either sense would improve the quality of EIAs in respect of the complex SESs that characterise much of the developing world. We suggest that by explicitly

incorporating resilience and ecosystem services into impact assessment, the framework contributes to some of the 'emerging opportunities' for EIA practice identified by Pope et al. (2013).

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CHAPTER 6: PAPER 4

A systems approach to analysing risks to and resilience of the woody-biomass industry in South Africa

Table 6.1. Summary of Paper 4

Information	Details
Title:	A systems approach to analysing risks to and resilience of the woody-biomass industry in South Africa
Paper status:	Submitted to <i>Biomass and Bioenergy</i> (7 March 2015)
Journal website:	www.journals.elsevier.com/biomass-and-bioenergy/
Citation:	Bowd, R., Quinn, N., & Kotze D. C. (Unpublished). A systems approach to analysing risks to and resilience of the woody-biomass industry in South Africa
Objective(s):	<ul style="list-style-type: none"> • To use a social-ecological system-based approach to help describe and analyse a South African woody-biomass industry. • Using this approach, undertake a retrospective resilience-based assessment of the four failed woody-biomass plants in South Africa. • Identify key risks to the establishment of a resilient woody-biomass sector in South Africa, and suggest mitigation measures to manage for these risks. • Advancement of previous SES conceptual frameworks towards their application in resource-based enterprises which feature production processes.
Methods used:	<ul style="list-style-type: none"> • Literature reviews on the following topics: <ul style="list-style-type: none"> ◦ risks associated with a woody-biomass industry in South Africa; ◦ risks associated with woody-biomass industry in Europe and the US; ◦ supply-chain optimisation; and ◦ sustainability criteria and indicators. • Engagement with representatives from the four failed woody-biomass plants in South Africa. • Development of a risk assessment based on Bowd et al. (2012a). • Review of risk assessment by former plant representatives. • Amendment to risk assessment in the light of the review.
Key findings / outcomes of paper:	<p>The developed risk assessment can be used at a broad level to highlight key aspects which must be considered as part of a feasibility assessment for a new pellet plant, and provides a good foundation for the development of a robust and practical woody-biomass tool which supports the establishment of a resilient biomass industry. However, further investigation into the long-term ecological risks associated with a woody-biomass industry under South African conditions is required. Although previous SES conceptual frameworks do provide a strong foundation on which to base a woody-biomass tool, previous SES frameworks are more applicable for analysis at a broad scale, landscape level, compared to at an enterprise level, as they do not explicitly address resource production processes, associated internal business dynamics, and ecological variable interactions as a consequence of resource use. The theoretical contribution of this paper is an advancement of previous SES theory, towards its application in resource-based enterprises which feature a production process.</p>

A systems approach to analysing risks and resilience in the woody-biomass industry in South Africa

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ABSTRACT

Currently more than 600 million of the 800 million people in sub-Saharan Africa are without electricity, and it is estimated that an additional 2500GW of power is required by 2030. Although the woody-biomass market in the developed world is well established, only four woody-biomass plants in sub-Saharan Africa have been established, all of which were closed by 2013. With its affordable labour, favourable climate and well-established forestry and agricultural sectors, South Africa appears to have the potential for a successful woody-biomass sector. This paper documents a first attempt at exploring why these plants failed. It aims to contextualise the potential role of a sustainable woody-biomass sector in South Africa, through firstly developing a social-ecological system-based analytical framework and secondly, using this to undertake a retrospective resilience-based risk assessment of the four former woody-biomass pellet plants in order to identify strategies for increasing the resilience of the industry. The social-ecological system-based framework advances previous theory, which usually focuses on natural resources and their supply, by introducing a production process (with inputs and outputs), internal business dynamics and ecological variable interactions. The risk assessment can be used at a broad level to highlight key aspects which should be considered during feasibility assessments for new plants. Further work is proposed to focus on splitting the social-ecological system into different scales for further analysis, and to investigate the long-term ecological impacts of woody-biomass utilisation.

KEY WORDS

South Africa, woody-biomass, social-ecological system, resilience, risk, framework

1. INTRODUCTION

1.1 Background

The population of sub-Saharan Africa (SSA) continues to grow, and its economies are continually developing and diversifying [1]. Energy provision is the key to unlocking industry and thus economic growth in SSA. Currently more than 600 million out of 800 million people in this area are without electricity, and it is estimated that an additional 2500GW of power is required by 2030 [1]. The greatest proportion of power demand comes from South Africa [2].

To meet this demand a mix of renewable and non-renewable solutions has been proposed [1] (e.g. the Inga3 4800MW hydroelectric dam in the Democratic Republic of Congo, the Khi Solar 50MW solar farm near Upington, South Africa). In the northern hemisphere there is increasingly tightening legislation which promotes substitution of fossil fuels with renewables (e.g. the EU Renewable Energy Directive [3], the US Energy Policy Act 2005 and US Energy Independent and Security Act of 2007 [4]). However, although work on renewable policy has been undertaken in South Africa [5, 6, 7], no legislation has been forthcoming [8]. Although wind, solar and hydropower have been considered, and in some areas implemented in South Africa, their main limitation is their dependence on weather conditions [9], which hinders their effective application; most notably with industry [10]. Biomass is the only renewable source of energy which is not weather-dependent. It is versatile in its application as it can be used for small-scale residential heating and cooking, for large-scale co-firing in existing coal furnaces, and for new industry [11]. Despite woody-biomass being the most utilised source of energy for people [12], it is typically overlooked as an alternative energy source in SSA [13], and is considered by some as an energy which 'engenders poverty', 'comes from the past', is 'dirty', 'inefficient' and a 'subsistence fuel' [14].

Owen et al. [13] explored the contradictions between the significance of biomass for countries in SSA, and the low profile it is given in national policies, arguing that biomass energy initiatives are not acknowledged by decision-makers, who consider economic growth and poverty reduction to be based on the use of fossil fuel. A greater number of jobs are created with woody-biomass production compared to coal, which can range from two to three times [15] to up to 20 times [16], and despite job creation being a priority in SSA, policy-makers in SSA are still dismissive of this energy source.

In 2010 the United Nations Foundation launched the Global Alliance for clean stoves, with the intention of distributing technologically improved stoves on a global scale. Owen et al. [13] recognised that these efforts predominantly focused on the distribution of the stoves, with limited attention given to the production and sustainability of the biomass fuels required to fuel them. Owen et al. [13] further noted that of 35 governments in SSA who have set strategic goals to increase access to electricity, only seven have been concerned with improving wood or charcoal stoves [17], and argues that SSA decision-makers will continue to support 'anything-but-biomass' policies, for as long as they do not recognise the significant contribution biomass can make to job creation, rural economic growth, energy security and 'green' sustainable

development. In addition to being renewable, an array of potential ecological, social and economic benefits has been attributed to the use of woody-biomass (Table 1).

Table 1. Potential ecological, social and economic benefits attributed to the use of woody-biomass

Aspect	Benefit
Ecological	<ul style="list-style-type: none"> • Reduced dependency on fossil fuels which in turn reduces the emission of harmful gases [18, 19, 20, 21, 22, 23, 24]. Although wood does contain sulphur and nitrogen, which yield SO² and NO_x when combusted, the rate of emissions is significantly lower than that of coal [18] • Pellets are carbon neutral [18, 25, 26]. As trees store carbon as a result of photosynthesis, there is no net production of carbon dioxide, The CO₂ generated during combustion of the wood equals the CO₂ consumed during the lifecycle of the tree [18] • The raw material is renewable, and thus can be continuously replenished and reliably supplied [18] provided that the soil nutrients supporting production are not depleted • Potential to recover waste that would otherwise be disposed of via landfills, incinerated, [18, 27] or left to decay and emit carbon dioxide [28] • Promoting best management practices can enable biomass harvesting to be used as a tool for ecosystem restoration [29] • More intensive harvesting can be beneficial for natural regeneration. Sikkema et al. [30] identified that the survival rate of pine seedlings from natural regeneration is enhanced by slash and stump removal after the final harvest, due to improved soil conditions • Short-rotation woody crops can provide a more desirable habitat for forest species than agricultural fields, especially when these new stands have a diversity of tree species, age, and growth habits [31] • The removal of forest waste and the retaining of twig and leaf matting (known as loess) can increase soil fertility [29] and biodiversity when intensively farmed crop lands are converted to forest [31] • Soil organisms can benefit from reduced tillage under perennial energy crops [32], which usually need fewer pesticides and fertiliser applications than traditional agricultural crops [31, 32] • Reducing the potential of forest fires through the removal of thinnings and forest waste [33]
Social	<ul style="list-style-type: none"> • Job creation throughout the supply chain and ancillary services industry, as well as for farm and forestry workers [26, 27, 29, 34], many of whom currently face economic hardship [12, 13, 18, 27, 28]. Existing jobs would be more secure in the biomass sector, as more manpower would be needed to grow, harvest and manage raw material [12] • The fuel can be burnt cleanly and safely, if properly prepared and used in efficient appliances [11, 12, 35] • Pellets are used in the same way as coal and wood, thus users are familiar with operating methods [13]
Economic	<ul style="list-style-type: none"> • The establishment of new industry and markets with the availability of reliable energy [18], will reduce local dependency on the international fuel market [12, 27, 29, 36] • Value being added to processed wood waste [18] • Helps societies diversity their energy sources by providing local energy for communities and through the potential sale of bioenergy products in the energy market [27] • Can be stored and used on demand, unlike solar and wind [37] • Can be stored for a long time [11], transported over long distances [11, 28], and can open up opportunities for trade in remote areas as it can be transported [13] • Can reduce imports and capitalise on SSA land, labour and climate [13] • Power can be fed into the existing grid [38]

- With combustible boilers, biomass is 80% cheaper for maintenance costs compared to coal and heavy oil [39]
- More efficient compared to coal [26] as the combustion efficiency of coal is ca. 31% [40] compared to 87% efficiency for wood pellets [39]
- For co-firing, present supply chains and infrastructure can be used for coal [11]
- Pellet plants can utilise dead timber damaged by fire and disease

Two types of biomass are commonly used as alternatives to coal: wood waste and agricultural residue (e.g. bagasse, cereals); this paper focuses on the former as the predominant type in South Africa. Woody-biomass is derived from a variety of sources (e.g. plantation and sawmilling operations, alien plant removal). Pelletisation prior to application is favoured over direct combustion as it has a higher calorific value [12], has negative emissions (<1% compared to ca. 65%) [41], creates greater job opportunities [29] and is more logistically favourable [42]. A simplified flow diagram of the pellet supply chain is presented in 1.

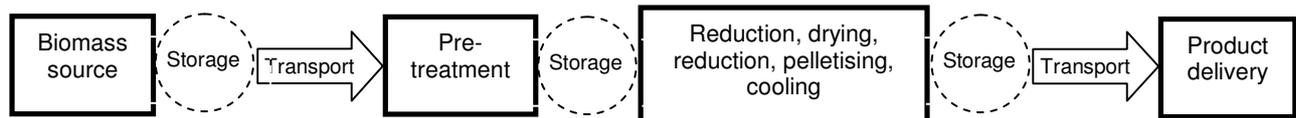


Figure 1. Woody-biomass production process

In many parts of Europe, South America and the US, the use of biomass pellets is increasing rapidly in the domestic, commercial and industrial sectors supplying electricity, heat (e.g. domestic stoves [36], bakery ovens [11]), combined heat and power (CHP), and fuel for transportation [43]. Co-generation applications, where some coal is substituted with pellets, are also increasing rapidly in the US, Finland, Denmark, Germany and Belgium [16]. In Europe alone, wood fuel production increased from 125 million m³ in 2001 to nearly 160 million m³ in 2011 [44], and about 4.4 million tonnes of wood-pellets were imported across European Union (EU) borders in 2012 [45].

The biomass sector has developed in response to the EU Renewable Energy Directive in which the 28 member states have agreed to a target of 20% of energy from renewables by 2020. In 2011 this was 10% of which 4.8% was from the use of wood and wood-waste material [46]. It is projected that more than 10% of final energy consumption will be derived from biomass by 2020 [20] with forest biomass likely to be a significant component [21].

There are an estimated 2.5 million tonnes of collectable biomass in South Africa, and significant

areas of South Africa (predominantly located within a 200km coastal buffer) are furthermore ideally suited to forestry [39]. Environmental conditions enable trees to reach maturity after ca. 15 years, whereas in Europe and North America trees need more than 50 years [47]. In South Africa, thinnings and plantation waste can be utilised as early as four years after planting, in contrast to much longer periods in the northern hemisphere (+10 years) [47]. Kranzl et al. [48] note that SSA has the potential to substantially contribute to the supply of bioenergy, and there is a considerable surplus of biomass production compared to demand in the developing world [49].

With the pellet bioenergy market going from strength to strength in the US and Europe, some might assume that the blueprint of what works in the US and Europe could be directly transferred to South Africa. With ample affordable labour [39] and a productive timber sector, South Africa is potentially an ideal location for the biomass industry. However, to date, only four pellet plants have been established in South Africa, all of which closed within six years of being commissioned (Table 2). Obviously unexpected events took place which the industry had neither anticipated nor prepared for.

Table 2. Details of the four former pellet plants in South Africa. Direct job creation refers to the number of onsite jobs created. Indirect job creation refers to the number of jobs which were created in the delivery of raw material to the plant and pellets to the harbour

Plant	Details	Plant	Details
Plant A	Located within KwaZulu-Natal Midlands Built to produce 65 000 tonnes/annum Operated at 98% capacity 325 000 tonnes sold to Europe Date commissioned: 2008 Date closed: 2013 Operated for five years five months Direct job creation: 52 Indirect job creation (est.): 25	Plant C	Located within Mpumalanga Built to produce 75 000 tonnes/annum Operated at 5% capacity 1000 tonnes sold to Europe Date commissioned: 2010 Date closed: 2012 Operated for one year five months Direct job creation: 51 Indirect job creation (est.): 22
Plant B	Located within northern KwaZulu-Natal Built to produce 75 000 tonnes/annum Operated at 10% capacity 800 tonnes sold to Europe Date commissioned: 2008 Date closed: 2010 Operated for two years one month Direct job creation: 60 Indirect job creation (est.): 25	Plant D	Located within the Eastern Cape Built to produce 80 000 tonnes/annum Operated at 20% capacity 10 000 tonnes sold to Europe Date commissioned: 2009 Date closed: 2012 Operated for three years Direct job creation: 55 Indirect job creation (est.): 25

To date no investigation has taken place into the contributing factors undermining the resilience of these plants, and which consequently led to their failure. This paper documents a first attempt at developing this understanding, given the apparently favourable conditions for the industry in

South Africa.

1.2 Sustainability indicators in the biomass sector

During the 1970s and early 1980s, biomass harvesting was portrayed as the leading driver for global deforestation under the 'woodfuel gap' theory [50], and concerns about negative impacts on the environment were often expressed. Concerns have continued to emerge and are linked to the possibility of losses in soil fertility and water [51] and the utilisation of indigenous forests to meet the need for biomass [52]. These have led to the development of sustainability criteria, indicators and certification as a way of monitoring the sector [53] (e.g. Buchholz et al. [54], Wang et al. [55], GBP [56], Myllyviita et al. [57]). Although generally considered useful when applied to bioenergy production [54, 57, 58] and forest management [59], limitations associated with these assessments have been acknowledged [57], including i) instructions on how to use them are not regularly presented; ii) bias towards data abundant indicators; iii) overlooking of some indicators due to deficient data; iv) social and cultural sustainability are often overlooked due to difficulties with identification and quantification; v) a need for them to be case study specific; vi) obtaining relevant data is time consuming; vii) thresholds are difficult to define; viii) impacts may vary in terms of time and space; and ix) identification of universally applicable and understood indicators is difficult. With such varied and considerable limitations, we see merit in developing an alternative method to assessing the sustainability of the woody-biomass pellet sector.

1.3 Supply chain optimisation strategies

Conflict can arise between managing for sustainability and optimising the bioenergy supply chain. Optimisation models and approaches (e.g. linear and mixed integer linear programming, scenario-based approaches, sensitivity analysis, stochastic and robust optimisation) have been used to provide optimal solutions for network design, technology, plant and storage location and scale, logistics options and material flows for the biomass industry [27]. However, economic rather than environmental and social objectives are invariably the focus [27].

As woody-biomass is currently predominantly produced and used in developed countries (e.g. the US and Europe) that have well-developed environmental knowledge and legislation relating to ecological and social protection, lack of social and ecological objectives within supply chain optimisation strategies may not result in unsustainable or non-resilient operations. However, in South Africa there is a dearth of social and ecological knowledge, and where legislation exists, it

is frequently not well enforced [8]. The economic emphasis in supply chain optimisation strategies, coupled with the potential for inadequate sustainability assessments, could result in the formation of an unsustainable and non-resilient woody-biomass industry in South Africa.

While pellet plant operation economics are similar in both developed and developing countries (e.g. transportation costs), ecological and social conditions can vary greatly. In developed countries there is formalised land tenure, and ownership rights are respected, whereas in the developing world, rural livelihoods are predominantly reliant on biomass and associated ecosystem goods and services, with access usually governed by traditional land rights [12]. Commercial interests in the developing world often override the interests of indigenous people and ethnic minorities who are reliant on land resources and lack land tenure [60, 61]. In addition, many of the basic services required for the pellet industry are in place in developed countries (e.g. established transportation infrastructure, reliable electricity), whereas large areas of South Africa are inaccessible and obviously lack electricity.

Given the traditional focus on economic objectives, a lack of social and ecological knowledge, legislation, policing, and the fact that the livelihoods of much of the South African population are reliant on ecological processes, there is great risk that a woody-biomass industry in South Africa would be unsustainable if developed-world supply chain optimisation strategies were adopted. As supply chain optimisation is predominantly driven by economic interest, it is vitally important that the risk assessment, which could be regarded as a form of sustainable assessment, considers social and ecological impacts.

1.4 Social-ecological systems (SEs) and the complexities of the supply chain

A complex set of interacting factors, which occur at different scales, potentially affects the resilience of woody-biomass operations. The forest industry consists of a variety of interrelated and interconnected sectors within their respective supply chains and variations in one part of the supply chain generally propagate into other areas (e.g. the downturn of the housing market results in a reduced demand for timber, which in turn results in decreased availability of wood chips, and thus a reduced availability of raw material for bioenergy [27]). Other factors which make bioenergy complex include: biomass is usually spread over larger areas, is bulky with relatively low density and has a high moisture content [62]. These characteristics are known to contribute to the high cost and complexity of forest biomass logistics [63]. These dynamics interlink with the ecological systems generating the biomass, forming a complex social-

ecological system (SES).

Social-ecological systems refer to social systems in which some of the interdependent relationships between humans are mediated through interactions with ecological units [64]. They are complex and adaptive [64], often functioning as a nested hierarchical structure, with processes occurring within different sub-systems at different rates and scales [65, 66]. For example, consider a SES involving a deep-sea fishing enterprise. Interactions take place at a 'boat' level, at a landscape level (geographical area where the fish are caught), and at a national and / or international level (area where fish are sold, and groups such as Green Peace have an interest in the policing of fishing practices).

To help understand these complexities, we use a social-ecological system-based approach to help describe and analyse woody-biomass pellet production and then use this to undertake a retrospective resilience-based assessment of the failed plants. We identify key risks to the establishment of a resilient woody-biomass sector in South Africa, and suggest mitigation measures to manage for these risks. Our novel contribution is the advancement of SES framework theory, as well as a practical risk assessment, which could be applied in other settings, such as for the assessment of natural resource-based enterprises.

2. METHODOLOGY

To help identify possible risks associated with the utilisation of woody-biomass, sustainability indicators and related criteria used in the bioenergy sector were reviewed, along with supply chain optimisation strategies. The latter was undertaken as these are likely to act as drivers for the industry and thus have the potential to contribute to risks in the bioenergy sector.

The analytical framework used to define the SES was developed as an extension of the Anderies et al. [64] approach which emphasises infrastructure as a component of a SES, the SES conceptual framework of Ostrom [67, 68] and McGinnis and Ostrom and [70], which identifies social-ecological variables affecting the resilience of a SES, and also the Bowd et al. [70] SES conceptual framework for wetland craft related natural resource-based enterprises (NRBEs), which is primarily based on Anderies et al. [64]. Figure 2 represents the resulting conceptualisation, as a set of interlinked SESs operating at different spatial scales.

Bowd et al. [70, 71] both present a methodology to assess the risks associated with NRBEs

which caters for the developing world social-ecological and economic conditions. Based on this approach, and the conceptualised SES, a set of open-ended questions relating to the elements and interlinkages, shown in Figure 2, was compiled. These questions were addressed to all four of the former pellet plant managers, during a series of telephonic interviews during September 2014. These interviews, along with understanding derived from a literature review on potential benefits of and constraints to the woody-biomass sector, were used to populate the risk assessment. Once completed, this was sent to the four former plant managers for review. Feedback from the review was used to make final amendments to the woody-biomass SES framework and risk assessment.

3. RESULTS

3.1 A woody-biomass SES framework

Figure 2 shows a global SES comprising two interlinked SESs: i) pellet production SES – the SES where the raw material is collected from, pellets are produced within and a portion of the pellets are used; and ii) energy supply SES – the SES where the pellets are used, but the material to produce them is not sourced from this SES. Although both SESs are part of one large global SES, we have separated the two as there are several factors which are only applicable to either the pellet production or energy supply SES. The arrows within and between the different elements of the framework indicate the interlinkages and interdependences within the respective SESs, and are discussed further in Table 3.

In the pellet production SES, which functions at a local scale, 'competing resource users and actors' emphasises that competition for raw material is a key factor which affects the functioning of the plant. The framework also highlights that the actual 'raw material', the 'physical', 'governmental' and 'social' infrastructures and those responsible for supplying these 'infrastructures' (referred to as 'infrastructure providers') are the other key elements which affect the plant. The actual plant is included within the 'infrastructure' component, and this is accentuated by the inclusion of 'internal business dynamics'. The 'product' is located within the pellet production SES as it is produced within that SES. There may also be demand for the product within the local SES from 'raw material suppliers' (e.g. sawmills needing heat to dry timber), 'competing resource users and actors' (e.g. poultry farms who use sawdust for bedding but also require energy for heating) and 'infrastructure providers' (government who is responsible for providing and maintaining roads, and also needs power for government services, such as hospitals). The framework represents the pellet production process through

displaying 'raw material' as an 'input', 'infrastructure' as the manufacturing process which involves 'physical infrastructure' (e.g. the plant), 'social infrastructure' (e.g. the work force, skills, technology and knowledge) and 'governmental infrastructure' (e.g. laws and policies governing operations and demand for product). The 'output' of the production process is the pellets which is the 'product'.

In the energy supply SES, 'product users and actors' indicates that this group can have demand for pellets, but also have access and a desire to use other energy resources. 'Energy resources' highlight that competition from (e.g. other pellet producers) or availability of other energy resources (e.g. coal, wind) could impact on the demand for the product. 'Infrastructure' draws attention to the fact that the following can impact on the demand for the 'product': i) 'physical infrastructure' which refers to the accessibility of the 'product'; ii) 'social infrastructure' which refers to the knowledge of the availability and application of pellets; and iii) 'governmental infrastructure' which refers to legislation and policy which supports or discourages the use of pellets. Also indicated are the 'infrastructure providers' which highlights the need to consider those responsible for provision of the 'infrastructure'. The framework also encourages the consideration of the preparedness for 'external biophysical forces' and 'external social, economic and technological forces' in both SESs.

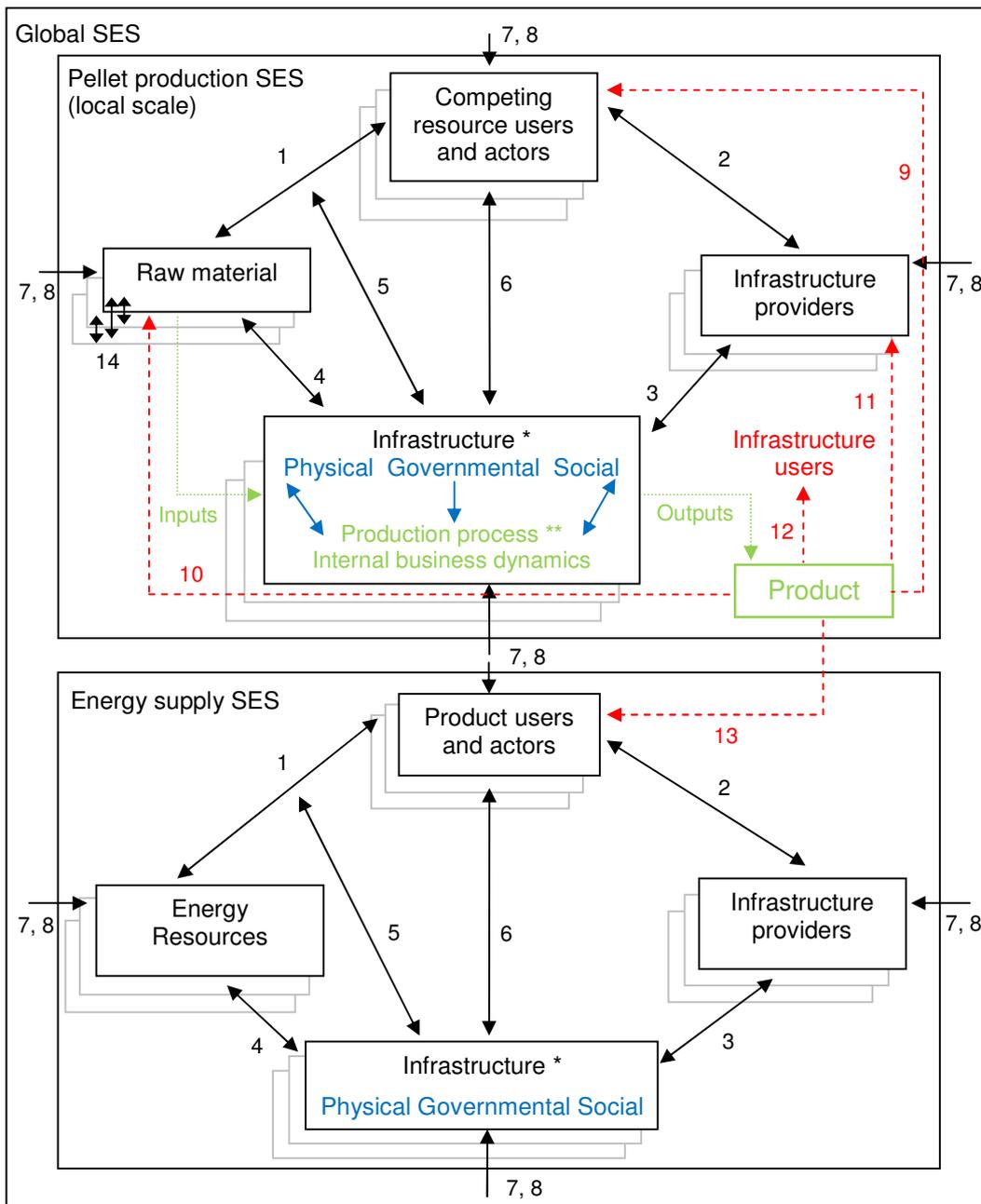


Figure 2. The South African woody-biomass social-ecological system framework. * Physical - transformation and communication infrastructure; governmental – legal and regulatory infrastructure; social – knowledge and skills infrastructure. ** Production process – input of raw material, pre-treatment and pelletising, delivery of product (output). Refer to Table 3 for definitions of the different interlinkages

Table 3. Defining elements of the South African woody-biomass social-ecological system framework

Pellet production SES	Definition / link	Examples
Raw material	Material to power the pellet plant and to produce the product (input for the production process)	<ol style="list-style-type: none"> 1. Sawmill waste – sawdust, off-cuts, shavings, chips, bark [30] 2. Short-rotation purpose-grown timber [29] 3. Low quality wood from small trees, branches and other slash [72, 73] 4. Alien vegetation infestations (rural) 5. Urban and rural municipal and domestic garden waste 6. Plantation thinnings (trees removed to allow expansion of growth) [30] 7. Plantation harvest waste [74] 8. Timber from de-stumping activities (however this is not currently desirable, as it has high silica from being contaminated with soil, and this reduces the life of combustion utilities) 9. Wood substances or objects which have performed their intended purposes (e.g. recovered construction wood or demolition wood), however this is not currently desirable, as this wood source has generally been treated (e.g. with creosote) [30, 52]
Competing resource users and actors	Those who utilise the same raw material required for pellet manufacture	<ol style="list-style-type: none"> 1. Sawmillers – material burnt to generate heat / substitute for wood drying instead of using electricity from grid 2. Paper, pulp and particle board manufacturers – material used to make paper, cardboard and chip board 3. Rural poor – plantation waste and alien vegetation collected for heating and cooking (if permitted) 4. Plantation companies – thinnings sold to fencing and pallet manufacturers or burnt to increase soil fertility 5. Municipalities – alien vegetation used as a 'balancer' to reduce contaminants from other landfill or sold for a purpose (e.g. tanning, charcoal, composting) 6. Poultry producers – material for bedding 7. Plastic and cement manufacturers [43] – material used for manufacturing process
Infrastructure	<p>Physical</p> <p>Transformation and communication infrastructure</p> <p>Governmental</p> <p>Legal and regulatory infrastructure</p>	<p>All manmade alterations to a landscape, transportation and telephonic / digital communication</p> <ul style="list-style-type: none"> • Transfer of raw material to pellet plant, and distribution of product to users (maritime and fluvial transport, railways, trucks, horse-drawn [11]) • Plant which produces the product • Stoves, burners and furnaces which burn pellets • Services required to produce and transport product (electricity to power the plant, roads, harbours, water, waste disposal, communication networks) <p>Laws in the form of acts, regulations, policy documents and customary regulations, and government / political structures (e.g. structures to define powers and responsibilities)</p> <ul style="list-style-type: none"> • Local, national and international legislation and policies which i) promote and support the use of pellets; ii) discourage the use of competing raw material users; iii) provide the associated services / infrastructure required to support product production; and iv) control the different aspects of the production process (e.g. labour law and air emission controls)

Social

	Knowledge and skills infrastructure	<p>Scientific / technical knowledge</p> <ul style="list-style-type: none"> • The level of technical knowledge available for the construction, operation and maintenance of the i) pellet plant; and ii) equipment which uses pellets (e.g. motors, bearings, IT) • Literacy level of those needing to be educated on the use of pellets • Ability of educators and media to inform the public on the use of pellets
Infrastructure providers	Those responsible for the provision of required infrastructure	<ol style="list-style-type: none"> 1. Governmental departments responsible for: <ul style="list-style-type: none"> • Implementing the governmental infrastructure (see above) • Supporting economic development 2. Private sector responsible for: <ul style="list-style-type: none"> • Providing the required transportation, communication etc. (e.g. privately owned trucks, telecommunications networks) • Middle-men who sell stoves, burners and furnaces
Product	Pellets as the output of the production process	Woody-biomass pellets which are utilised by those within the production process SES, and those located within energy supply SESs
Interactions within pellet production SES		
1	Between raw material and competing resource users/actors	Competition between the pellet producers who need biomass for the manufacturing process (e.g. sawdust to fuel the kiln which creates heat to make the pellets) and to make the product, and other industries which utilise biomass (e.g. composting, animal bedding enterprises)
2	Between competing resource users/actors and infrastructure providers	The promulgation and enforcement of legislation and policies which favour one resource use over another (e.g. laws which specify that a portion of plantation waste must go to renewable energy)
3	Between infrastructure providers and infrastructure	The provision, monitoring and maintenance of infrastructure by those responsible for providing infrastructure (e.g. the continual updating of laws and regulations to be in line with best practice, such as air emission standards)
4	Between infrastructure and raw material	Infrastructure or lack of infrastructure which enables raw material to be utilised (e.g. roads which permit biomass to be accessed in remote areas, laws which control the combustion of biomass)
5	Between infrastructure and raw material dynamics	Legislation, physical infrastructure and technical knowledge which impacts on the availability and / or nature of the raw material (e.g. scientific knowledge, such as soil and climatic data, can help towards optimising timber yield)
6	Between competing resource users/actors and infrastructure	The impact of actions of the pellet producers and other resource users/actors on the availability or nature of infrastructure (e.g. not respecting the weight limit on plantation access roads could lead to the roads becoming impassable)

7	External biophysical forces on raw material, infrastructure and infrastructure providers	Severe weather and natural disasters (e.g. excessive rainfall) could: i) hinder harvesting, and thus reduce the availability of timber for the sawmills, which in turn will reduce the availability of sawdust and off-cuts for bioenergy; and ii) increase the moisture content of raw material which will increase production costs which in turn will impact on profitability)
8	External social, economic and technological forces on infrastructure providers, infrastructure and raw material	External forces could include, changes in political system (e.g. war, conflict or change of government may cause a loss in investment), advancements in technology (e.g. advancements which make other renewable energies more or less desirable compared to woody-biomass)
9	Demand for product by competing resource users/actors	Those located within the pellet production SES and who have demand for the pellets (e.g. a poultry farmer who uses pellets to heat poultry houses, but also uses sawdust as bedding)
10	Demand for product by raw material suppliers	Raw material suppliers may have demand for the product (e.g. a fencing and pallet manufacturer who provides the plant with sawdust, may use wood pellets to dry their timber prior to manufacture)
11	Demand for product from infrastructure providers	Those responsible for providing the infrastructure who have demand for the product (e.g. electricity providers may use pellets to produce power)
12	Demand for product by infrastructure users	Those who use the same infrastructure as the woody-biomass plant (e.g. use the same roads or are governed by the same municipal by-laws) but are not infrastructure providers, raw material suppliers or competing resource users/actors (e.g. a nearby abattoir which burns wood pellets to heat water)
13	External demand for the product	Those who have demand for the product and who are not located within the same SES as pellet producers. They do not depend on the same infrastructure or compete with the same resource users/actors as the pellet plant (e.g. when the pellets are shipped overseas, and the users are not controlled by the same legislation)
14	Ecological interactions	The interactions between ecological variables as a consequence of the enterprise (e.g. a fishing enterprise may exceed a fishing quotas which results in the collapse of a seal colony).

Energy supply SES

Product users/actors	Those who have demand for the product but do not rely on the same raw material for another purpose	<ol style="list-style-type: none"> 1. National enterprises <ul style="list-style-type: none"> • Companies located within the same country, but which do not compete for the same raw material. These product users/actors may be governed by the same overarching legislations (e.g. a country's constitution, however there may be different local by-laws, regulations etc.). These product users/actors are likely to be physically located a significant distance from the plant 2. International enterprises <ul style="list-style-type: none"> • Companies located outside of the country of pellet production. These countries are governed by different legislation and controls, and may have access to different technologies due to scientific knowledge or environmental situation (e.g. have the option of thermal energy as an alternative to biomass energy)
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Energy resources	Alternative energy sources	Changes in policy, legislation, profitability and / or evolving scientific knowledge (with or without vested interest) could result in the preference of one energy source over another by a country or enterprise (nationally or internationally). Alternative energy sources include: biofuel, solar, wind, hydro, thermal, traditional fossil fuels. The supply of pellets from a different SES is also considered here
Infrastructure required to enable the delivery and use of the product	Physical Transformation and communication infrastructure	All manmade alterations to a landscape, transportation and telephonic / digital communication <ul style="list-style-type: none"> • Distribution of product to users (e.g. trucks, roads) • Services required for the product to be used (e.g. burners which are suitable for pellets, electricity infrastructure to carry power to users)
	Governmental Legal and regulatory infrastructure	Laws in the form of acts, regulations, policy documents and customary regulations, and government / political structures (e.g. structures to define powers and responsibilities) <ul style="list-style-type: none"> • Legislation, policies etc. which support i) the use of pellets; and ii) services / infrastructure required to utilise the product
	Social Knowledge and skills infrastructure	Scientific / technical knowledge <ul style="list-style-type: none"> • literacy level which enables users to understand the benefits and constraints of using, and the knowledge required to efficiently utilise the pellets
Infrastructure providers	Those responsible for the provision of required infrastructure	<ol style="list-style-type: none"> 1. Governmental departments responsible for: <ul style="list-style-type: none"> • implementing the governmental infrastructure (see above) • supporting economic development 2. Private sector responsible for: <ul style="list-style-type: none"> • Providing the required transportation, communication etc. (e.g. privately owned trucks, telecommunications networks) Middle-men who sell stoves, burners and furnaces
Interactions within energy supply SES		
1	Between alternative energy resources and product users/actors	The demand for pellets may increase or decrease as a result of the availability or preference to an alternative energy resource (e.g. pellet production may become established in a country where it was not previously available. Thus it will likely be cheaper for users to use locally produced pellets as opposed to importing pellets from elsewhere. A government may change its policy and favour the use of thermal power to biomass. This will result in a reduced or lost market for biomass)
2	Between product users/actors and infrastructure providers	Legislation, policies, agreements and regulations which support or do not support the use of pellets (e.g. the introduction of carbon tax will encourage the use of renewables)
3	Between infrastructure providers and infrastructure	The provision, monitoring and maintenance of infrastructure by those responsible for providing infrastructure (e.g. the maintenance of pellet burners at a facility, or ships and harbours used to transport pellets)
4	Between infrastructure and alternative energy resources	Infrastructure or lack of infrastructure which may led to the favouring of one energy resource to another (e.g. the absence of a harbour, or a harbour which is unable to receive pelletised product)

5	Between infrastructure and alternative energy resources dynamics	Legalisation, physical infrastructure and technical knowledge which impacts on the utilisation of different energy resources (e.g. a lack of scientific knowledge may result in some governments favouring fossil fuels as they are wary of change)
6	Between product users/actors and infrastructure	The impact of actions of the product users/actors on the availability or nature of infrastructure (e.g. the demand for pellets may result in improved transportation networks, or the installation of modern, clear and efficient kilns)
7	External biophysical forces on alternative energy resources and infrastructure	Severe or changes in weather may result in an increased or reduced demand for alternative energy sources (e.g. the demand for pellets produced from outside the pellet production SES may increase if local pellet supplies have been affected by flooding)
8	External social, economic and technological forces on infrastructure providers, infrastructure and energy resources	External forces could include changes in political system, advancements in technology (e.g. advancements which make other renewable energies more or less desirable compared to woody-biomass)

3.3 Key factors underpinning the failure of the pellet plants

Contamination and European technology not appropriate for South African conditions

All four representatives operated using sawmill waste exclusively. Plant A representative confirmed that harvesting practices, sawmill management and housekeeping were extremely poor in South Africa, thus contamination from soil (silica), rocks and non-organic waste (e.g. plastic and metal) was significantly higher compared to European and US counterparts. High silica content not only comes from poor harvesting practices, but timber grown in South Africa is naturally higher in silica compared to timber grown in Europe or the US, due to soil type. This contamination not only affected pellet quality, but increased the threat of explosions during the drying and milling processes.

Initially all four plants were designed and established based on European technology and standards. The raw material for Plant B was collected from several different sawmills, unlike in Europe where pellet plants obtain sawdust from adjacent sawmilling operations. The raw material in Europe is managed in such a way that it does not come into contact with the ground, thus expensive technology is not required for screening the raw material in Europe.

Once operational, it soon became apparent to Plant A that the decontamination and preparation of particle size prior to drying was paramount. It took approx \$3 million to hone the skill and develop technology to decontaminate and prepare this raw material prior to pelleting at this plant. This new technology included the development of a pelleting die ideal for use with contaminated raw material, and which could be refurbished up to four times, compared to twice (the industry norm). As well as the die being suitable for South African conditions, this advancement also made the die 50% more cost effective and thus reduced maintenance costs.

Plant D thought that a significant contributor to contamination was the high turnover of unskilled general workers operating the sawmill who often confused raw material containers as waste receptacles. This confusion increased contamination which on one occasion resulted in an explosion within the hammer mill when a piece of metal approximately 2cm² was struck by a blade. This first explosion caused a second explosion in the holding hopper beneath the hammer mill, so powerful it moved a concreted I-beam 30cm.

At another plant, a dust explosion during the pellet production process fatally injured an operator. This explosion was the result of contaminated raw material, although the exact type of

contaminate which caused the explosion is still unknown.

Plant A representative suggested that due to the ever-growing shortage of global raw material, the experience acquired in South Africa to manufacture Grade A pellets from contaminated material may become all-important to this industry in the future. Plant D stressed that conditions in South Africa are completely different to that of Europe and the US, and that it was dangerous to assume that there are any similarities.

Logistics

All four plants identified that logistics were a fundamental risk to the industry, especially as all products were exported. Only Plant A was considered well-positioned in terms of distance to raw material and port. The other plants had an average round trip of 500km for raw material (for Plant A it was 80km). All representatives identified that the running costs per kilometre were very high and inefficient. Although transportation costs were considered during the feasibility phase, it emerged that transportation providers escalated costs as demand increased due to a lack of competition. Plant A addressed this issue with running return loads (delivering product and returning with raw material). Plant B informed that it was 30% cheaper to deliver one tonne of pellets to the UK, compared to delivering the same amount to Cape Town, Western Cape, from northern Zululand (3 000km return trip). Plant A saved 30% on logistic costs by owning and operating its own trucks in year three. Plant C saw logistics in South Africa as being dominated by road transportation, as the rail system is poorly maintained and unreliable and sea freight is too expensive over short distances (<1 500km). Plant D told of truck turnaround times being frequently doubled due to congestion on the roads and at the harbour.

Reliable supply of raw material

The establishment of Plant C was based on obtaining the raw material from a major timber supplier that withdrew its commitment after being offered a more lucrative arrangement from a non-bioenergy enterprise. This played a key role in the collapse of this plant.

At Plant D the majority of timber producers in the local area choose to continue to send their raw material overseas instead of supporting the local pellet industry. The representative attributed this reluctance to ignorance, poor management and an outdated mindset, and is of the opinion that greater returns for the raw material suppliers can be achieved if the raw material is converted into pellets.

Lack of ancillary services and technical knowledge

Plant C raised the issue of a lack of ancillary services (e.g. welders, boiler makers, fitters and turners, electricians and millwrights) as being a key cause of plant failure, and contributed it to the abandonment of technical training colleges and apprentices by the government post-1994. He added that although these technical colleges have recently reopened, the level of skills required to maintain pellet plants is seriously lacking, and this is further compounded by a lack of technical skills in associated support companies (e.g. IT) which are needed to build and service the plants.

Plant A was supplied capital equipment that did not achieve the stated production rate due to equipment being installed which was not compatible with South African wood. When taken to task the suppliers refused to replace the under-performing equipment. This resulted in the plant performing 15 000 tonnes per annum under capacity. This occurred due to a lack of knowledge of South African conditions.

3.4 Woody-biomass risk assessment

The risk assessment displays a variety of risks which have the potential to arise with each combination of relationships between the different elements shown in Figure 2. Shabani et al. [27] differentiate between different levels and types of risks (e.g. short-term, level 1 – machine failure, long-term, level 2 – supply of raw material and seasonal demand for product). The risk assessment focuses on level 2 long-term uncertainties; however some general short-term level 1 risks have been included as a multitude or combination of short-term level 1 risks could be more detrimental to a pellet plant compared to a single long-term level 2 risk.

The initial version of the woody-biomass risk assessment was amended with feedback from the former plant operators (Table 4) and is discussed further in Section 3.5. The parts of the risk assessment which were amended on the basis of this review are indicated in italics.

Table 4. Woody-biomass risk assessment showing potential risks and associated mitigation measures

Questions	Potential risks	Mitigation measures
Pellet production SES		
Relationship between competing resource users/actors		
<ul style="list-style-type: none"> Identify conflicts between competing resource users/actors 	<ul style="list-style-type: none"> Rural poor, composting (including soil fertility), plastic, cement, fencing and pallet manufacturers. In forestry there are different values and stakeholder preferences which cannot always be understood, interpreted and quantified completely [75], and social and cultural values and opinions can change within short timeframes [57, 76]. Options within stakeholder groups can also vary widely [51] 	<ul style="list-style-type: none"> Spend time and money on stakeholder consultation [27]. Develop best management practices for planted and hydrologically sensitive areas (where high surface runoff and high potential sedimentation loss are anticipated) (e.g. retain harvesters' off-cuts and organic material for soil productivity and biodiversity [77, 78]. <i>Investigate production sector mechanisms (e.g. the Forestry Stewardship Council (FSC) certification, which could be used to encourage timber companies to contribute to renewable energy production</i>
<ul style="list-style-type: none"> Identify what advantages the off-take for a pellet plant has over competing resource users/actors 	<ul style="list-style-type: none"> Minimum raw material preparation required prior to delivery (no separation or sorting of raw material into different sizes is required), whereas there may be financial implications with supplying alternative competing resource users/actors who require uniform sized or type of raw material 	<ul style="list-style-type: none"> N/A
<ul style="list-style-type: none"> Identify what disadvantages the off-take for a pellet plant has over competing resource users/actors 	<ul style="list-style-type: none"> If raw material is contaminated (e.g. treated with creosote), the pellet plant will reject the material 	<ul style="list-style-type: none"> Pellet plant to oversee harvesting, processing and housekeeping at source
Relationship between competing resource users/actors and the raw material suppliers		
<ul style="list-style-type: none"> Is there sufficient raw material to supply the production process? 	<ul style="list-style-type: none"> Unlikely, as the pellet plant intends to meet both local and non-local demand 	<ul style="list-style-type: none"> <i>Pellet plant to obtain raw material from numerous suppliers to spread risk of losing suppliers</i>
<ul style="list-style-type: none"> <i>Is the source of raw material reliable?</i> 	<ul style="list-style-type: none"> <i>As suppliers are opposed to committing to long-term contracts, due to an awareness that wood waste could gain in value, it is not possible to confirm a long-term reliable source of material</i> 	<ul style="list-style-type: none"> <i>Be consistent on collections, as often enterprises which pay for wood waste are not long-term. Purchase round-wood and / or plantations</i>
<ul style="list-style-type: none"> Are there other sources of raw material for pellet production? 	<ul style="list-style-type: none"> There is an abundance of round-wood available from private timber growers. However, the pellet plants will compete with the commercial market for this resource 	<ul style="list-style-type: none"> <i>Seek local markets to achieve higher returns, which will enable the plant to compete with commercial buyers for the round-wood</i>
<ul style="list-style-type: none"> Is the available raw material consistently suitable for production? 	<ul style="list-style-type: none"> As material comes from a variety of different sources, there can be variations in the quality of pellets [27]. The pellet plant can take all types of raw material, except treated wood 	<ul style="list-style-type: none"> Consider forest productivity, including site conditions, soil characteristics, harvesting methods, vegetative cover, and management history [79, 80] when securing supply Educate suppliers on what is classified as

- Is the plant optimally located for logistics?
- Ever-changing fuel prices and biomass being spread over large areas [27] contribute to uncertainties of profit
- Is the source of raw material sustainable?
- Possible degradation of forests and soil fertility, and reduced water availability [53], and thus ecosystem services, as a result of increased planting, harvesting and removal of residue [30]. Possible reduction in water quality due to increased soil and vehicle movement

treated wood

- Consider a series of different configurations and improvements in logistics, when deciding on plant location [11, 27]
- A balance is needed between conservation and plantations, and must be based on the principles of ecosystem management [29, 81, 82]
- Policies to protect the environment from potential mismanagement due to growth of bioenergy sector must be developed [48]
- Combustion residue (oxides) to be returned to plantation soils

Relationship between infrastructure and competing resource users/actors

- Is there sufficient infrastructure in place to access the raw material and deliver the product?
- Some areas maybe inaccessible, due to weather conditions or a lack of linear or fluvial infrastructure
- Upgrade existing or build new transportation infrastructure to access material and deliver product. Investigate public and private funding sources as the improved infrastructure may not only benefit the pellet industry
- Is there policy / legislation in place to promote and support pelleting as opposed to other raw material uses?
- In the developed world legislation which stipulates that biomass must be used for combustion to produce power to reduce emissions is in place, however this legislation is absent in South Africa. The biomass sector is neglected and poorly governed [13]. Policies that regulate the market are often in conflict, are unrealistic or ineffective, partly due to the biomass energy being governed by different sectors, ministries and agencies, and reliable statistical data are generally not available [14]. Policy implementation is also usually influenced by economics
- Policy-makers to develop and enforce legislation which supports the development of the biomass sector to provide local power

Relationship between infrastructure and raw material suppliers

- *Are there procedures in place to ensure that the risk of organic and non-organic contamination is minimised?*
- *Often the origin of the wood waste is unknown to the plant prior to its arrival. Thus there may be high levels of silica, and thus organic contamination in the biomass. Poor housekeeping and high staff turnover can lead to non-organic contamination of biomass*
- *Plant management to oversee harvesting process and housekeeping of raw material suppliers*
- Is there sufficient technical knowledge to plan, operate and execute the procurement of raw material?
- No, not specific to South African conditions. Knowledge is deficient on harvesting techniques, raw material handling, climatic conditions, labour force, growing time and biomass composition as South African conditions are unique
- Funding to be channelled towards research on unique South African conditions
- Is there the correct type of equipment to effect the procurement and delivery of
- There is a lack of specifically designed equipment for the transportation and handling of biomass in South Africa
- Funding to be channelled towards the design and building of logistical and transportation

- raw material?
- Is there legislation / best practice guidelines on forestry and agricultural management?
 - Is South African knowledge evolving in line with international best practice?
 - What rules, regulations and legislations govern property rights, national parks and biosphere reserves which could impact on accessibility and growing of raw material [52]?
 - *Is the supply chain operating optimally?*
- Although legislation and management guidelines exist, frequently they are outdated and inefficient in South Africa
 - No, in South Africa opinion and research is frequently influenced and driven by negative economic influence, or it is simply outdated
 - Although conservation areas are well demarcated in South Africa, there are vast areas of tribal lands which have no formal (documented) controls. Land ownership disputes are common in rural areas
 - For many catchments in South Africa the limits for plantation forestry have been reached and authorisation of further expansion is unlikely
 - *The variables associated with logistics are ever changing and complex*
- equipment [29]
- *Funding to be channelled towards developing legislation and guidelines which are specific to South African conditions*
 - Unbiased funding to be made available to re-educate and enlighten researchers and future generations
 - Confirm land tenure when securing supply
 - *Take into consideration when identifying future supplies that some plantations may not be replanted due to water availability and / or permitting constraints*
 - *Have a designated logistics expert who continuously assesses and manages logistic variables*
- Relationship between the physical, social and governmental infrastructures associated with the pellet production process
- To what degree is there governmental support for the pellet industry?
 - *Are investor interests aligned with the objectives of the pellet plant?*
 - *Has financial provision been made to meet out-of-budget occurrences?*
- Currently there is no governmental support for the pellet industry as governmental revenue is mostly allocated to developing fossil fuel development
 - *South Africa is frequently seen as a country to exploit, due to widespread corruption.*
 - *Investors frequently under-fund projects in developing countries due to a lack of enforceable judicial legislation*
- Relationship between infrastructure and raw material dynamics
- Are there any renewable obligation rewards available to raw material suppliers?
 - Are there any penalties applicable to raw material suppliers that do not dispose of their waste legally?
- In the EU and US there are rewards for end-users and methane avoidance to suppliers, however there are currently no rewards for raw material suppliers in South Africa (although FSC could be a mechanism to encourage raw material suppliers to direct wood waste to renewable energy production)
 - Legislation exists for the correct management of waste, however the policing of this legislation is lacking
- Relationship between infrastructure providers and competing resource users/actors
- Lobby for international support from renowned green energy bodies (e.g. WWF) to apply pressure at government level. Lobby for support from international importers to insist on renewable energy being used for manufacturing
 - *Introduce checks and balances in shareholding and funding contracts*
 - *Full funding, with contingency, must be deposited in an escrow account*
 - Lobby at governmental level for the effective implementation of renewable obligation rewards [84]
 - Lobby at government level for the effective implementation of waste management controls

- *Are there existing and favourable relationships between competing resource users/actors and those responsible for the provision of infrastructure used by the competing resource users/actors?*
- *There is potential for some government departments to favour some industries over others (e.g. a municipality may prefer a poultry farm over a sawmill, as poultry pays higher municipal rates compared to sawmilling operations). Corruption within the government may also influence resource user/actor preference (e.g. government officials having private business ventures which benefit from certain industries)*
- *Ensure that infrastructure providers are educated on the direct and indirect benefits of renewable energy, and blow the whistle on corrupt government officials*

Relationship between infrastructure providers and infrastructure

- *What infrastructure is available and to what extent is it developed, maintained and useable?*
- *Roads are available in some areas; however they are frequently not maintained. High fuel price has a negative impact on profitability and could account for 50% of the total delivery cost [83]. Traffic congestion slows turnaround times on deliveries. Extensive railway line infrastructure exists in some areas, however it is not maintained. There is also insufficient and ill maintained railway rolling stock. Diversion of electrical power from electrified sections to the main grid causes railway delays. Harbours are over burdened, lack loading and storage facilities, and have high harbour and stevedoring tariff rates [11]*
- *Lobby at government level for logistic concessions [86]. Pellet plant to own and operate transport. Focus on local market which reduces transportation costs. Pellet plant to utilise its own power. Return loads to be utilised*
- *Are there sufficient skills at government level to ensure the provision and maintenance of the required infrastructure for the pellet plant?*
- *There is a lack of knowledge, capacity and organisation at government level to ensure the provision of infrastructure. Government discourages the transition from traditional fossil fuels to biomass, as their self-financial interest is in fossil fuels, due to a well-established mining sector*
- *Are there sufficient skills and knowledge in the private sector to establish and maintain a pellet plant, including all ancillary services?*
- *A full suite of skills is available for the establishment and operation of a pellet plant in South Africa, however these specialised skills have been honed by only a small nucleus of individuals*
- *Are there sufficient skills and knowledge to retrofit traditional fossil fuel boilers / furnaces to accept biomass?*
- *Limited technical knowledge is currently available. However the necessity to find solutions is rising due to ever increasing cost of electricity and environmental awareness*
- *International environmental pressure and importers of South African goods to insist that a healthy percentage of renewable energy be used in production, instead of fossil fuels*
- *The pellet sector must up-skill to a competent technical level to meet the demands of the developing biomass industry*

Relationship between infrastructure providers

- *Is there a weak link in the supply chain which impedes on delivery to end user?*
- *The fragile and erratic service delivery of public infrastructure creates bottlenecks in the supply and delivery of product*
- *Raw material, pellet production and end users should be in close proximity to one another to minimise logistic limitations*

Relationship between external biophysical forces and infrastructure providers, infrastructure and raw material

- *To what degree are the infrastructure providers prepared for anticipated external biophysical forces?*
- *Preparedness for biophysical events varies amongst public and private sectors and localities*
- *Both the public and private providers must have funds available to be prepared for and manage unforeseen biophysical events*
- *What infrastructure could be impacted upon by an external biophysical force?*
- *Heavy rainfall can inhibit access to raw material and delivery of product to end user*
- *Maintain access routes*
- *What natural occurrences could affect or enhance procurement of raw material and*
- *Excessive rainfall could i) hinder harvesting, and thus reduce the availability of timber for sawmilling, which in turn will reduce the*
- *Irrigation could be used to promote growth during drought [86] in catchments with surplus*

production?

availability of sawdust and off-cuts for bioenergy; ii) increase the moisture content of raw material which would increase production costs which in turn will impact on profitability; and iii) increase silica contamination which in turn increases production and maintenance costs. Drought will impede agricultural production, and thus limit available residue. Although trees killed by fire can be used in pellet production, in the long term fires will impact negatively on the viability of the timber industry

water. Oversee all aspects of the biomass supply chain, especially agricultural and forestry management [27]. Consider utilising more advanced technologies [27]

Relationship between economic forces and infrastructure providers, infrastructure and raw material

- What external social, technical and economic forces could impact on infrastructure providers and the availability of infrastructure and raw material?

- Public opinion is that biomass is viewed as a fuel of the past – how to change public opinion [13]
- Hard to predict profitability due to variable exchange rates [27]
- High bank interest rate has negative influence on the purchasing of capital equipment, which in turn has a negative impact on profitability. This is not attractive to investors

- Educate users on the modernity of using pellets as opposed to fossil fuels
- *Take out forward cover insurance on transactions. Selling to a local market*
- Where possible, pay upfront for equipment

Demand for product

Demand from:

- Raw material suppliers
- Competing resource users/actors
- Infrastructure providers
- Infrastructure users within the pellet production SES
- Energy supply SES

- Markets can become unstable [62]
- Those interested will search for information to help them in their decision to convert to pellets. If information does not exist, is difficult to find or is deficient, the change to pellets will not be made [84]
- High cost of converting to pellets and lack of a well-developed commercial strategy for biomass [84] and knowledge about the benefits of pellets compared to conventional products [90]. This is complex; fuel-price itself may not be the deciding factor [90]

- Market incentives, reliable support from financial institutions and be prepared for times of instability [87] (e.g. contingency plans for times of instability)
- Effective information tools designed to influence consumer behaviour by persuasion, communication and knowledge transfer is recommended [88]
- Consumers to be given firm incentives to switch to biomass energy. There should be incentives and access to capital to convert to pellets. For example: tax credit in Sweden [92], carbon taxes in Sweden and in Finland [93], quota systems for green certifications in Belgium, investment subsidies and feed-in tariffs in the Netherlands have facilitated biomass energy transition [94].
- Suppliers must endeavour to deliver sustainably sourced pellets in line with market demand [84]. Suppliers must not flood the market, as surplus product will reduce profitability of the industry. Likewise, a lack of

- With increasing market demand for pellets comes an increasing need to secure sustainable supply of raw material [91]. Changes in consumer demand are beyond the control of the producer. Policy measures determine large parts of the trade, and unexpected changes in policy can result in rapidly changing trade patterns (e.g. the UK has promoted

domestic supply of biomass and restricted subsidies if the imports exceeded certain limits, resulting in almost no trading of pellets into the UK at one time) [11]

- A lack of logistic infrastructure

reliable fuel will encourage consumers to move to an alternative fuel source, which may not be sustainable or environmentally acceptable

- Both exporting and importing countries are required to have infrastructure which enables the product to move from the plant to the consumer [11]

Energy supply SES

Relationship between alternative energy resources and product users/actors

- What alternative energy resources (including competing pellet suppliers) are available to the product users/actors and to what degree are these energy resources likely to be used?
 - The establishment of new plants in close proximity to existing markets can create a threat to current suppliers
 - Solar and wind can supplement current demand for pellets, however they are unable to meet a 24/7 energy demand
 - Conversion back to fossil fuels if pellet suppliers cannot meet demand
- Establish smaller plants close to raw material and potential markets (plants to be 50% smaller compared to the failed plants, as logistic costs are 50% of operational costs). Have a broad consumer base. Develop markets for alternative applications
- Continuous exploration of alternative markets and applications
- Have alternative arrangements in place should orders not be able to be fulfilled (e.g. have agreements with other plants to supply pellets during times of poor production, breakdowns, lack of raw material)

Relationship between product users/actors and infrastructure providers

- How could infrastructure providers influence the use of pellets by product users/actors?
 - Legislators can: i) be influenced by incentives from fossil fuel suppliers to prioritise the use of fossil fuels; and ii) increase tariffs that would jeopardise the feasibility of producers to make export less feasible
- Development of local markets and applications. Public lobbying to encourage the use of renewables. Development of local markets close to raw material and plant. Encourage production sector initiatives to promote more sustainable production (e.g. through mechanisms such as FSC)

Relationship between infrastructure and alternative energy resource dynamics

- What infrastructure can influence the use of alternative energy resources dynamics?
 - A lack of transportation network and power can hinder pellet logistics and production, thus users are forced to use alternative energy sources
 - Misinformed policy makers have the potential to favour non-combustible renewables
- Establish plants in close proximity to raw material and markets
- Implement strategies to educate policy-makers

Relationship between product users/actors and infrastructure

- What infrastructure is required to ensure that product users/actors receive pellets timeously?
 - Lack of transportation network maintenance and increased congestion of logistics (e.g. trucking delays at harbour)
- Establish smaller plants close to market and raw material

Relationship between external biophysical forces and alternative energy resources and infrastructure

- What external biophysical forces can affect the use of alternative energy resources?
 - A lack of raw material (e.g. due to flooding and thus inaccessibility of material) can result in product demand not being met. This in turn will likely result in product users/actors turning to alternative energy resources
 - Extreme weather events could hamper product delivery
- What external biophysical forces could impact on the infrastructure required to deliver product to product users/actors?
 - Develop agreements with other plants which are located outside the same SES as the pellet plant to supply pellets during times of poor production
 - Stockpile product for when supply cannot meet demand

Relationship between external social and economic forces and infrastructure providers, infrastructure and alternative energy resources

- What external social, economic and technological forces could impact on infrastructure providers, infrastructure and alternative energy resources?
 - War, conflict, famine could reduce the demand for pellets
 - Recession and government budget allocations could affect the availability of funds for infrastructure provision
 - Investor interest and preference for pellets, to an alternative energy resource, may be influenced by conflict, change in government (e.g. threat of privatisation of plant may cause investors to lose confidence in the long-term availability of pellets)
 - Establish a broad consumer base
 - Establish a broad consumer base. Develop markets for alternative applications
 - Develop agreements with other plants which are located outside the same SES as the pellet plant to supply pellets, should the plant cease to function
-

3.5 Review of the risk assessment by representatives from the four former pellet plants

The representatives were asked three open-ended questions in review of the initial risk assessment:

1. Have any risks been omitted or not adequately addressed in the risk assessment?

Investor exploitation and a lack of support from government and banking institutions

Although investor confidence features in the risk assessment, three plants considered it required much more emphasis. The consensus was that there was no support from government, venture capitalists or the banking sector to fund pellet plants in South Africa. Plant C referred to the large bank investments associated with fossil fuels and their aversion to supporting the renewable fuel industry. Plant B indicated that overseas investors view South Africa as a poor investment option and those which do venture into the country frequently exploit projects with high interest rates and unfair contractual conditions. Plant A gave the example of receiving R 85 million from a UK investor, and then undergoing an 18 month environmental authorisation process. Of the R 85 million received, the plant was forced to repay the investor R 33 million in interest during the first year, before construction had even started.

Plant A obtained investment indirectly from the South African arms trade offset deal, which the implementers were unaware of at the conception of the project, as these funds were channelled through a major UK based bank. Once an investigation was launched into corruption associated with the arms deal, the investor and bank called in the loan, which resulted in the collapse of the plant.

Management and a lack of technical skills

All plants suggested more focus on management issues and a lack of skills. At all plants, except A, administrative mismanagement and an absence of technical skills at an operational level significantly contributed to plant failure. Conflicting agendas between management and investors was also a key cause of failure at all plants. It was Plant A's intention to grow the pellet industry in South Africa and it regularly offered technical advice to the other three plants. However, personal agendas prevented these plants from accepting advice. Plant B experienced an investor interfering technically from an ignorant perspective. This interference created ill feeling between the investor and operations management.

2. Are the mitigation measures adequate, realistic and manageable?

Securing raw material supplies

Although all representatives agreed with securing long-term contracts with raw material suppliers, in reality all claimed that this was not possible. The consensus is that raw material suppliers are becoming increasingly aware that waste material is gaining value, and do not want to be locked into long-term contracts as they wish to keep their options open. This opinion is valid, given that in Europe in 2005 the cost per tonne of raw material was \$5, and by 2010 it had increased to \$50 per tonne [39]. Knur et al. [86] noted that, although the woody-biomass sector is still in its infancy, the competition for raw material has already become a serious challenge in German and several other European countries. All representatives thought owning plantations was a potential solution, however they had reservations about long-term land tenure due to political conflict in South Africa.

Forest productivity, including site conditions, soil characteristics, harvesting methods, vegetative cover, and management history should be considered when securing supply [79, 80]. However Plant A, B and D stressed that it was impossible to become involved in this part of the process, because in this industry “beggars can't be choosers” and “you must take what you can get”. Generally the raw material received is waste, thus “it is impossible to be picky about the source of the material”.

Legislation, guidelines and standards must be specific to South African conditions

Three plants were adamant that the development of legislation and guidelines must not be based on developed world experience, as the South Africa situation is entirely different. A key difference is that the specification standards are based on EU and US wood types and conditions, and thus in South Africa the quick growing trees (15 years compared to 55 years in the EU and US) vary in structure and therefore the EU specifications are unlikely ever to be achieved, without great expenditure on technological advancement as machinery and combustible equipment are entirely different in South Africa.

Knur et al. [86] suggest that irrigation could be used to promote growth during drought. Plant B raised the concern that South Africa was a water sparse country and that afforestation was already seen as a stream-flow reduction activity. Thus to encourage additional irrigation was unlikely to be favourably received by government or the private sector. Plant C also had concerns about this suggestion, as irrigated water in South Africa could have contaminants

which would affect the emission specifications of the pellets (e.g. high chlorine levels).

3. Are there any mitigation measures missing from the risk assessment?

Plant D recommended that to reduce the potential for contamination, pellet plant management must be involved with raw material management before it is harvested, and that they must consider investing in demarcated hubs at each sawmill. Plant C recommended that investors must have adequate funding for unforeseen events, due to the unpredictability and complex components of the pellet industry in South Africa. Plant B recommended that the anticipated cost of building a plant must be doubled due to the lack of logistics in South Africa, and also recommended that a South African biomass association be formed which offers skills, support and technical manpower to help establish, operate and maintain the pellet plants.

4. DISCUSSION

The key risks to a sustainable South African pellet industry are a mix of social, ecological and economic constraints, as suggested by Kranzl et al. [48] who identified that these and logistical challenges needed to be overcome before Africa was prepared for the woody-biomass industry. From a social perspective, the risk assessment identified that training (from basic housekeeping to advanced technical knowledge), skills, education and awareness of the benefits associated with the industry were lacking. From an ecological perspective, contamination caused by a high silica content of wood waste (both naturally occurring and through poor harvesting practices) and the spatial location of plantations and sawmills, increases the cost of pellet production. From an economic perspective, the cost of logistics, investor exploitation, turbulent interest rates and fixed costs were fundamental to the resilience of a pellet plant. This research illustrates that the SES surrounding the pellet industry is highly complex and that there are many interconnecting relationships which interact between the different components.

External review of the risk assessment highlighted that the plants had adaptive capacity (and thus increased resilience) in some aspects. For example, Plant A chose to purchase its own trucks, use return loads to counter increased transportation costs, and develop technology to cope with the unique South African conditions. However with other aspects, such as corrupt investors, adaption to cope with this risk was not possible.

The initial risk assessment included the majority of the key risks which affected the resilience of the four former plants. However the initial draft failed to include: i) Investor funding exploitation

and a lack of support from government and banking institutions; ii) internal mismanagement; iii) sufficient funding to address unpredictability associated with construction and initial operation; and iv) legislation, guidelines and standards needing to be specific to South African conditions. Two aspects which were identified, but required more emphasis, were contamination management and a lack of technical skills. All these risks relate to financial or technical internal business operations, or are linked to conditions in South Africa where woody-biomass is a new industry and where support for the industry is low, and corruption is high. As the risk assessment was predominantly based on literature from the developed world, failure to identify investor corruption is not unexpected, as this risk is more commonly associated with business in Africa, compared to more developed countries. This is demonstrated by South Africa being ranked 72nd out of 177 countries in 2013 for perceived corruption, obtaining a score of only 42 out of 100 (where 0 means that a country is perceived as being highly corrupt, and 100 means it is considered 'clean') [95].

Bowd et al. [70] applied the Anderies et al. (2004) [64] framework to a NRBE, and also found that the risks not identified through application of the framework were predominantly economic, and were related to the internal business dynamics of an enterprise; and those that were identified were all linked to social aspects within a SES. This was not considered entirely unexpected as the Anderies et al. (2004) [64] SES conceptual framework is not directly concerned with economic impacts, but focuses on social and social-ecological interactions at a landscape level [96]. For this reason, the woody-biomass SES framework was amended to reflect these omissions (see Figure 2, Tables 2 and 5).

The use of SES theory for this application has highlighted that there can be resilient and non-resilient activities occurring within the pellet production SES simultaneously, and at different scales. For example, the collection and processing of sawdust prevents illegal dumping. This practice reduces potential for groundwater contamination and increases the resilience of the surrounding ecological environment. However, at the same time, the long-term effects of woody-biomass removal from plantations may negatively impact on soil productivity if not managed correctly. This practice could be amplified in South Africa, in comparison to Europe and other temperate regions, as the warmer climate increases rotation cycles, and thus more frequent soil disturbance is experienced over time.

Ecological risks were identified in the risk assessment (e.g. possible reduction in soil fertility

from the removal of plantation waste, reduced water availability in catchments due to timber using more water than agriculture, loss of biodiversity from converting natural areas to plantation as demand increased). However, as previous SES frameworks are based on social and social-ecological interactions, and not ecological interactions, there is concern that not all risks associated with ecological components and interactions are adequately addressed when applying earlier SES theory to NRBEs. Although Anderies et al. [64] did include external biophysical factors on the 'resource' and 'infrastructure' (arrow 7), they did not consider biophysical interactions as a consequence of 'resource users' actions. The woody-biomass SES framework includes the addition of multi-tiered ecological variables (which show that there are many different ecological variables), and arrows which interlink these variables (arrow 14) (Figure 2, Tables 2 and 5). Table 5 provides expanded explanations for the amendments made to the Anderies et al. (2004) framework [64]. To realise the many benefits associated with a sustainable and resilient South Africa woody-biomass industry, strategies to achieve this are provided in Table 6.

Table 5. Advancements made to the Anderies et al. (2004) social-ecological system conceptual framework for South African woody-biomass enterprises

Amendment	Explanation
Raw material replaces 'resource'	This substitution draws attentions to the fact that the enterprise is based on an ecological good, which is unprocessed. The multi-tiers behind this component indicate the different ecological components with which the raw material interacts.
'Competing' and 'actors' added to 'resource users'	'Competing resource users and actors' emphasises that competition for raw material is a key factor which affects NRBE. 'Actors' has been introduced as it is important to consider the behaviour of third parties who are not direct users or consumers of the raw material in question. This amendment is made by McGinnis and Ostrom (2014) [69] to the Ostrom (2007, 2009) SES framework [67, 68].
Multiple SESs	Three nested SESs are indicated: the global SES comprising two interlinking SESs. 1) Pellet production SES (local SES) – the SES where the raw material is collected from, and a portion is used by those who are governed by the same rules and / or use the same infrastructure as the NRBE; and 2) Energy supply SES – the SES where the product is used, but the material to make the product is not sourced from, but those who use it are not governed by the same rules and / or use the same infrastructure as the NRBE. Although both SESs are part of one large global SES, the SESs have been separated as there are several factors which are only applicable to either the pellet production SES or the energy supply SES.
Product	'Product' refers to the output of the production process. The 'product' is located within the pellet production SES as it here that it is produced. There may be demand for the product within the local SES from 'raw material suppliers', 'competing resource users and actors' and 'infrastructure providers'.
Components of the energy supply SES	The energy supply SES features: 'product users and actors' indicates that this group can have demand for the product, but also have access and a desire to use a similar or same product from elsewhere. 'Energy resources' highlight that competition from or availability of other resources could impact on the demand for the product. 'Infrastructure' draws attention to the fact that the following can impact on the demand

for the 'product': i) 'physical infrastructure' which refers to the accessibility of the 'product'; ii) 'social infrastructure' which refers to the knowledge of the availability and use of the product; and iii) 'governmental infrastructure' which refers to legislation and policy with supports or discourages the use of the product. Also featured is the 'infrastructure providers' which highlights the need to consider those responsible for provision of the 'infrastructure'.

Production process	The production process labels 'raw material' as an 'input', 'infrastructure' as the production process which involves 'physical infrastructure' (e.g. the processing plant), 'social infrastructure' (e.g. the work force, skills, technology and knowledge) and 'governmental infrastructure' (e.g. laws and policies governing operations and demand for product). The 'output' of the production process is the 'product'.
Internal business dynamics Multi-tier variables illustrated by layers behind the four main components	This element has been added within the 'production process' box, as it relates to those involved in the production process. Anderies et al. [64] make it appear as though the framework requires consideration of one level or scale of interactions. The amendment accentuates the need to consider multiple 'infrastructure providers', 'infrastructure' and 'competing resource users and actors'. This amendment is made by McGinnis and Ostrom (2014) [69] to the Ostrom (2007, 2009) [67, 68] SES framework.
Ecological interactions	The consideration of ecological interactions is encouraged by the addition of linkage '14' which shows that the interlinkages between different ecological variables must be considered.
Addition of infrastructure users	As Anderies et al. [64] are only concerned with those who directly use or who facilitate the use of the 'resource', there is no consideration for those who solely use the same infrastructure as the enterprise (but do not provide infrastructure or compete for raw material). The introduction of linkage '12' and 'infrastructure users' ensures that practitioners consider those who could negatively impact on the availability of infrastructure required by the NRBE.
Infrastructure being split into physical, governmental and social	The framework now differentiates between 'physical', 'governmental' and 'social' infrastructures as the term 'infrastructure' used by Anderies et al. [64] is considered too broad, and there was concern that practitioners might overlook one of these elements.
Introduction of 'technology' as an external factor	Technology has been added to external social and economic forces as it cannot be classed as either 'social' or economic', and it is an external factor which could significantly impact upon a NRBE (both positivity and negatively). This amendment is made by McGinnis and Ostrom (2014) [69] to the Ostrom (2007, 2009) [67, 68] SES framework.
External biophysical, social, economic and technological factors influencing all components	With a NRBE, biophysical, social, economic and technical factors can affect all components of the SES.

Table 6. Strategies towards the establishment of a resilient pellet industry in South Africa

Aspect	Strategy
Ecological	<ul style="list-style-type: none">• Research, development and implementation of best management practices for the forestry sector in sub-Saharan Africa [22, 28]. These strategies must be expanded to include management practices specific to the woody-biomass industry (e.g. methods for returning ash to the plantations)
Social	<ul style="list-style-type: none">• Plant management to oversee harvesting, processing and housekeeping at source• Educate and incentivise: i) raw material providers to minimise contamination; and ii) society to be aware of and benefit from the various applications of wood pellets• Lobby for policy-makers to develop and enforce legislation which supports the development of the biomass sector (e.g. logistic concessions, renewable obligation rewards, provision of infrastructure, investment subsidies, feed-in tariffs, carbon tax, public-private partnerships to assist with conversion) [28, 97]• Up-skill a workforce to have a competent technical level to meet the demands of a developing biomass industry [28, 97]• Up-skill power utility users with technical instruction on the applications of woody-biomass pellets• Continual research into design and building of logistical and transportation equipment, as well as pelleting technology to optimise operations• Be aware of changes in plantation land tenure• Be aware of knowledge gaps when implementing the risk assessment
Economic	<ul style="list-style-type: none">• Investigate purchasing areas of plantation, however be aware of land tenure issues (tribal land claims)• Ensure that resources are available to continually investigate logistical optimisation• Ideally raw material, pellet production and end users should be in close proximity to one another to minimise logistic limitations – thus prioritise local markets• Ensure that sufficient funds are available to prepare and manage for natural disasters• Do not over commit and fail to meet orders, and have agreements with other plants which are located outside the same SES as the pellet plant to supply pellets during times of poor production• Thoroughly investigate investors prior to embarking on a new venture• Establish a broad consumer-base• Continually explore alternative markets and pellet applications

Limitations and further work

This paper documents the first attempt at developing a practical tool which has the potential to increase the resilience of a woody-biomass industry in South Africa. Although basing the risk assessment on SES theory increases the level of confidence in the results obtained from implementation, far more work is required before a robust risk assessment is available. In its current form, it can be used at a broad level to highlight key aspects which must be considered as part of a feasibility assessment for a new plant. However, social, ecological and financial data relevant to the pellet industry in South Africa is deficient, thus the accuracy of the information to populate it may be poor, which could result in incorrect conclusions. Even with this limitation, the risk assessment provides a good starting point for the development of a robust and practical tool. This tool, when complete, could also be transferable to the agricultural

residue biomass sector with some amendments, even though limited work has been undertaken on agricultural residue in comparison to woody-biomass. The SES conceptual framework presented in this paper could also be applied to other NRBEs which are based on a production process.

Although the risk assessment has been amended to incorporate all risks identified by the former plant representatives, as the plants were not operational for a long period, there is a danger that some fundamental issues about the overall system, and particularly ecological components, have not been identified. The short-term operation of the plants could also result in the SES framework not being considered to have been fully applied to this application, as the effects of the use of the resource on the ecosystem supplying the resource was unable to be assessed over a prolonged period. With the dearth of ecological data available for South African conditions, the accuracy of results obtained from any attempts at predictive ecological modelling might be questioned.

The accuracy of the results when implementing the risk assessment, or final tool, will be heavily dependent on the level of stakeholder engagement. A limitation of this paper is that it only involved representatives from the four failed pellet plants. Engagement with other stakeholders (e.g. competing resource users and actors) may have yielded additional results. Industries which are not linked to the pellet production SES (e.g. swine, dairy and meat processing industries) should be consulted, as this might lead to these industries meeting their sustainability goals (which might increase their resilience), and to amendments or additions to the risk assessment and accompanying SES framework. Thus further work in both of these areas is suggested.

A potential starting point to address these limitations is to examine the current risks in more depth by splitting the SES into different scales for analysis. For example, at a pellet plant level, further investigation into the internal operational dynamics should be undertaken (e.g. trade union strikes, stealing of product). Although these dynamics may not be biomass-sector specific, they still need to be incorporated into a comprehensive risk assessment. At a landscape level, further investigation into the needs of competing resource users and actors, and the possibility of cross-sector management to help mitigate against these risks, is also suggested. This could include combining logistics (e.g. the timber industry could 'load-share' with the woody-biomass industry: trucks could be used to transport logs and biomass material at

the same time) and adopting trade-off strategies with competing resource users (e.g. subsidised pellets could be sold to the poultry industry if an alternative to woodchips for bedding is used). At a national level, further investigation into the social, economic and ecological implications of an emerging woody-biomass industry, which could include the ability of the country's judicial system to control the establishment of illegal plantations, and the possibility of government transferring interest from fossil fuels to biomass, is recommended.

One aspect which Anderies et al. [64] do not specifically address, and which is highlighted by Bowd et al. [70], is that of monitoring, which is particular pertinent to ecological risks and impacts. Although Anderies et al. [64] include rules and regulations (under 'infrastructure') and those that police these (under 'infrastructure providers'), there is no prompt for ongoing assessment and monitoring. We do not consider it appropriate to include this aspect in the SES framework, but recommend that the risk assessment, or final tool, be implemented prior to an enterprise being established, as this will hopefully give the enterprise a better chance of being resilient. To enhance the operational resilience of the enterprise, the assessment should be periodically repeated as it is anticipated that further risks (and associated mitigation measures) will emerge during the lifetime of the enterprise. Prior to the assessment being repeated, the SES conceptual framework should be referred to, in conjunction with the previous results, and the assessment, or tool, should be updated, as it is likely that the interlinkages and interdependence within the SES will change as the enterprise expands and evolves. This progressive application links well with strategic adaptive management, as the first assessment of the SES feeds into initial management vision and objective setting, and the second (and further assessments, as required) are linked with review and learning.

5. CONCLUSION

This paper documents the first investigation into why all four previously established pellet plants in South Africa failed. Publication of this work may encourage decision-makers to revisit the use of woody-biomass for power provision on a national scale, and to take action to improve the chances of a resilient wood-pellet industry in South Africa.

The risk assessment can be used at a broad level to highlight key aspects which must be considered as part of a feasibility assessment for a new pellet plant, and provides a good foundation for the development of a robust and practical woody-biomass tool which supports the establishment of a resilient biomass industry. However, further investigation into the long-term

ecological risks associated with a woody-biomass industry under South African conditions is required. The risk assessment could also be useful to inform the overall question of the viability of the pellet plant industry in South Africa. Future work is proposed to focus on splitting the SES into different scales for analysis.

There are many benefits associated with a South African woody-biomass industry, however many social and economic risks exist (e.g. lack of skills, knowledge and education), which are typically associated with the developing world, and require considerable attention in order for the many benefits associated with this emerging industry to be realised in this country. An important element which future woody-biomass enterprises must address as a priority, is the need to develop a local market for the pellets. Having a local market addresses many of economic risks associated with establishing the industry in South Africa. One sector which should be pursued as a priority is the agriculture sector, such as dairies, poultry and abattoirs. These operations are generally located in rural areas, and may be in close proximity to a wood supply.

The South African situation is unique compared to Europe and the US, and although South Africa shows potential for being able to sustain a woody-biomass industry, there are a number of factors which need to be addressed. Thus more detailed research is required before a robust and practical tool is available.

Applying previous SES theory to a woody-biomass enterprise proved highly beneficial at a landscape level. However elements it failed to address, when applied to a NRBE, were:

- A lack of ecological variable interactions as a consequence of enterprise operation;
- An absence of a production process with inputs, outputs and demand for a resource-based product; and
- Internal business dynamics at an enterprise level.

The theoretical contribution of this paper is an advancement of previous SES theory, towards its application in resource-based enterprises which feature a production process. Our contribution addresses the three missing elements identified above.

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CHAPTER 7: RESEARCH SYNTHESIS AND CONTRIBUTIONS

7.1. THE THEORETICAL BASIS OF THE STUDY

The aim of this research is to integrate social-ecological system (SES) theory into natural resource management practice, so that the concepts of resilience, risk and ecosystem services assessment can be applied effectively in the understanding of natural resource-based enterprises (NRBEs). To meet this aim, four objectives were developed to collectively investigate a diversity of NRBEs in South Africa, each of which was the subject of a research paper:

- i) Integrate ecosystems services evaluation and SES theory to derive a conceptual framework to identify and assess opportunities for natural resource-based economic empowerment at two estuary study sites in the Eastern Cape, South Africa;
- ii) Apply and adapt the resulting SES conceptual framework to enhance understanding of the resilience of a SES supporting a wetland-based craft enterprise in KwaZulu-Natal, South Africa;
- iii) Apply and adapt the resulting SES conceptual framework to an Environmental Impact Assessment (EIA) setting to evaluate whether such a framework would constitute a useful tool in EIA practice; and
- iv) Apply and adapt the resulting SES conceptual framework to build understanding of key issues linked to the pellet bioenergy sector in South Africa.

At the start of this study, SES theory was considered an appropriate foundation for assessing NRBEs, as these enterprises depend on interactions between ecological and socio-economic aspects, and SES theory helps disaggregate and understand the interdependencies and interlinkages between social and social-ecological dynamics (Walker et al. 2002, Anderies et al. 2004). In applying SES theory in this study a post-normal science (PNS) approach has been adopted. Post-normal science explicitly engages uncertainty, value loading and multiple legitimate perspectives (Funtowicz and Ravetz 2008). For this study, uncertainty was considered in the systematic examination of the likelihood of risks. Value loading was addressed through one of the practical contributions (ecosystem services inventory) requiring different stakeholders to assign scores to semi-quantify the demand for different ecosystem services. The development and application of the practical contributions (ecosystem services inventory, risk assessments and social-ecological system - environmental assessment (SES-

EA)) provided mechanisms for both scientists and non-scientists, who can have contrasting views on social and social-ecological interactions, to contribute their perspectives (Funtowicz and Ravetz 2008). The practical contributions are predominantly populated with subjective data, and are thus relative rather than empirical. The very fact that the data is subjective and involves those from multiple disciplines and backgrounds contributes to addressing the hiatus between theory and practice, which is a well documented shortcoming of ecosystem management practice (Pullin et al. 2004, Knight et al. 2006, Turner and Daily 2007, Daily and Matson 2008, Temperton et al. (2013).

To assess the extent to which SES theory is applicable in assessing NRBEs, it was applied to a range of NRBEs. For this thesis, SES theory has been used to identify and assess resilience, and to provide strategies to increase the resilience of NRBEs. The NRBE case studies vary from being located within 'simple' SESs, where only low-level environmental impacts are likely to occur (e.g. where the economic benefits are experienced by relatively few, and the ecological impacts are minimal), to a NRBE which is situated within a highly complex SES, which reaches beyond the borders of South Africa. This NRBE has the potential to contribute to poverty alleviation at a national scale, through job creation and power provision, but also carries potential to cause significant ecological degradation if not managed correctly.

7.2. CASE STUDY OVERVIEW

Paper 1 addresses Objective 1, and documents an ecosystem services framework (ESF) which incorporates a practical ecosystem services inventory and risk assessment. When applied, the ESF: i) enables stakeholders to realise the benefits, both social and economic, of responsibly managing natural resources; and ii) helps to identify resilient NRBEs. The practical contributions were tested at two rural estuaries in the Eastern Cape: i) Umngazi estuary, which has limited human activity and is the location of a proposed small-scale community-based tourist accommodation enterprise; and ii) Tyolomnqa estuary, which is located near to the urban centre of East London, is an area which has become well policed by government departments, and is the location of a proposed wilderness camp.

Paper 2 addresses Objective 2, and documents a method for assessing the resilience of a specific NRBE. This method investigates the threats and opportunities associated with the commercialisation of a NRBE, and uses these findings to increase the likelihood of establishing

a resilient enterprise which benefits the rural poor. This paper applies an amended version of the practical contributions developed in Paper 1 to a failed wetland-based enterprise. The case study site is a rural wetland which is located at Mbongolwane, near Eshowe, KwaZulu-Natal. The ecosystem services provided by the wetland are relied upon by the majority of the local population, and there are a variety of both public and private stakeholders who are either directly or indirectly concerned with the services provided by the wetland system. By applying the developed practical contributions to a single, existing enterprise, which is located within a relatively 'simple' SES, the applicability of SES theory, and the associated concepts of resilience, risk and ecosystem services, could be more fully explored.

Paper 3 addresses Objective 3, and documents the development of a SES-EA framework which helps address the problem that social and ecological impacts are seldom assessed in an integrated manner within an environmental impact assessment (EIA). The approach helps understand and interpret the interrelationships and interdependences within a SES that a proposed development could impact upon. The framework adapts previous SES conceptual frameworks into a practical contribution for EIA practice. The SES-EA framework is public participation-focused, and gives socio-economic impacts as much importance as ecological impacts when conducting EIAs (an inadequacy of EIA practice in South Africa noted by du Pisani and Sandham (2006) and Hildebrandt and Sandham (2014)). The consideration of socio-economic impacts is paramount in South Africa, given the highly complex SESs which characterise the country, and coupled with the fact that development has the potential to negatively impact upon natural resources which provide the basic services which are relied upon by a large proportion of the rural population. The SES-EA framework was tested at two locations: i) the community-based accommodation at Umngazi estuary which features in Paper 1; and i) a proposed wine estate in the KwaZulu-Natal Midlands.

Paper 4 addresses Objective 4 where the evolved SES conceptual framework and risk assessment have been further developed for a production-based NRBE. The resulting conceptual SES framework incorporates the highly complex social and social-ecological dynamics of a woody-biomass enterprise in South Africa. This evolved framework led to the compilation of a more advanced risk assessment for NRBEs which are based on the processing and selling of an ecosystem good (woody-biomass). Representatives from the four failed woody-biomass pellet plants in South Africa contributed to this risk assessment. The high level of complexity of this SES contributes to this industry having potential to contribute to poverty

alleviation at a national scale through job creation (both directly – those employed directly by the plants, and indirectly – those employed in the ancillary services used by the plants) and job security (those employed in the timber sector). A resilient woody-biomass industry in South Africa could also bring reliable power to rural areas which in turn could enable economic development and thus social upliftment to occur in impoverished areas.

The evolving SES conceptual framework was predominantly founded on the Anderies et al. (2004) framework for studying the robustness of SESs, however a variety of other academic works have helped to compile, direct and assess the framework and practical contributions developed as part of this study, namely the Ostrom (2007, 2009) framework for analysing sustainability of SESs, and its evolution documented in McGinnis and Ostrom (2014), the Turner and Daily (2007) constraints to making an ESF approach operational, and the Binder et al. (2013) criteria for evaluating the effectiveness of social-ecological conceptual frameworks.

7.3. SUMMARY OF KEY FINDINGS AND SCIENTIFIC CONTRIBUTIONS

7.3.1. Key findings and contribution of Paper 1

Paper 1 uses the Turner and Daily (2007) critique to inform the identification of a set of four criteria that would be instrumental in a successful ESF. Criterion 1 refers to the need for an ESF for economic empowerment to be participative, and combines both a generic ‘top-down’ scientific approach with a case-specific ‘bottom-up’ approach, which is obtained through active engagement of a diversity of stakeholders. At Umngazi implementing the ESF, via the practical contributions, revealed that an estuary rehabilitation programme would have created greater economic upliftment compared to community-based accommodation. However the community was strongly against a rehabilitation programme, as similar initiatives had failed in the past. It is likely that without the participation of the community and the testing of the ESF, decision-makers would have pursued the rehabilitation programme, which would most likely not have been supported by the community. Thus the ESF can be seen to have enabled better decision-making.

Criterion 2 highlights the need for an ESF to provide detailed information on ecosystem services. Implementing the practical contributions, derived from the ESF, provides a shared understanding of the way in which stakeholders benefit from ecosystem services. At Umngazi this mutual understanding will help improve the resilience of the community-based

accommodation enterprise, as the stakeholders now understand why this particular enterprise has been chosen and what services are required.

Before the workshop at Tyolomnqa, the planning authority believed that there were many estuary-based enterprise opportunities, due to the estuary already being utilised for a wide range of activities. However, the ESF highlighted a considerable number of constraints of which the planning authority was unaware. This emphasises the value of the ESF in promoting discussion based on structured consideration of ecosystem services.

The third criterion was that an ESF must consider resilience. As the ESF promotes a shared understanding of the resource and of resource users, enterprises which do not affect, or have limited impact on the availability of the services used by other resource users, and vice versa, were identifiable. This knowledge is the foundation for identifying resilient enterprises.

The fourth criterion was that an ESF must accommodate complex socio-ecological contexts. By the end of the workshop the stakeholders had a good understanding of both the ecosystem services utilised by other stakeholders, and the complexities of the SES, and it is concluded that this process could be categorised as a good example of social learning (Bandura 1977).

Although the published SAWRC Report referred to in Chapter 1 (Bowd et al. 2012b) is not included in this submission, there is merit in including the key findings of this report in this thesis, as it documents the practical, stakeholder-informed application of the research undertaken for Paper 1. The report concludes that stakeholder response to the research was overwhelmingly positive; there appeared to be genuine appreciation of the structured yet flexible, participative learning process for the content that was generated, and participants appeared to gain new insights into and appreciation of ecosystem values. Participants in the working sessions were comfortable assigning scores to the different ecosystem services and engaged freely with other participants in discussing the basis for their scores. Adoption of a PNS approach allowed multiple legitimate perspectives to contribute usefully to stimulating dialogue and helped to build a common understanding of the systems.

The report demonstrates that there are significant opportunities for the establishment of NRBEs that can act as catalysts for economic empowerment, but that there is a lack of support necessary to do this. In the rural context the lack of physical infrastructure is often a major

constraint and, in both rural and urban situations, local government is either unwilling or unable to provide the necessary support. It is here where major risk to development and thus poverty alleviation lies.

The report suggests three ways in which the ESF could be further applied:

1. As a proactive planning tool to determine what the most appropriate enterprises and enterprise mix might be and what might be the risks of establishing these enterprises;
2. As a reactive or responsive management tool to assess the appropriateness of an enterprise development proposal including the risks of its establishment; and
3. To guide a situation assessment of a particular SES.

Also suggested is that the above three applications could be conducted as participative processes or as expert-based desktop exercises.

In summary, Paper 1 presents an ESF for identifying resilient estuarine NRBEs through enabling stakeholders to gain an understanding of and appreciation for ecosystem services provided by a natural resource, and by highlighting the demand for services used by other stakeholders. The ESF is participatory and thus considers the highly complex social systems which characterize South Africa. The practical tools have a variety of potential applications by a variety of different stakeholders. A secondary output of Paper 1 is a summary of lessons learnt for stakeholder engagement, which consider variable literacy levels and the consequences of past racial discrimination in South Africa.

7.3.2. Key findings and contribution of Paper 2

Through applying the resulting SES conceptual framework and practical contributions from Paper 1 to a specific and pre-existing NRBE, it emerged that, while earlier SES theory provides a good foundation for understanding the social-ecological interlinkages at a landscape level, it does not adequately address external impacts on the demand for a natural resource-based product (NRBP), nor does it consider external impacts on the internal business dynamics of a NRBE. An explanation for this is that previous SES conceptual frameworks draw primarily from the political and the ecological sciences (Binder et al. 2013), and to a lesser extent from the business sciences. To address this shortcoming the following three additional components were added to the SES conceptual framework: i) external impacts on internal dynamics ('government and institutions', 'public infrastructure', 'the resource'); ii) internal dynamics which impact upon product supply and the

creation and meeting of demand; and iii) external impacts on demand ('government and institutions', 'public infrastructure'). What also emerged from the paper was the identification of the four main underlying and interlinked obstacles which hinder achieving resilient craft-related NRBE: material being sourced from a common pool resource, gender inequality, poverty and low literacy; it is suggested that solutions to overcoming these obstacles lie in external assistance. What also became apparent was that the resilience to internal shocks to a NRBE, is equal in importance to assessing the resilience to external shocks. In fact the degree to which an enterprise is resilient to external shocks is highly likely to be influenced by the level of internal resilience (or adaptive capacity) of an enterprise.

7.3.3. Key findings and contribution of Paper 3

The SES-EA framework documented in Paper 3 is a first attempt at applying and formalising SES constructs to EIA practice in South Africa within a regulated procedure. The framework supports the identification and understanding of i) a variety of levels of the social system; ii) a variety of levels of the ecological system; and the iii) interrelationships between these two systems. The framework addresses well-documented inadequacies of EIA practice, namely: i) a focus on biophysical impacts and a failure to consider other environmental impacts (Hacking and Guthrie 2008, Sandham and Pretorius 2008, Kidd and Retief 2009, Morrison-Saunders and Retief 2012); ii) a lack of consideration of the linkages between the different environmental aspects; and iii) a lack of meaningful public participation during the process (du Pisani and Sandham 2006, Esteves et al. 2012, Morgan 2012, Pope et al. 2013). Recent EIA reviews call for EIA practice to include ecosystem services thinking and to also move towards more complete 'sustainability assessment' (Morrison-Saunders and Retief 2012, Baker et al. 2013, Partidario and Gomes 2013). The SES-EA framework provides a mechanism for doing so.

The framework is applicable to different types of development and helps identify: i) trade-offs which could give development a greater chance of success; and ii) who is responsible for supplying the infrastructure required for a proposed development. These two considerations are generally not addressed in traditional EIAs. Implementation of the framework (which incorporates all six environmental aspects required to be assessed by the National Environmental Management Act, No. 107 of 1998) in a sequential and systematic way ensures that all aspects of the environment are addressed, and a holistic understanding of the affected SES is obtained.

7.3.4. Key findings and contribution of Paper 4

Paper 4 documents the first attempt at developing a practical tool which has the potential to increase the resilience of a woody-biomass enterprise in South Africa, and is the first investigation into why all four previously established woody-biomass plants failed in South Africa. Through applying the resulting conceptual SES framework and risk assessment, which was adapted for a woody-biomass enterprise, the majority of the key risks which affected the resilience of the four failed plants were identified. However, there were several fundamental risks which the risk assessment failed to address, namely: i) investor funding exploitation and a lack of support from government and banking institutions; ii) internal mismanagement; iii) sufficient funding to address unpredictability associated with construction and initial operation; and iv) legislation, guidelines and standards needing to be specific to South African conditions. Two aspects which did feature, however, and required more emphasis, were contamination management and a lack of technical skills. These generally relate to financial or technical internal business operations and, as the Anderies et al. (2004) SES conceptual framework is not directly concerned with economic impacts, but focuses on social and social-ecological interactions at a landscape level (Binder et al. 2013), these omissions were not unexpected. Another shortcoming with applying SES theory to NRBEs was that it missed or inadequately addressed risks associated with different stages of a production process. This is because SES theory typically focuses on natural resources and their supply to a social system, rather than a production cycle with inputs and outputs which are demand driven. The final omission with applying SES theory for this study was that there was limited consideration of ecological variable interactions as a consequence of an enterprise operation. The SES conceptual framework and associated risk assessment were therefore amended to incorporate these findings.

The use of SES theory for this application highlights that there can be resilient and non-resilient activities occurring within the pellet production SES at the same time, and at different scales. Although the risk assessment was amended to incorporate all risks identified by representatives of the four former plants, as the plants were not operational for long and ecological impacts generally take time to emerge in comparison to economic risks, the risk assessment is not considered a comprehensive list of all risks. However the risk assessment, in its current form, can be used at a 'broad level' to highlight key aspects which must be considered as part of a feasibility assessment for a new pellet plant. It may also influence those in positions of authority to take action to improve the chances of a resilient woody-biomass industry being established in

South Africa. Publication of this work may encourage decision-makers to revisit the use of woody-biomass for power provision on a national scale.

7.4. CASE STUDY COMPARISONS

This thesis applies elements of SES theory to a broad range of purposes and contexts in order to determine the extent to which SES theory, and the associated concepts of risk, resilience and ecosystem services, can be applied to understand NRBEs. In this section the different purposes and contexts are compared against the following attributes:

1. Complexity of the overall SES;
2. Complexity of the production process;
3. Stakeholder engagement;
4. Scale and type of key risks to the NRBE;
5. Degree of environmental impacts associated with a NRBE;
6. An established NRBE vs. a proposed NRBE;
7. Identification of a resilient NRBE vs. assessing the resilience of a specific NRBE; and
8. Ability to address the hiatus between theory and practice.

Attributes 1-5 and 8 were primarily derived from NRBE variables identified in the problem statement (Section 1.2), however these variables were reinforced by reviewing the key findings of the papers and identifying the main differences amongst the case studies. These attributes are considered to have the potential to impact on the relevance of applying SES theory to NRBEs. Attributes 6 and 7 were also identified through comparison of the case study data.

7.4.1. Complexity of the overall social-ecological system

The 'baseline' of the South African SESs is highly complex. This is due to South Africa being a young democracy, which is trying to get to grips with new policies, institutions and tenure arrangements, and much of the country's population being reliant on natural resources for their livelihoods. Although the 'baseline' level of complexity is considered high, the different SESs investigated in this study vary in their complexity (Figure 7.1). Figure 7.1 provides a pictorial representation of the range in complexity and level of likely environmental impacts of the different NRBEs featured in this study. Environmental impacts can broadly be grouped into social, economic or ecological impacts, and can be regarded as positive or negative, depending on a particular stakeholder's interest.

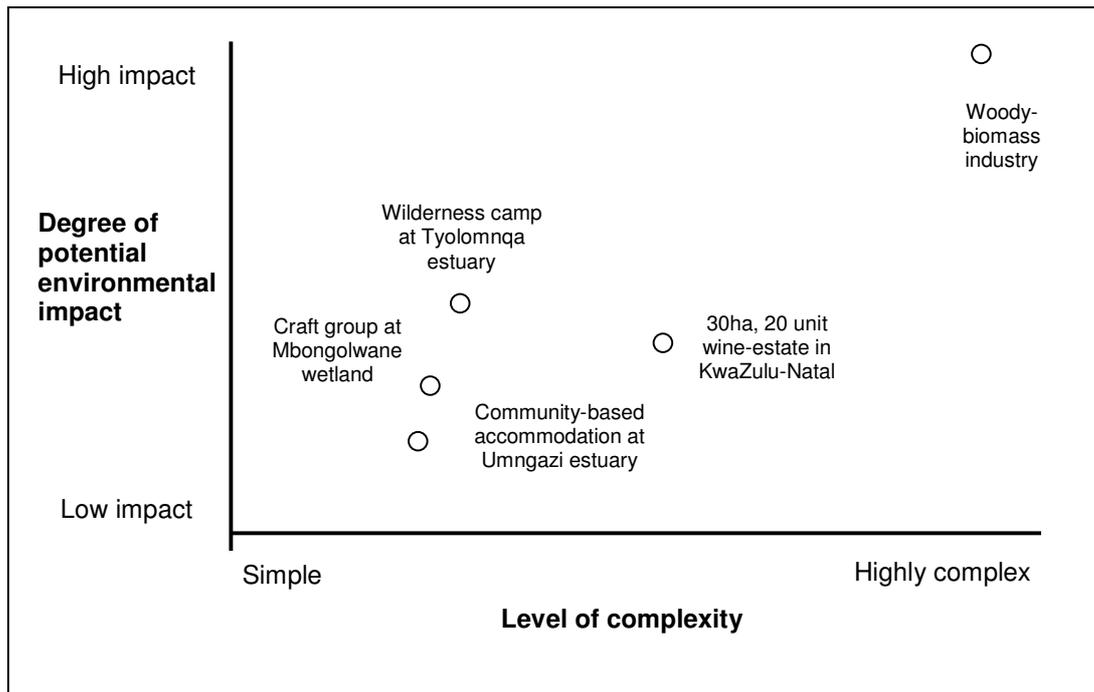


Figure 7.1. The range in 'potential environmental impact' and 'level of complexity' of the different applications of social-ecological system theory applied in this thesis

The case studies at Umngazi, Mbongolwane and Tyolomnqa had the lowest level of complexity because those who are directly impacted upon by these NRBEs, either positively or negatively, or who are involved in the enterprises, are relatively few in number compared to the other two case studies. The wine estate in the Midlands was considered to have the next complex SES, as this enterprise type is more controversial compared to small-scale accommodation or craft enterprises, and thus involves more stakeholders. The most complex SES by far, was the woody-biomass enterprise, which involves a wide variety of stakeholders (from rural communities who could compete for the woody-biomass, to national and international policy-makers). The fact that this enterprise operates at a much larger geographic scale, compared to the other enterprises also contributes to it being the most complex SES. Although international guests are expected to visit Umngazi and Tyolomnqa, and some crafts from Mbongolwane are likely to leave Africa, the physical footprints of these operations are far smaller compared to the woody-biomass operation, which relies on raw material being continuously collected from sources which are +/- 100km away. The complexity of the woody-biomass enterprise led to the resulting SES conceptual framework acknowledging the need for three scales of SESs (pellet production SES, energy supply SES and a global SES, which incorporates the other two SESs). Chapters 3 to 7 demonstrate that SES theory is applicable across simple and complex SESs.

7.4.2. Presence and complexity of production processes

Natural resource-based enterprises can be based on ecosystem 'goods', 'services', or a mixture of the two. The craft enterprise at Mbongolwane and the woody-biomass industry are both based on the use of ecosystem 'goods', and involve a production process. A natural resource production process is where an ecosystem 'good' is an input, which requires processing, before it produces an output, which is a product, which is in demand by those within, as well as those located outside of, the natural resource supply level SES. Although commercially-planted timber is not indigenous to South Africa and thus might not be regarded as 'natural' by some, this study regards woody-biomass as a natural resource. The Umngazi community-based accommodation, the Tyolomnqa wilderness camp and the residential wine estate in the KwaZulu-Natal Midlands are enterprises which do not physically sell products derived from a natural resource, but are enterprises which are based on services provided by a natural resource (e.g. natural beauty, open water to host recreational activities). Although the 'wine' component of the residential wine estate is not the main source of income for the residential estate, commercially grown grapes could be considered as a 'natural' resource (to the same extent commercially grown timber is regarded as a natural resource).

The stages in the production process for a woody-biomass plant are similar to that of a wetland craft enterprise (refer to Figures 7.2 and 7.3). Although the two enterprises differ in that the craft enterprise is from a natural ecosystem while the wood-pellet enterprise is from an ecosystem planted to exotic trees, both use plant biomass as the raw material for production. However, as the woody-biomass plant operates on a much larger scale, and features many more subsystems, it is much more complex in comparison to the wetland craft enterprise which has fewer subsystems and thus interactions.

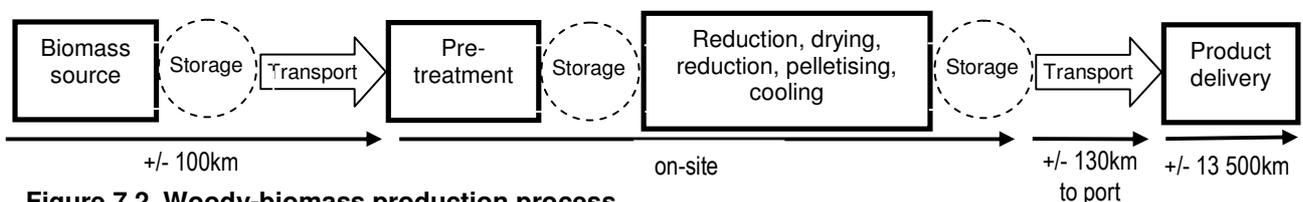


Figure 7.2. Woody-biomass production process

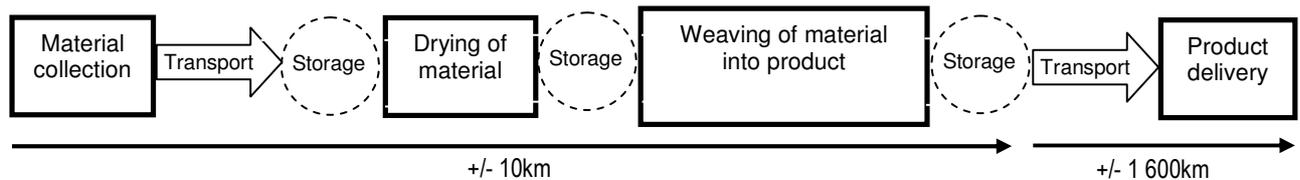


Figure 7.3. Wetland craft production process

Through separately applying SES theory to NRBEs based on ecosystems goods, and those that are based on ecosystem services, current SES theory is considered less able to fully address the different elements of SESs which surround production process NRBEs. This limitation of SES theory is acknowledged in Sections 7.2.2. and 7.2.4.

7.4.3. Stakeholder engagement

Previous papers on conceptual SES frameworks (e.g. Walker et al. (2002), Anderies et al. (2004), Ostrom (2007, 2009) and McGinnis and Ostrom (2014)) adopt a PNS approach and strongly emphasise stakeholder engagement. These frameworks encourage consultation with resource users, governance systems and infrastructure providers. Although all four papers emphasise the need for high levels of stakeholder engagement when implementing the practical contributions (e.g. risk assessment), the degree to which stakeholders were engaged varied between the papers. This variation is mainly attributed to the papers having varying purposes. Papers 1 and 3 had the highest level of stakeholder engagement with representatives ranging from local individuals to national government departments. Paper 2 had moderate input; although a large number of the crafters from the NRBE contributed to data collected, there was limited government department involvement. Paper 4 involved representatives from the four previous South African woody-biomass plants. Although a more 'normal' science approach was suggested in Section 7.3.1, whereby scientists could implement the ecosystem services inventory and risk assessment through desktop-based exercises (i.e. with no stakeholder engagement), the validity of the results with adopting a non-consultative approach would be questionable.

Stakeholder engagement is important for understanding both simple and highly complex SESs, however the more complex a SES, the greater the number and variety of stakeholders likely to be involved. There are prominent groups of stakeholders which are referred to in all case studies (local community, government departments, scientists and interest groups). Angelstam et al. (2013) define barriers and bridges for a transition from disciplinary academic research to transdisciplinary research, by supporting the integration of multiple disciplines through engaging stakeholders who represent a range of societal sectors in problem formation, knowledge production and learning. They believe that to make the transition from academic research to transdisciplinary research, there must be an understanding of the interests and needs of different stakeholders, and of the interconnectedness of regional, national and international

levels of stakeholders (Leemans 2000). The four papers acknowledge that the interests of various stakeholders must be identified, and that these stakeholders are from a range of social levels, however the degree to which the different stakeholders need to be engaged with varies when applied to different enterprise contexts. For example, with the NRBEs which benefit a relatively small group of individuals (e.g. at Umngazi and Tyolomnqa) it is necessary to involve all potentially benefiting individuals, but it is not that crucial to consult scientists if the expected impacts on the social, economic or ecological environments are negligible. However, with a NRBE which has the potential to provide large scale employment or cause widespread ecological degradation, scientists, national and international interest groups, policy-makers and product users must be involved. Engagement with the local community must also not be overlooked with large scale NRBEs, as this group could well depend on the natural resources in question for their livelihood (e.g. plantation waste may be a community's only source of heat for domestic chores). The engagement with stakeholders from a variety of different sectors and level of governance contributes to an all-round increase in social learning for all involved (Bandura 1977).

7.4.4. Scale and type of key risks to the natural resource-based enterprise

A comparison of the different type of risks (social, economic, ecological) to the case studies, and the scale at which these risks are experienced (e.g. site level, local level) is presented in Table 7.1.

Table 7.1. Comparison of type and scale at which the key risks are experienced by the enterprises investigated in this study

Type	Case study	Site / enterprise	Scale of risk		
			Local	Provincial	National
Ecological	Accommodation at Umngazi	-	-	-	-
	Camp at Tyolomnqa	-	-	-	-
	Craft enterprise at Mbongolwane	<ul style="list-style-type: none"> • Flooding which inhibits access and availability of raw material • Overharvesting resulting in a lack of material to make craft 	-	-	-
	Wine estate in KZN Midlands	-	<ul style="list-style-type: none"> • If stormwater and effluent is not managed correctly, soils and underground aquifer could become polluted which will impact on local flora, fauna and water resources 	-	-
	Woody-biomass pellet plant in SA	-	-	<ul style="list-style-type: none"> • Reduced availability of water in the catchment if agricultural land is converted to timber to meet demand • Loss of valuable vegetation types if indigenous areas are converted to timber • Reduction in soil fertility if biomass extraction from plantations is unsustainable 	
Social	Accommodation at Umngazi	<ul style="list-style-type: none"> • Lack of skills to communicate to potential markets 	<ul style="list-style-type: none"> • Declining quality of attractions due to sand mining 	-	-
	Camp at Tyolomnqa	<ul style="list-style-type: none"> • Poor security which discourages tourists • Poor access which prevents tourists visiting the enterprise 	<ul style="list-style-type: none"> • Poor water quality due to a lack of maintenance and enforcement of legislation 	<ul style="list-style-type: none"> • Intensity of use is controlled by provincial and national government departments which lack regulating capacity 	
		<ul style="list-style-type: none"> • Half of the river has been transformed (by bank stabilisation) resulting in habitat destruction. This loss of 			

		habitat reduces ecosystem services, which discourages tourists visiting the enterprise			
	Craft enterprise at Mbongolwane	<ul style="list-style-type: none"> • Lack of skills and knowledge to develop other products and markets • Internal mismanagement (e.g. overrunning deadlines, stealing of funds, erratic payments) • Gender inequality (wetland managed – burning and grazing, more in the interests of male cattle owners than a female-run craft enterprise) 	-	-	-
	Wine estate in KZN Midlands	<ul style="list-style-type: none"> • Conservation groups lobby against residential development in rural areas 	<ul style="list-style-type: none"> • Surrounding neighbours lobby against reduced local agricultural sense of place • Pollution from mismanaged activities on site could affect main water supply for area 	-	-
	Woody-biomass pellet plants in SA	<ul style="list-style-type: none"> • Internal mismanagement (e.g. investors becoming involved with operations, drip-feeding of funds) • Lack of scientific knowledge of South African timber • Applying European technology which is not appropriate for South African conditions • Improper management of raw material increases contamination which increases process cost and the chance of explosions 	<ul style="list-style-type: none"> • Lack of skills and knowledge and technology available from ancillary service providers 	-	<ul style="list-style-type: none"> • Legislation, guidelines and standards: i) from the developed world not being applicable to South Africa; and ii) from South Africa not encouraging the use of woody-biomass
Economic	Accommodation at Umngazi	<ul style="list-style-type: none"> • Location relative to demand • Delays in receiving payment for orders 	-	-	-
	Camp at Tyolomnqa		-	-	-
	Craft enterprise at Mbongolwane	<ul style="list-style-type: none"> • Competition from other craft groups taking market share 	-	-	-
	Wine estate in KZN Midlands	<ul style="list-style-type: none"> • Offensive odour from nearby poultry 	<ul style="list-style-type: none"> • Reduced availability of 	<ul style="list-style-type: none"> • Road maintenance is the 	

Woody-biomass pellet plant in SA	<p>facility could reduce sales</p> <ul style="list-style-type: none"> • Insufficient investor funding and exploitation 	<p>water could negatively impact upon local agricultural activities</p> <ul style="list-style-type: none"> • Inability to secure a reliable raw material supply 	<p>responsibility of provincial and national department which frequently lack funds</p> <ul style="list-style-type: none"> • Expensive and inefficient logistics at a national scale • Lack of economic support from government and banking institutions
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Application of SES conceptual frameworks in the four papers generally surfaced more social risks than ecological risks, and common themes in the social risks across the case studies were identified:

- Lack of skills and knowledge (from un-skilled to professionals);
- Inadequate legislation;
- Lack of regulatory capacity for legislation which is in place;
- Mismanagement of enterprises (from exploitation, erratic cash-flow and funding – which could also be contributed to a lack of regulatory capacity and legislation); and
- Inefficient or poorly maintained logistical infrastructure.

These risks are all characteristic of a developing country (Mahembe 2011), and need to be addressed in order to facilitate the establishment and operation of enterprises which create jobs and thus lead to poverty alleviation.

Relatively few economic risks were identified in comparison to social risks; however, in general, the magnitude of the economic risks are probably more critical to the survival of the NRBEs, than the social and ecological risks, at least in the short term. For example, a lack of skills can be overcome with proper training as the plant operates. However, if there are insufficient funds to pay for escalating logistical costs, the enterprise will cease immediately.

From the five case studies only six ecological risks were identified. An explanation for this could be that SES theory is fundamentally anthropocentric, and focused on ecosystem services which are directly relevant to humans (Walker et al. 2002, Anderies et al. 2004) rather than those which are important underlying services. A lack of consideration for ecological interactions is viewed as a shortcoming of previous SESs theory when applying it to NRBEs. Another explanation for a scarcity of ecological risks may be as a result of ecological impacts associated with an enterprise only arising after an enterprise has been operational for a substantial period of time. As none of the NRBEs investigated were fully operational for longer than 10 years, it is unlikely that there was sufficient time for all ecological impacts to arise.

Although some NRBEs are based on ecosystem goods and others on ecosystem services, there was not strong differentiation between the types of associated risks. The key risks mainly arise at a site / enterprise level, and the scale of the risks mirror that of Figure 7.1, in that the higher the complexity and the greater the potential for environmental impacts of a particular

NRBE, the greater the range in the scale of risks (i.e. from site level to national level). Anderies et al. (2004), but more so Ostrom (2007, 2009) and McGinnis and Ostrom (2014) encourage the identification and consideration of interactions at different scales (referred to as tiers by McGinnis and Ostrom (2014)). The results in Table 7.1 provide evidence that the resulting SES conceptual framework addresses interactions at different scales. The consideration of multiple-scales is emphasised in the final SES conceptual framework (Section 7.5), as multiple-tiers are illustrated behind each of the four main elements of the framework.

7.4.5. Degree of environmental impacts associated with a natural resource-based enterprise

Environmental impacts can be social, economic or ecological in nature, and can be regarded as positive or negative. The case studies display a range of potential for environmental impacts (Figure 7.1): Umngazi is considered to have the least potential and a woody-biomass enterprise is deemed to have the greatest potential for environmental impacts. As a woody-biomass enterprise is expected to operate at both a national and international scale, the level of potential for environmental impacts, both positive and negative, is expected to be far greater in comparison to a community-based accommodation enterprise, which is only expected to operate at a local scale, and thus only has localised environmental impacts. The potential for environmental impacts occurring is influenced by the number and nature of interactions taking place within a SES, which are positively related with the complexity of a SES (Figure 7.1).

Paper 3 documents how SES theory has been successfully applied to recognise and understand the interactions of a SES within which a proposed development is located. This led to the development of a framework which specifically promotes the identification and consideration of the six types of environmental impacts (geographical (spatial), physical, biological, social, economic and cultural) required by NEMA to be assessed as part of an EIA. The SES theoretical framework provided a solid foundation on which to show how the six different environments interlink with each other, and are organised within an SES within which a proposed development is located.

7.4.6. An established natural resource-based enterprise vs. a proposed natural resource-based enterprise

Of the five NRBEs investigated, two were proposed enterprises (community-based accommodation at Umngazi and the residential wine estate in the Midlands) and three were failed NRBEs (craft enterprise at Mbongolwane, wilderness camp at Tyolomnqa and the four woody-biomass plants). Only one main difference emerged when using the risk assessment for an established enterprise versus a proposed enterprise: when it was applied to an existing enterprise the risks associated with internal business dynamics, such as mismanagement, were identified as key risks. Risks associated with internal business dynamics did not emerge for an enterprise which had yet to be established, as those involved had yet to be identified and conflicts had yet to occur. Although these internal business risks did not appear, internal business risks are as relevant to a new enterprise, as they are to a pre-established enterprise. It is recommended that further work be undertaken to develop a preliminary assessment of likely internal risks to a proposed enterprise based on the particular social context within which a proposed enterprise is to be located (e.g. level of business skills of the producers). Although application of such an assessment for a proposed enterprise is likely to yield less accurate results, compared to when applying it to a previously established enterprise, the results are considered to still be useful.

7.4.7. Identification of a resilient natural resource-based enterprise vs. assessing the resilience of a specific natural resource-based enterprise

For this study, SES theory was used twice to identify potential resilient NRBEs (at Umngazi and Tyolomnqa), and on three occasions to assess the resilience of a pre-selected NRBE. The main difference between the two types of application is the purpose and importance of implementing the ecosystems services inventory. The inventory was developed to gain a broad understanding of what ecosystems services are present, and is centered on understanding 'the resource' aspect of the SES. The inventory plays a critical role when identifying a potential NRBE, as it helps determine the availability of services on which to base a NRBE. For a pre-selected NRBE, the ecosystem services inventory is only used to help the stakeholders gain a mutual understanding of the SES within which a NRBE is located, and thus plays a less important role. The other three aspects of the SES framework (resource users, public infrastructure and public infrastructure providers) are of equal importance when developing risk assessments for both types of applications.

7.4.8. Ability to address the hiatus between theory and practice

Through collective review of the findings from the four papers, which each document the transfer of SES theory into practical contributions, it is evident that the conceptual framework is widely applicable to a great diversity of different types of NRBEs. Thus, the practical contributions (i.e. the ecosystem services inventory (Appendix A) and various risk assessments (Chapters 3, 4 and 6)) which are derived from the above SES works have made a tangible and broad ranging contribution to bridging this hiatus.

7.5. PRESENTATION AND EVALUATION OF THE CONCEPTUAL SOCIAL-ECOLOGICAL SYSTEM FRAMEWORK FOR NATURAL RESOURCE-BASED ENTERPRISES

7.5.1. Presentation of the conceptual social-ecological system framework for natural resource-based enterprises

The resulting conceptual SES framework for NRBEs (Figure 7.4 and Table 7.2), encapsulates the main contribution of this thesis to the development of SES theory for NRBEs. The general extensions made to the Anderies et al (2004) SES framework are presented in Table 7.3. Whereas the earlier SES conceptual frameworks have been shown to be less applicable to NRBEs which are based on an ecosystem good, as opposed to a service, as they do not illustrate a production process where a resource is physically processed into a product which is sold, the final SES conceptual framework is applicable to both types of enterprise. Only slight differences apply, and these are indicated in Table 7.3.

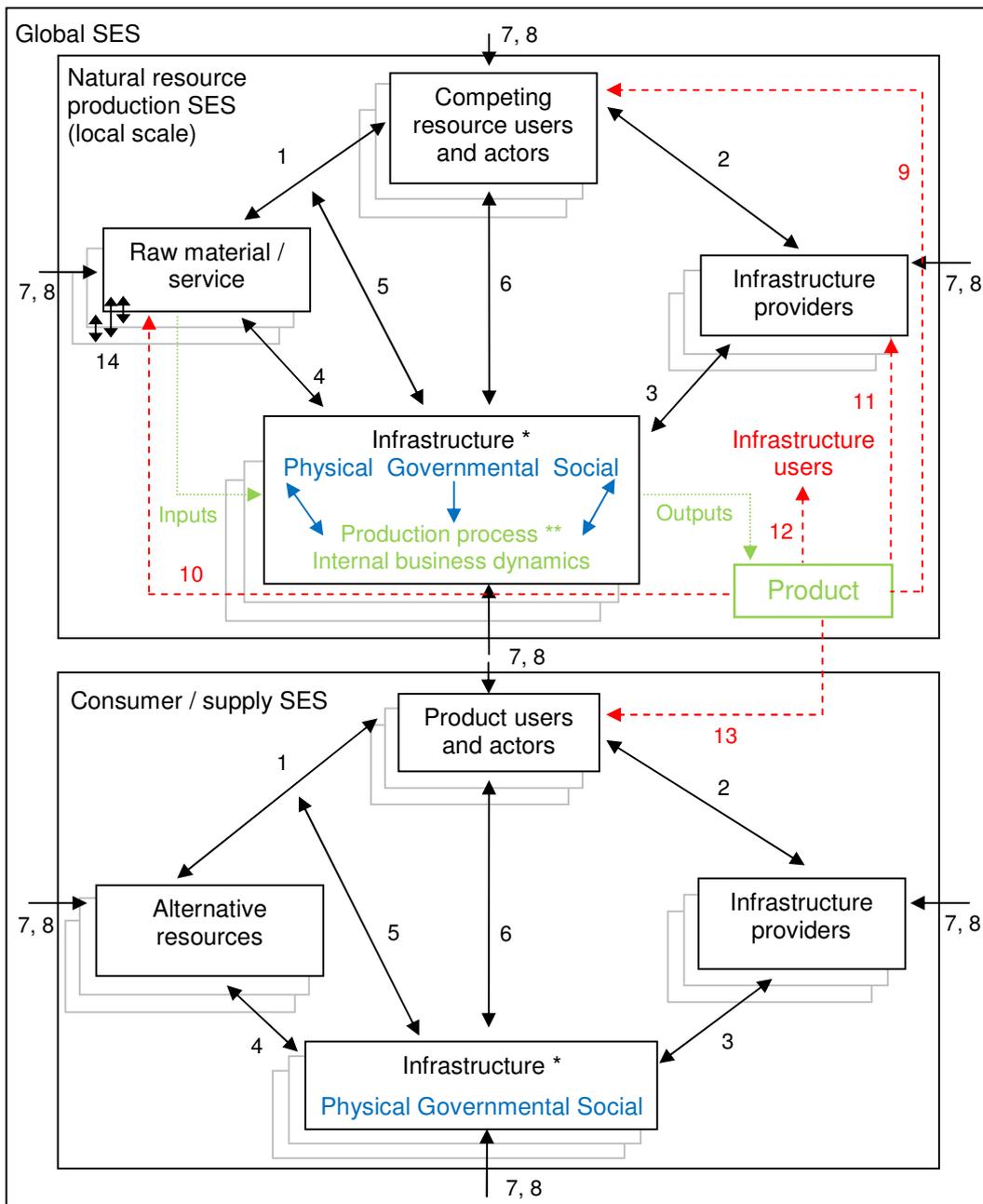


Figure 7.4. The social-ecological system conceptual framework for natural resource-based enterprises. * Physical - transformation and communication infrastructure; governmental – legal and regulatory infrastructure; social – knowledge and skills infrastructure. ** Production process – input of raw material, pre-treatment and manufacture, delivery of product (output). Refer to Table 7.2 for definitions of the 14 different interlinkages

Table 7.2. Defining elements of the social-ecological system conceptual framework for natural resource-based enterprises

Natural resource production SES	Definition / link	Explanations / examples
Raw material / service	Ecological good(s) and / or service(s) the enterprise is based on. Also referred to as the 'input' in a production process	<p>Ecosystem goods</p> <ul style="list-style-type: none"> • Plantation harvest waste • Wetland plants <p>Ecosystem services</p> <ul style="list-style-type: none"> • Scenic beauty • Open water for recreational activities
Competing resource users and actors	Those who utilise or influence those who utilise the same goods or services as the enterprise	<p>Individuals</p> <p>Communities</p> <p>Local, provincial and national government departments</p> <p>Private companies</p> <p>Non-governmental organisations (e.g. interest groups)</p>
Infrastructure	<p>Physical</p> <p>Transformation and communication infrastructure</p> <p>Governmental</p> <p>Legal and regulatory infrastructure</p> <p>Social</p> <p>Knowledge and skills infrastructure</p> <p>Production process</p>	<p>All manmade alterations to a landscape, transportation and telephonic / digital communication</p> <p>Laws in the form of acts, regulations, policy documents and customary regulations, and government / political structures (e.g. structures to define powers and responsibilities)</p> <ul style="list-style-type: none"> • Local, national and international legislation and policies which i) promote and support the enterprise; ii) discourage competing raw material / service uses; iii) provide the associated services / infrastructure required to support the enterprise; and iv) control the different aspects of the functioning of the enterprise (e.g. labour law) <p>Scientific / technical knowledge</p> <ul style="list-style-type: none"> • The level of technical knowledge available for the construction, operation and maintenance of the: i) enterprise infrastructure; and ii) equipment needed to maintain the enterprise • Literacy level of those needing to be educated on the enterprise • Ability of educators and media to inform the public about the enterprise <p>Input of raw material, pre-treatment and manufacture, delivery of product (output) (not applicable to an ecosystem services-based enterprise)</p>
Infrastructure providers	<p>Internal business dynamics</p> <p>Those responsible for the provision of required infrastructure</p>	<p>Risks associated with the internal functioning of an enterprise (e.g. mismanagement, stealing)</p> <p>Governmental departments responsible for:</p> <ul style="list-style-type: none"> • Implementing the governmental infrastructure (see above) • Supporting economic development <p>Private sector responsible for:</p> <ul style="list-style-type: none"> • Providing the required transportation, communication etc. • Middle-men who sell the 'output'

Product	A processed 'good' or a 'service' is a product	<p>Ecosystem good</p> <ul style="list-style-type: none"> • Woody-biomass pellets • Conference folders made from wetland plants <p>Ecosystem services</p> <ul style="list-style-type: none"> • Holiday destination which offers scenic beauty • A venue for a water sports competition which requires open water
Interlinkages within the natural resource production SES		
1	Between raw material / services and competing resource users / actors	Competition between the enterprise who needs the raw material / service to produce / offer the product, and other raw material / service users
2	Between competing resource users / actors and infrastructure providers	The promulgation and enforcement of legislation and policies which favour one resource use over another
3	Between infrastructure providers and infrastructure	The provision, monitoring and maintenance of infrastructure by those responsible for providing infrastructure
4	Between infrastructure and raw material / services	Infrastructure or lack of infrastructure which enables raw material / services to be utilised
5	Between infrastructure and raw material / service dynamics	Legislation, physical infrastructure and technical knowledge which impacts on the availability and / or nature of the raw material / service
6	Between competing resource users / actors and infrastructure	The impact of actions of the enterprise and other resource users / actors on the availability or nature of infrastructure
7	External biophysical forces on raw material / services, infrastructure and infrastructure providers	Severe or changes in weather may result in an increase or decrease in the availability of the raw material / service
8	External social, economic and technological forces on infrastructure providers, infrastructure and raw material / services	External forces (e.g. changes in political system, technological advancements) could impact on infrastructure providers, infrastructure and raw material / services
9	Demand for product by competing resource users / actors	Those located within the natural resource production SES and who have demand for the product
10	Demand for product by raw material suppliers	Raw material suppliers may have demand for the product
11	Demand for product from infrastructure providers	Those responsible for providing the infrastructure who have demand for the product
12	Demand for product by infrastructure users	Those who use the same infrastructure as the enterprise, but are not infrastructure providers, raw material suppliers or competing resource users / actors
13	External demand for the product	Those who have demand for the product and who are not located within the same SES as the enterprise. They do not depend on the same infrastructure or compete with the same resource users / actors as the enterprise
14	Ecological interactions	The interactions between ecological variables as a consequence of the enterprise (e.g. a fishing

enterprise may exceed a fishing quotas which results in the collapse of a seal colony)

Consumer / supply SES

Product users and actors	Those who have demand or who influence demand for the product, but do not rely on the same raw material / service for another purpose	<p>National enterprises</p> <ul style="list-style-type: none"> • Companies located within the same country, but do not compete for the same raw material / service. These product users may be governed by the same overarching legislations (e.g. a country's constitution, however there may be different local by-laws, regulations etc.). These product users are likely to be physically located a significant distance from the enterprise <p>International enterprises</p> <ul style="list-style-type: none"> • Companies located in a different country to that of the enterprise. These countries are governed by different legislation and controls, and may have access to different technologies due to scientific knowledge or environmental situation
Alternative resources	Availability of alternative resources	Changes in policy, legislation, profitability and / or evolving scientific knowledge (with or without vested interest) could result in the preference of one product to another by an individual, enterprise or country etc. The supply of the product from a different SES is also considered here
Infrastructure required to enable the delivery and use of the product	<p>Physical Transformation and communication infrastructure</p> <p>Governmental Legal and regulatory infrastructure</p> <p>Social Knowledge and skills infrastructure</p>	<p>All manmade alterations to a landscape, transportation and telephonic / digital communication</p> <ul style="list-style-type: none"> • Distribution of product to or access to product by users • Services required for the product to be used <p>Laws in the form of acts, regulations, policy documents and customary regulations, and government / political structures (e.g. structures to define powers and responsibilities)</p> <ul style="list-style-type: none"> • Legislation, policies etc. which support the i) use of product; and ii) services / infrastructure required to distribute / access the product <p>Scientific / technical knowledge</p> <ul style="list-style-type: none"> • Literacy level and knowledge which enables users / actors to understand the benefits and constraints of using / accessing the product
Infrastructure Providers	Those responsible for the provision of required infrastructure	<p>3. Governmental departments responsible for:</p> <ul style="list-style-type: none"> • Implementing the governmental infrastructure (see above) • Supporting economic development <p>4. Private sector responsible for:</p> <ul style="list-style-type: none"> • Providing the required transportation, communication etc. • Middle-men who sell the product
1	Interlinkages within the consumer / supply SES Between alternative resources and product users / actors	The demand for the product may increase or decrease as a result of the availability or preference to an alternative resource (e.g. pellet production may become established in a country where it was not previously available. Thus it will likely be cheaper for users to use locally produced pellets as opposed to importing pellets from elsewhere. A government may change its policy and favour the use of

2	Between product users / actors and infrastructure providers	thermal power to biomass) Legislation , policies, agreements and regulations which support or do not support the use of the product / resource
3	Between infrastructure providers and infrastructure	The provision, monitoring and maintenance of infrastructure by those responsible for providing such infrastructure
4	Between infrastructure and alternative resources	Infrastructure or lack of infrastructure which may led to the favouring of one product / resource over another
5	Between infrastructure and alternative resource dynamics	Legislation, physical infrastructure and technical knowledge which impacts on the utilisation of different resources / products
6	Between product users / actors and infrastructure	The impact of actions of the product users / actors on the availability of infrastructure
7	External biophysical forces on alternative resources, infrastructure, infrastructure providers and product users / actors	Severe or changes in weather may result in an increase or decrease in demand for alternative resources / products
8	External social, economic and technological forces on alternative resources, infrastructure, infrastructure providers and product users / actors	External forces could include changes in political system and advancements in technology etc. These changes could result in a change in demand for the product

Table 7.3. Advancements / amendments made to the Anderies et al. (2004) social-ecological system conceptual framework for nature resource-based enterprises

Amendment / addition	Explanation
Raw material / service replaces 'resource'	'Raw material' indicates a NRBE which is based on using an ecosystem good as an input, and 'service' indicates a NRBE which is based on an ecosystem service. Although a 'raw material' and an ecosystem 'service' are both resources, the re-labelling helps practitioners to make an initial differentiation between NRBEs which are based on goods and those that are based on services, as the production process element of the framework is not relevant to a service-based NRBE.
'Competing' and 'actors' added to 'resource users'	'Competing resource users and actors' emphasises that competition for raw material / services is a key factor which affects the functioning of a NRBE. 'Actors' have been added as it is important to consider the behaviour of third parties who are not direct users or consumers of the product or service in question, but who can influence users or consumers. This amendment is made by McGinnis and Ostrom (2014) to the Ostrom (2007, 2009) SES framework.
Multiple SESs	Three nested SESs are indicated. The global SES comprising two interlinking SESs: 1) Natural resource production SES (local SES) – the SES where the raw material is collected from, and a portion is used, or where the service is offered from and is used by those who are governed by the same rules and / or use the same infrastructure as the NRBE; and 2) Consumer / supply SES – the SES where the product is used, but the material to make the product is not sourced from, or where the service is used, but those who use it are not governed by the same rules and / or use the same infrastructure as the NRBE. Although both SESs are part of one large global SES, the SESs have been separated as there are several factors which are only applicable to either the natural resource production SES or the consumer / supply SES (refer to Table 7.2).
Product	'Product' refers to either an output of a processed ecological good, or an ecological service. The 'product' is located within the natural resource production SES as it is here where it is produced. There may be demand for the product within the local SES from 'raw material suppliers' (e.g. from sawmillers needing heat to dry timber), 'competing resource users and actors' (e.g. poultry farms who use sawdust for bedding but require energy for heating, or those who want to holiday at a wilderness location, but who also want to commercialise fishing at the same location) and 'infrastructure providers' (government who is responsible for providing and maintaining roads, and also need power for government services, such as hospitals).
Components of the consumer / supply SES	The consumer / supply SES features: 'product users and actors' indicates that this group can have demand for the product, but also have access and a desire to use the same product, or a similar or an alternative product, from elsewhere. 'Alternative resources' highlight that competition from or availability of other resources could impact on the demand for the product. 'Infrastructure' draws attention to the fact that the following can impact on the demand for the 'product': i) 'physical infrastructure' which refers to the accessibility of the 'product'; ii) 'social infrastructure' which refers to the knowledge of the availability and use of the product; and iii) 'governmental infrastructure' which refers to legislation and policy with supports or discourages the use of the product. Also featured are the 'infrastructure providers' which highlight the need to consider those responsible for provision of the 'infrastructure'.
Production process	For a NRBE which is based on an ecosystem good, the production process labels 'raw material' as an 'input', 'infrastructure' as the production process which involves 'physical infrastructure' (e.g. the processing plant), 'social infrastructure' (e.g. the work force, skills, technology and knowledge) and 'governmental infrastructure' (e.g. laws and policies governing operations and demand for product). The 'output' of the production process is the 'product'.

	<p>For a NRBE which is based on a ecosystem service the production process is interpreted as follows: 'service' is an 'input', 'physical infrastructure' is the actual NRBE building and associated physical structures utilised by the NRBE (e.g. access roads), and 'social infrastructure' and 'governmental infrastructure' is the same as a 'goods' NRBE. The 'output' is the 'sold service'. An example of a 'service' production process is the building of a hotel which has a scenic view over an estuary, and skills and knowledge enable good marketing and service delivery which is sold as a package to holiday makers. The package is the product.</p>
Internal business dynamics	<p>As SES theory is based more on political and ecological science (Binder et al. 2013) than business science, internal business dynamics are not a feature of previous SES conceptual frameworks. This element has been added within the 'production process' box, as it relates to those involved in the production process.</p>
Multi-tier variables illustrated by layers behind the four main components	<p>Anderies et al. (2004) make it appear as though the framework requires consideration of one level or scale of interactions. This amendment accentuates the need to consider multiple 'infrastructure providers', 'infrastructure' and 'competing resource users and actors', and is made by McGinnis and Ostrom (2014) to the Ostrom (2007, 2009) SES framework.</p>
Ecological interactions	<p>As SES theory is based on interactions which are social or social-ecological in nature (Walker et al. 2002, Anderies et al. 2004), specific interactions between ecological variables are not identified in previous SES conceptual frameworks. The consideration of ecological interactions is encouraged by the addition of linkage '14' which shows that the interlinkages between different ecological variables must be considered.</p>
Addition of infrastructure users	<p>As Anderies et al. (2004) is only concerned with those who directly use or who facilitate the use of the 'resource', there is no consideration for those who solely use the same infrastructure as the enterprise (but do not provide infrastructure or compete for raw material). The introduction of linkage '12' and 'infrastructure users' ensures that practitioners consider those who could negatively impact on the availability of infrastructure required by the NRBE.</p>
Infrastructure being split into physical, governmental and social	<p>The framework now differentiates between 'physical', 'governmental' and 'social' infrastructures as the term 'infrastructure' used by Anderies et al. (2004) is considered too broad, and there is concern that practitioners might overlook one of the three elements which make up 'infrastructure'.</p>
Introduction of 'technology' as an external factor	<p>Technology has been added to external social and economic forces as, it cannot be classed as either 'social' or economic', and as it is an external factor which could significantly impact upon a NRBE (both positively and negatively). This amendment is made by McGinnis and Ostrom (2014) to the Ostrom (2007, 2009) SES framework.</p>
External biophysical, social, economic and technological factors influencing all components	<p>As external social, economic and technical factors can affect the availability and accessibility of infrastructure and raw material / services, and external biophysical factors can affect infrastructure providers, competing resource users and actors, and product users and actors when a SES for a NRBE is being assessed.</p>

7.5.2. Evaluation of the conceptual social-ecological system framework for natural resource-based enterprises

The conceptual contribution (Figures 7.4 and 7.2) has been critiqued against the Binder et al. (2013) criteria for evaluating the effectiveness of social-ecological conceptual frameworks, and the Ostrom (1990) design principles for common pool resources (with slight amendments as suggested by Cox et al. (2010)) (Table 7.4). The Ostrom (1990) principles provide a means to evaluate the SES conceptual framework for NRBEs, as Anderies et al. (2004) claim that a robust system is characterised by incorporating a large number of these principles. Underlying assumptions of this thesis are that, if these principles are not present in the resulting SES conceptual framework, then the ability of the framework to help assess the resilience of NRBEs is questionable; and if these principles are incorporated, this strengthens the scientific contribution of the framework.

Table 7.4. Evaluation of the social-ecological systems conceptual framework for natural resource-based enterprises using the Binder et al. (2013) criteria for evaluating the effectiveness of social-ecological conceptual frameworks, as adapted (criteria 1-5), and the Ostrom (1990) design principles for common pool resources (criteria 6-13)

Criteria	Evaluation
1. Does the framework encourage a diversity of social levels and interactions across these levels?	Adoption of a PNS approach allows and encourages a variety of different stakeholders to be identified and engaged with. Stakeholders range from individuals with low literacy levels, to scientists.
2. Does the framework encourage the conceptualisation of the ecological system in relation to the anthropocentric paradigms versus ecocentric paradigms?	The framework favours the conceptualisation of the ecological system in relation to the anthropocentric paradigms. However the addition of linkage '14' encourages the consideration of ecological interactions.
3. Does the ecological system influence the social system (E→S), do human activities affect the ecological system or ecosystem services (S→E), or does the framework permit evaluation of reciprocity between the social and ecological systems?	The framework equally permits evaluation of reciprocity between the social and ecological systems. This is indicated by two-way arrows between ecological and anthropogenic activities.
4. Does the framework analyse both ecological and social systems to the same extent?	The addition of linkage '14' will encourage the consideration of ecological system interactions. With this addition the framework is considered to analyse both the ecological and social systems to the same extent.
5. Is the framework 'analysis-oriented', where the framework is aimed at framing research questions, or 'action-oriented' where the framework is aimed at interventions?	The framework can be applied to both, however it is considered more applicable to identifying interventions, rather than framing research questions.
6. Clearly defined boundaries: The boundaries of the resource system and the individuals or groups with rights to use the resource are clearly defined.	The addition of 'actors' assists with identifying not only competing resource users, but also those who do not use but who can influence the use of the resource (raw material / service). The ecological boundaries are identified by the use and interests of both 'users' and other 'actors'. Not only is the focal / natural resource SES defined, but the consumer / supply SES that the focal SES is located within is also indicated. The boundaries of both SESs are clearly defined.
7. Proportional equivalence between benefits and costs: Rules specifying the amount of resource products that a user is allocated are related to local conditions and to rules requiring labour, materials, and / or money inputs.	'Infrastructure' (which includes rules and regulations) and 'infrastructure providers' (which includes those responsible for enforcing these rules and regulations) are present. The addition of 'Government' under 'Infrastructure' emphasises consideration of these rules and regulations. Linkages 4 and 3 illustrate the link between the 'raw material / service', the rules governing the use of the 'raw material / service' and those responsible for enforcing these rules.
8. Collective choice arrangements: Most individuals affected by harvesting and protection rules are included in the group who can modify these rules.	Those responsible for determining rules are identified under 'infrastructure providers'. Those who are influenced by these rules are identified under 'competing resource users and actors'. Although the framework allows a comparison between these two groups to be made, the framework does not explicitly promote the inclusion of those affected by harvesting and in any modification of the rules.

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|---|---|
| <p>9. Monitoring users: Monitors who are accountable to the users, monitor the appropriation and provision levels of the users.
Monitoring the resource: Monitors who are accountable to the users monitor the condition of the resource (Cox et al. 2010).</p> | <p>The provision, maintenance and monitoring of 'infrastructure' (rules) and 'infrastructure providers' (regulatory bodies) is indicated with linkage '3'. Although a lack of specific steps to monitor the impacts of a NRBE, once established, on the receiving SES is acknowledged, if the practical contributions are periodically repeated for a NRBE, this principle is addressed.</p> |
| <p>10. Graduated sanctions: Users who violate rules-in-use are likely to receive graduated sanctions (depending on the seriousness and context of the offence) from other users, from officials accountable to these users, or from both.</p> | <p>Those who use the 'raw material / service', the rules and regulations which govern the use of the 'raw material / service' and those that enforce these rules and regulations are indicated by the framework. As the framework facilitates stakeholder interaction, and if periodically repeated, it is likely that those stakeholders (e.g. those associated with the NRBE or who are competing resource users or actors) who violate the rules or regulations will be sanctioned, however the framework in its current form does not make explicit reference to the 'graduated' aspect of sanctions.</p> |
| <p>11. Conflict-resolution mechanism: Users and their officials have rapid access to low-cost, local arenas to resolve conflict among users or between users and officials.</p> | <p>As the framework facilitates interactions amongst competing resource users and actors, there is opportunity for conflicts to be openly discussed and resolved.</p> |
| <p>12. Recognition of rights to organise: The rights of users to devise their own institutions are not challenged by external governmental authorities, and users have long-term tenure rights to the resource.</p> | <p>Although the rights of users are catered for under 'social infrastructure', the framework does not explicitly make reference to the rights to organise. Thus practitioners using the framework will not be promoted to consider these.</p> |
| <p>13. Nested enterprises: Appropriate, provision, monitoring, enforcement, conflict resolution and governance activities are organised in multiple layers of nested enterprises.</p> | <p>The framework pictorially illustrates that the NRBE is located within a SES, which is nested within a consumer / supply SES, and that there are multiple layers of the different elements (e.g. infrastructure providers) within each of the systems.</p> |
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It is concluded that the resulting SES conceptual framework adequately addresses most of the criteria identified by Ostrom (1990) and Binder et al. (2013), although some are not dealt with in any great detail (e.g. recognition of rights to organise). This result increases confidence in the academic contribution of the conceptual framework. One of the aspects which could potentially be strengthened is 'monitoring', especially for ecological variable interactions, as NRBEs which are based on a production process, rely on ecological interactions for their survival. The most obvious suggestion to tackle this is for the risk assessments, which are based on the SES framework, to be periodically repeated. It is recommended that they be implemented prior to a NRBE being established, as this will hopefully give a NRBE a better chance of being resilient. To enhance the resilience of a NRBE, the risk assessments should also be periodically repeated (e.g. every few months or years depending on the dynamics of the enterprise). It is anticipated that further risks (and associated mitigation measures) will emerge during the lifetime of the enterprise, and as understanding of the system and its dynamics is often far from complete and therefore predictions are often not accurate (Walker et al. 2002). Prior to this, the SES conceptual framework must be referred to, in conjunction to the previous results, and the analysis updated, as it is likely that the interlinkages and interdependence within the SES will change as the NRBE expands and evolves. This progressive application links well with strategic adaptive management (Oglethorpe 2002), as the first assessment of the SES feeds into initial management vision and objective setting, and the second (and further assessments, as required) are linked with review and learning.

It must be acknowledged that when a NRBE is reliant on a production process, the ecosystem on which it is based can be 'coerced' into being resilient (Rist et al. 2014) (i.e. the state of the ecological system is managed by human intervention). Although 'coerced' resilience can be advantageous for a particular NRBE, there are many disadvantages associated with this. These include: i) the masking of a loss of alternative regimes; ii) increased cross-boundary interactions which can impact on system sustainability; iii) the permitting of a high level of production at the expense of ecological resilience; and iv) a loss of future alternative options as the system is being held in an otherwise unstable state (Rist et al. 2014). These factors lead to a need for a NRBE to recognise that increased resilience for one enterprise may mean a lack of resilience for another enterprise. Although the framework does identify competing resource users, who could be enterprises, it does not encourage the consideration of how the NRBE in question impacts on the resilience of other resource users or NRBEs which have overlapping SESs. As the focus of this thesis is on the resilience of specific NRBEs, and not on the resilience of SESs,

the resilience of competing resource users has not been incorporated into the framework. As the actions of competing resource users can impact on the availability of raw material / services, it is recommended that all stakeholders are involved, and that the assessments are continually repeated, and the findings reviewed, to monitor the ever-changing social and ecological dynamics within as SES.

7.6. ORIGINAL CONTRIBUTION OF THE RESEARCH

This thesis presents both theoretical and practical contributions which have the ability to help towards poverty alleviation. The research has also proven to be applicable to sophisticated entrepreneurial activities, such as wine estates, for the more affluent. The contributions, both theoretical and practical take into consideration the complex nature of South African SESs, and are applicable to a variety of types and scales of NRBEs.

The contributions strongly encourage stakeholder identification, consideration and engagement, and this emphasis contributes towards the balancing of both economic empowerment and sustainable resource use. In addition to the insights and practical outcomes described in the Papers, which were yielded at the level of individual sites, the contributions also have the potential, through engagement of government organizations, to inform and guide policy development at a strategic level.

Although limitations associated with the contributions and areas for further work are provided in Section 7.9, this thesis provides the first ever theoretically-based methodology for selecting, assessing, evaluating and operating NRBEs in the interests of both natural resource management and poverty alleviation. By applying SES theory to the development of a conceptual framework specifically for NRBEs, and through the development of practical applications based on the conceptual framework, this thesis helps address the hiatus between theory and practice which has previously been documented by Pullin et al. (2004), Knight et al. (2006), Turner and Daily (2007), Daily and Matson (2008) and Temperton et al. (2013) to hinder achieving effective ecosystems management.

7.7. RELATION OF THE CONCEPTUAL AND PRACTICAL CONTRIBUTIONS TO RELEVANT PUBLISHED LITERATURE

Although the resulting SES conceptual framework is primarily based on the Anderies et al. (2004) framework, and not the Ostrom (2007, 2009) framework, there are many similarities between the two (see Chapter 2). McGinnis and Ostrom (2014) question how broadly the Ostrom (2007, 2009) SES framework is applicable to complex SESs in which multiple users and actors, who are governed by multiple and overlapping governance systems, use a diversity of resource units. They proposed that the Ostrom (2007, 2009) framework, with their suggested amendments, is applicable to the governance of artificially constructed technological systems in which users experience interactions within a social-ecological technical system (SETS), and believe that the dependence on a SETS may be more in terms of a continuous supply of a services, rather than the purchase of a particular resource unit. Although McGinnis and Ostrom (2014) relate the continual supply of a service to a SETS, and not the purchase of a resource unit, and Paper 4 documents the use of an ecosystem 'good', rather than a 'service', Paper 4 is considered to apply the resulting SES conceptual framework to a complex artificially constructed SETS (as the commonly planted plantation species in South Africa are not indigenous to the continent) which has multiple governance systems. Paper 4 concludes that previous SES theory was found to be largely appropriate; and the omissions of applying SES theory (as documented above), are not considered to be attributed to the fact that the main resource in the SES was artificial (timber), but due to previous SES theory being situated in ecological and social sciences (Binder et al. 2013), rather than business sciences. Thus the McGinnis and Ostrom (2014) suggestion that the original SES framework has broad application is supported by the findings of this thesis.

Huntsinger and Oviedo (2014), who assess SES interactions at a landscape level in the context of Californian Mediterranean rangelands, note that scientists find it challenging to compare and assess many ecosystems services, such as viewsheds and open spaces, as they cannot be ascribed a monetary value, unlike ecosystem goods. The ecosystem services inventory, which involves the ascribing of scores to the level of ecosystem services available within the focal SES (Appendix A, Bowd et al. 2012b), is considered a tool which can assist scientists with the comparative valuing of ecosystem services and goods.

Cumming et al. (2006) report that there can be a decrease in social-ecological resilience when there is a mismatch between the scale at which natural resources are managed, and the scale

at which ecological processes take place; and that this mismatch comes about because the area of interest generally ranges across many scales, and the measurable observations are generally limited to a scale from which information can be collected. As application of the practical contributions is intended to lead to NRBEs influencing the management of natural resources, a mismatch between management practices and ecological processes could occur if the practical contributions do not extend to ecological interactions within the broader SES. Cumming et al. (2006) recommend that more interdisciplinary research is required, specifically on the development of tools to diagnose scale mismatch, and on the dynamics that maintain institutional arrangements. Fabinyi et al. (2014) and Nuno et al. (2014) also believe that interdisciplinary research which combines knowledge of social psychology with natural resource management, will facilitate successful resource management. Nuno et al. (2014) recommend that factors which drive resource user behaviour be incorporated in SES research. As the practical contributions are based on continual stakeholder engagement (through repeat application – refer to Section 7.9) which involves stakeholders from a range of disciplines, and provide a mechanism to explore and help understand dynamics between different institutional infrastructures, they are considered tools which could help towards reducing these mismatches, provided further work is undertaken on the identification of risks associated with ecological interactions, and that these are adequately incorporated into the risk assessment (refer to Section 7.9).

7.8. CONCLUSIONS

This thesis seeks to integrate components of SES theory into natural resource management through applying the concepts of resilience, risk and ecosystem services management to NRBEs. To achieve this, SES theory was applied in this study to:

1. Identify potential resilient NRBEs (Paper 1);
2. Assess the resilience of selected NRBEs with the view of providing strategies (mitigation measures) to increase the resilience of these enterprises (Papers 1, 2 and 4);
3. Assess the resilience of NRBEs which have previously been established, and failed (Papers 2 and 4);
4. Assess the resilience of proposed NRBEs which have not been previously established (Papers 1 and 3);
5. Assess the resilience of NRBEs which are based on ecosystem services which do not need to be altered/processed prior to utilisation (Papers 1 and 3); and

6. Assess the resilience of NRBEs which are based on a production process where an ecosystem 'good' is an input, which is processed to form an output which is sold for revenue (Papers 2 and 4).

It can be concluded that, even with the 'baseline' of the South African NRBE SESs being highly complex, the use of SES theory proved to be applicable to the six types of applications listed above. However the level of applicability varied amongst the different applications (as described in Section 7.4), and this variation was highlighted through the identification of limitations associated with each application (see Section 7.9 below). These identified limitations, which were noted in addressing each thesis objective, contributed to the evolution of the resulting SES conceptual framework (Figure 7.4 and Table 7.2). Figure 7.5 pictorially summarises how the resulting SES conceptual framework evolved through the compilation of the four papers.

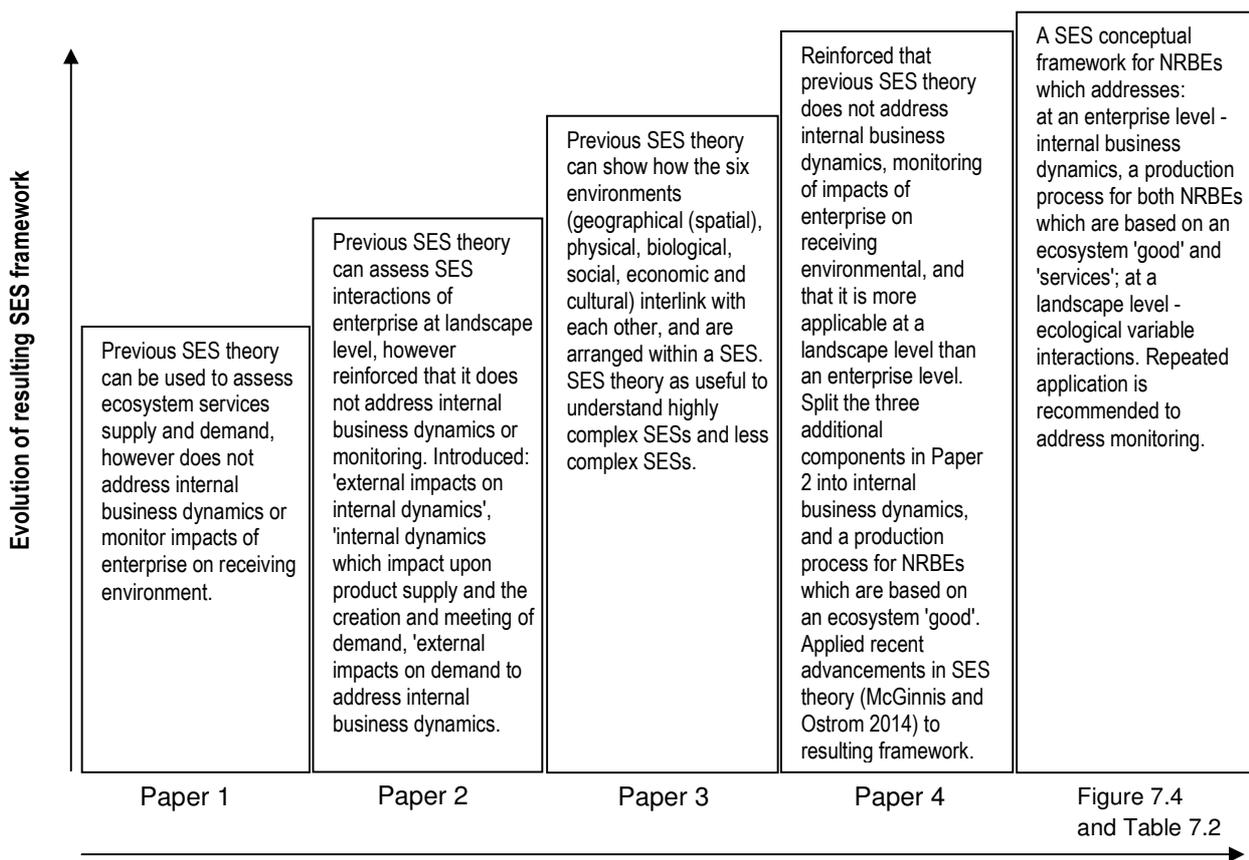


Figure 7.5. Evolution of the resulting social-ecological system conceptual framework for natural resource-based enterprises

This study reveals that SES theory can be used to disaggregate and understand the interlinkages and dependencies within both simple and highly complex SESs which surround NRBEs. An understanding of cross-scale interactions enhances resilience, adaptability and transformability of enterprises (Walker et al. 2002). Social-ecological systems theory endorses a PNS approach whereby engagement with both scientific and non-scientific stakeholders is advocated. In fact the greater the number and variety of stakeholders involved, the greater the relevance of data obtained (Angelstam et al. 2013). This increased understanding, and thus knowledge, is the key to establishing and operating resilient NRBEs, and helps to address the hiatus between theory and practice with ecosystem management which has been frequently documented (Pullin et al. 2004, Knight et al. 2006, Turner and Daily 2007, Daily and Matson 2008, Temperton et al. 2013). Through applying SES theory it became apparent that various stakeholder groups are relevant to all case studies (e.g. the local community, government departments responsible for logistics). Without adopting a PNS approach, and combining SES theory with stakeholder engagement, it is likely that:

- Decision-makers at Umgazi would have pursued a rehabilitation programme not supported by the local community;
- Decision-makers at Tyolomnqa would have fundamental environmental constraints to several proposed enterprises;
- The environmental study for the proposed residential wine estate would not have identified those responsible for the supply and maintenance of infrastructure and possible trade-offs which could increase the resilience of the enterprise; and
- The same mistakes which led to the failure of the woody-biomass industry in South Africa and the wetland craft enterprise at Mbongolwane, would be repeated if and when these enterprises become re-established, as previous mistakes may not be reflected on by those involved.

When applying SES theory to identify a resilient NRBE, the ecosystem services inventory plays a pivotal role. The ecosystem services inventory is based on ecological component interactions, thus when using SES theory for this application, ecological component interactions are adequately addressed. As many previous SES frameworks do not explicitly encourage the consideration of interlinkages between ecological variables, and as an ecosystem services inventory is only used to gain a mutual understanding of the SES when used for an established NRBE, the resulting SES framework includes multi-tiered variables under 'raw material / service'

(which represents ecological variables in the framework) and two-way arrows showing possible interconnections between these variables.

The SES framework provides a solid foundation on which to show how the six different environments, listed in NEMA, interlink with each other, and are arranged within a SES of a proposed development. This theory also proved to be as useful with identifying the degree for potential environmental impacts associated with a highly complex NRBE, as it is with a less complex NRBE.

Previous SES theory is less applicable for NRBEs which are based on an ecosystem good, as opposed to a service, as previous frameworks do not illustrate a production process where a resource is physically processed into a product which is sold. The resulting SES conceptual framework addresses this omission.

In summary, previous SES theoretical frameworks proved most applicable when i) identifying potential NRBEs; ii) assessing a proposed NRBE which has not been previously established; and iii) used on a NRBE which is based on ecosystem services and which do not need to be altered in order to be utilised. Previous SES theory proved to be least applicable when i) assessing a selected NRBE which has previously been established (as it omits risks associated with internal business dynamics); and ii) used on a NRBE which processes an ecosystem good through a production process. Previous SES theory also revealed to be most applicable when used at a broad, strategic, long-term level, than at a short-term, operational enterprise level where internal business dynamics play more of a key role with resilience. These findings are not unexpected as previous SES frameworks are not specifically aimed at understanding the interlinkages of SESs which surround NRBEs.

Although combining SES theory with the concepts of resilience, risk and ecosystem services has proven to be very appropriate for contributing towards natural resource management practices which help alleviate poverty, it has also proven to be applicable to sophisticated entrepreneurial activities. This research reflects the findings of Walker et al. (2002), Anderies et al. (2004), Folke et al. (2004) and Ostrom (2007), in that the concept of resilience can be used to help understand and manage complex SESs, as this research has been successfully used to analyse a variety of complex SESs. In accordance with the findings of Walker et al. (2002) and Westley et al. (2002), this use of SES theory has also enabled constructive communication

between scientists and non-scientists who understand the SES at different scales and perspectives, and has emphasised the need to consider human adaptability (Gunderson and Holling 2002, Walker et al. 2006). Although this study has identified limitations with applying SES theory to assessing the SESs which surround NRBEs (see Section 7.9), it has nevertheless provided a strong foundation for achieving resilient NRBEs which will contribute toward poverty alleviation.

7.9. LIMITATIONS OF THE STUDY AND FURTHER WORK

Limitations at three levels are presented in this section. The limitations associated with the practical contributions produced as part of this study are presented first, followed by the limitations of applying SES theory to assessing NRBEs. Finally, the limitations of SES theory have been used to identify general limitations associated with this research, together with recommendations for further work.

Limitations of the practical contributions developed as part of this study:

- Limited identification and consideration of internal business functioning dynamics;
- Only ecological risks which are directly relevant to human well-being are identified. This raises the possibility that some ecological impacts might be unobserved; and interactions between different ecological components may be overlooked;
- The implementation process is lengthy, time-consuming and intellectually demanding;
- The accuracy of the findings rely on i) the involvement and cooperation of key stakeholders; ii) the accuracy of the data obtained to populate the risk assessments and conceptualisations (Gunderson 2000); iii) the completeness and thoroughness of the application; and iv) those implementing the approach do not have hidden agendas (e.g. political, economic) (Pritchard et al. 2000) or favour one element of the model to others, as they are more familiar with certain aspects (e.g. they are ecologists who concentrate on ecological dynamics, as opposed to economic and social dynamics (Schlüter et al. (2014);
- A lack of specific steps to monitor the impacts of an enterprise on the receiving SES, once established. However if the assessments are periodically repeated during operation, this limitation is eliminated;
- As a SES is ever-changing and unpredictable (Walker et al. 2002), and as there are barriers within a SES which prevent parts of the system from being observed (Carpenter

et al. 2005), the accuracy of results maybe questioned. However, if the analysis is frequently repeated, especially after significant disturbances (Carpenter et al. 2006) (e.g. severe climatic events, such as floods, fires and droughts), these limitations can be reduced; and

- As the adaptability, and thus the resilience of an enterprise, is human driven, it is difficult to accurately gauge the resilience of an enterprise without it first being established. However if the methods are periodically repeated during operation, this limitation is eliminated.

Limitations of using SES theory to assess NRBEs

- SES theory is primarily based on the political and the ecological sciences. Relatively little consideration is given to business sciences, and thus there is limited explicit consideration of internal business dynamics and market chain;
- Interdependencies and interlinkages between ecological variables are not explicitly examined; and
- The theory is less applicable for assessing a NRBE which is based on an ecosystem 'good' compared to an ecosystem 'service', as the theory omits the element of demand for a physical and quantifiable product.

General limitations associated with this research and recommendations for further work

Although the case studies used in this study varied in terms of context and scale, only five case studies were used, and all of which were located in rural areas within South Africa. A larger sample size, which could include urban settings, natural resources being extracted from a protected area, or an area controlled by a corporate company, could enhance the basis for determining how widely applicable the frameworks/tools are. In addition, application of the practical contributions to other countries could also have increased confidence in the findings.

Although Papers 2 and 4 attempt to identify risks associated with internal business dynamics, far more work is required to integrate risks associated with internal business dynamics (for both an existing and proposed enterprise), as well as risks associated with interlinkages between ecological variables. A potential starting point to address these recommendations is to split the SES into different scales for analysis, much like the recommendation from the Resilience Alliance (2007) for historically profiling a SES, and Huntsinger and Oviedo (2014) for analysing SESs which feature ecosystem services to which it is difficult to ascribe monetary value. For

example, at an enterprise level to further investigate the internal operational dynamics, at a landscape level to further investigate the needs of competing resource users, and at a national or regional level, to further investigate the social, economic, ecological and technical implications of a potentially emerging natural resource-based industry (Resilience Alliance 2007). Wu (2013) recommends that more in-depth landscape level analysis deserves more attention than it currently receives, in terms of sustainability research, as 'on-the-ground' sustainability outcomes arise from interactions of higher-level drivers and local-level system dynamics (Hanspach et al. 2014).

As the SES conceptual framework and practical contributions have largely been applied as a 'once-off' assessment, the ongoing application within the context of an adaptive management process has not been documented. Thus, it is recommended that long-term studies within an adaptive management framework should be undertaken to assess the effects of the enhanced understanding of the long-term viability of NRBEs.

It is recommended that testing of the resulting SES conceptual framework, through the practical contributions, be applied to other artificial systems, such as where crafters have purposefully planted weaving material (Kotze and Traynor 2011), or where farmers have planting commercial crops (Rist et al. 2014). It is also suggested that the practical contributions are tested for commercial and subsistence livestock farming SES. Case studies for these scenarios should vary in scale, climatic region (Ruiz-Mallén and Corbera 2013) and level of affluence.

Hinkel et al. (2015) believe that the Ostrom (2007, 2009) framework does not provide a means to capture how multiple uses and benefits are connected, nor does it represent the dynamic aspects of 'resource unit' stocks and activities of actors. Although the introduction of interlinkage '14', multi-tier variables and 'competing resource users and actors' are considered to adequately address the dynamic aspects of 'resource unit' stocks and actor activities, the SES framework fails to consider how multiple user benefits are connected. It is recommended that additions are made to the risk assessment which consider the benefits between different resource users and actors, which are not the NRBE being investigated.

Whilst the risk assessments identify risks associated with conflicting resource users and actors, it is recommended that social psychological theory be applied to enhance the risk assessment

through the identification of factors which drive resource use behaviour (as recommended by Fabinyi et al. (2014) and Nuno et al (2014)).

It was identified that the SES framework does not include consideration of the risks to the resilience of competing resource users / enterprises. As the intention of this thesis is to focus on specific NRBEs, and not the impact of multiple NRBEs within a SES, this shortcoming is not unexpected. If practitioners wish to apply the framework to increase the resilience of a specific SES, it is recommended that the practical contributions are made applicable and then applied to the prominent competing resource users / enterprises within the SES. The results for each competing use / enterprise can then be evaluated to determine which use(s) contribute most to the resilience of the SES. However, prior to this type of application, it must be determined whether short or long-term resilience is desired, as different activities can affect resilience over different time scales.

If the contributions are considered to be used at a government organisation level to inform and guide policy, it is recommended that both senior management as well as those at a practitioner level be involved with any application or further development of the contributions.

Although the SES conceptual framework presented in this chapter is regarded as a significant contribution to science, there is the possibility that the suggested further work might result in the SES conceptual framework being more refined. Thus the resulting conceptual SES framework presented in Figure 7.4 and Table 7.2 is currently regarded as work in progress, much like the Ostrom (2007, 2009) SES conceptual framework (McGinnis and Ostrom 2014).

7.9.1. Postscript

The candidate has been approached by a multinational energy company to further develop and refine the woody-biomass risk assessment presented in Paper 4. It is hoped that this funding will result in the development of a robust and practical product which will overcome the identified limitations of the current woody-biomass risk assessment, and potentially other limitations identified in this study.

The candidate has been approached by organisers of the Argus Conference, to present Paper 4. The Argus Conference is an annual event where the international biomass pellet industry gathers to: listen to presentations, discuss problems, exchange technical and scientific

knowledge and problem solve on subjects surrounding the biomass industry. The biomass world is looking closely at Africa as the next source of woody-biomass, and it is hoped that presentation of Paper 4 will contribute to the establishment of a resilient biomass industry in South Africa. Hopefully this will lead to increased development and, in turn, help alleviate poverty. However the successful establishment of this industry is dependent on whether the obstacles identified in Paper 4 can be overcome. The presentation of findings of this research to an international audience may help avoid South Africa being exploited (both socially and ecologically) by 'roving bandits' (Olson 2000, Berkes et al. 2006), as the potential for exploitation in South Africa would have been brought into a public arena where there are 'watchdogs' whose primary interest is that of the social and ecological well-being of developing countries. Bringing the findings of this research to an international audience should encourage decision-makers to revisit the use of woody-biomass for power generation in South Africa. This attention may lead to decision-makers taking steps to help address the obstacles to establishing a resilient industry which were identified through this research.

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APPENDIX A