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An essential variable approach for integrated social-ecological systems monitoring to determine sustainability in a South African catchment

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Itzkin, Adela. (2024). An essential variable approach for integrated social-ecological systems monitoring to determine sustainability in a South African catchment. [PhD thesis, University of the Witwatersrand, Johannesburg]. https://hdl.handle.net/10539/41487

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An essential variable approach for integrated social-ecological systems monitoring to determine sustainability in a South African catchment.

by
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Thesis
Submitted in fulfilment of the requirements for the degree
Doctor of Philosophy
in
Animal, Plant and Environmental Sciences
in the Faculty of Science, University of the Witwatersrand, Johannesburg, South Africa

Supervisor: Professor Mary Scholes
Co-supervisors: Dr. Jai Kumar Clifford-Holmes and Dr. Kaera Coetzer

May 2024

DECLARATION

I declare that this thesis is my own, unaided work. It is being submitted for the Degree of Doctor of Philosophy at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University.



_____ ___ (Signature of candidate)

30th day of May 2024

ABSTRACT

This thesis presents an essential variable (EV) approach tailored for integrated social-ecological systems (SES) monitoring within the Tsitsa River Catchment (TRC) in South Africa. The study addresses the conceptual and methodological challenges inherent in SES integration and monitoring to provide insights into sustainable landscape management. The research methodology employed a transdisciplinary social learning process, integrating systems thinking and participatory research methods across three related publications.

In the first publication, systems diagramming, qualitative interviews, and participatory data collection provided a systemic snapshot of the interconnected social and biophysical drivers of land degradation in the TRC. The findings underscored the dual benefits of changes in land use and grazing practices for landscape improvement and sustainable livelihoods, informing the identification of monitoring variables crucial for sustainable land management.

In the second publication, a social learning process, termed participatory self-observation, explored approaches to enhance integration and monitoring of biophysical and social data for adaptive management. The process identified data integration, overload, scale, learning-oriented monitoring, and relationship-building as key challenges in SES monitoring Recommendations included participatory approaches focusing on applied work, identifying essential data for SES monitoring, and improving transdisciplinary collaboration.

In the third publication, a transdisciplinary process guided by EV development identified Essential Social-ecological System Variables (ESEVs) for the TRC, emphasising the relational connection between social and ecological aspects of SESs. ESEVs were prioritized based on essentiality scores and participant consensus, facilitating integrated planning and management at the catchment scale. The ESEVs identified for the TRC include 'soil erosion related to human actions on the land,' 'participation in natural resource governance,' 'grazing and rangeland sustainability,' and 'land cover and condition. Participants proposed three additional ESEVs, 'access to water,' 'local natural resource governance system,' and 'human well-being in the landscape'.

The study concludes that collaborative learning informed by diverse transdisciplinary perspectives can guide adaptive monitoring approaches, with lessons from the TRC applicable

to diverse contexts. The ESEV approach offers wider application value, addressing the question of the minimum variables needed for integrative landscape management in complex SESs. Overall, this thesis pioneers a transdisciplinary mixed-methods approach for efficiently monitoring social-ecological sustainability outcomes. Through advancements in conceptualizations of integrated, contextually grounded monitoring, it offers a novel perspective for understanding the implications of development interventions, bridging critical gaps in SES monitoring.

ACKNOWLEDGEMENTS

I would like to express my heartfelt gratitude to several individuals and organisations who have supported me throughout my academic journey and the completion of this thesis.

First and foremost, I extend my sincere appreciation to my supervisors, Professor Mary Scholes, Dr. Jai Clifford-Holmes and Dr. Kaera Coetzer. Your guidance, support, and constructive feedback have been invaluable. I am deeply grateful for your mentorship and for helping me navigate the challenges of this research process.

I am also grateful to the National Research Foundation and Department of Science and Innovation (NRF/DSI), specifically Professor Mary Scholes' Research Chair in 'Systems Analysis and Climate change' and the 'Social Learning and Sustainable Development' Community of Practice at Rhodes University. Their funding support has been instrumental in enabling me to pursue my academic goals and contribute to the body of knowledge in my field.

To my colleagues, particularly the members of 'Mary's Lab', I extend my thanks for the mutual support, accountability, and encouragement throughout our academic journeys.

Special thanks are due to the Rhodes University Tsitsa Project team, especially Margaret Wolff and the 'Knowledge and Learning' Community of Practice, for welcoming me into their space and sharing valuable data collected by the project. Working within such a large transdisciplinary praxis project has been a transformative experience, allowing me to gain valuable insights and maintain a focus on action-oriented research.

I am grateful to the participants in my research for their openness, expertise, and willingness to engage with complex social-ecological challenges. Their contributions have been instrumental in shaping my understanding of sustainable development and the importance of a social-ecological systems approach within an African context.

This research journey was undertaken in the context of a global pandemic, a high-risk pregnancy, first-time parenting, and the heartbreak of witnessing a genocide unfold. In this regard, I am deeply indebted to my dearest husband, Tariq Gardee, for his unwavering love,

support, gentleness, and encouragement during difficult moments. Tariq's enthusiasm to step up with our son, travel with us to conferences and workshops, and help me in countless small and big ways, have been instrumental in my journey. Tariq, I am so incredibly grateful for your presence in my life! You are the best partner I could ask for, and this achievement is ours.

To my son, Sami, your infectious smiles, warm hugs, playful dances, and budding conversations have been a source of great joy and inspiration through this journey.

I would also like to express my deep gratitude to my parents, Ayesha and Eric Itzkin, and my in-laws, Rashida and Yoosoof Gardee, for their unwavering support and for being such involved and loving grandparents. Furthermore, I extend my thanks to all Sami's caregivers for their exceptional care and dedication. It takes a village to raise a child, especially while his mummy is completing her PhD.

To Em, I appreciate your consistent care and presence in my life. To my brother, Riaz, and sister-in-law, Sameera, thank you for the encouragement through this journey.

I would also like to take a moment to remember my late granny, Rhona, who had unwavering belief in me. She would have been so proud of this achievement.

Finally, I am thankful to all my dear friends and family, who are too numerous to list here, for their ongoing support, encouragement, and understanding. Your companionship, whether over Friday afternoon teas, Catan nights, between-work meetups at Doppio, play dates, video chats, or quick text check-ins, has been a source of comfort and joy.

To everyone mentioned above, and to those who have supported me in ways both seen and unseen, I extend my deepest gratitude. This achievement is a testament to the support of a remarkable community, and I am truly grateful for each and every one of you.

Thank you.

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ABBREVIATIONS

CLD/s	Causal Loop Diagram/s
DFFE	Department of Forestry, Fisheries and the Environment
DPSCR$_4$	Drivers-Pressure-Stressors-Condition-Responses
DPSIR	Driver-Pressure-State-Impact-Response
ESEV/s	Essential Social-ecological System Variable/s
EV/s	Essential Variable/s
LDN	Land Degradation Neutrality
M&E	Monitoring and Evaluation
MEL	Monitoring, Evaluation and Learning
NRM	Natural Resource Management
PMERL	Participatory Monitoring, Evaluation, Reflection and Learning
PSO	Participatory self-observation
SES/s	Social-Ecological System/s
TP	Tsitsa Project
TRC	Tsitsa River Catchment

CHAPTER 1 – INTRODUCTION

The complex, interconnected nature of social-ecological systems (SES) underscores the urgent need for integrated monitoring approaches. This chapter begins with an exploration of the broader context surrounding the imperative for integrated SES monitoring approaches. It begins by providing a global perspective (1.1.1), followed by an examination of the South African context (1.1.2), before focusing on the Tsitsa River Catchment case study (1.1.3). Building upon this contextual foundation, the rationale (1.2), aim (1.3), and objectives (1.4) of this study are elucidated. Subsequently, the study's contribution to the field of science is presented (1.5). Finally, the structure of the thesis provides a roadmap for navigating through the subsequent chapters and their respective contributions to the overarching research endeavour (1.6).

1.1. Background

1.1.1 General problem context: The need for integrated social-ecological systems monitoring approaches globally.

In an era marked by growing environmental concerns and an increasing recognition of the complex social-ecological connectivity, the pursuit of sustainable practices has become an imperative goal. An SES research approach embraces complexity and dynamic interconnectivity to improve our understanding of SESs (Herrero-Jáuregui et al., 2018). There has been a significant increase in SES publications since 2010, aimed to improve our understanding of the complex, dynamic and integrated nature of real-world problems (Guerrero et al., 2018). This has been accompanied by concerted efforts to develop new methods for SES research (Biggs et al., 2021). Yet the discipline still faces methodological and theoretical challenges. Integrated monitoring for assessing sustainability outcomes is a key challenge in SES research (Gurney et al., 2019; Schlüter et al., 2021), and novel approaches to monitor the sustainability of SESs are needed (Rosenberg & Kotschy 2020; Gain, Ashik-Ur-rahman & Vafeidis 2019).

Real-world applications monitoring the progress of SES projects towards meeting their vision and objectives remain scarce (Gurney et al., 2019; Selomane et al., 2019). Factors that may be hindering SES monitoring include (i) relatively few methods to assess the impacts of

research and action in SES (Schlüter et al. 2021; AWARD 2017), (ii) different conceptual frameworks and terminology used in in disciplinary based research areas used to characterize SES including earth observation, evaluation, and social learning, all of which may characterise elements of a SES project, but prevent a common understanding, and (iii) the complexity of the SES predisposes monitoring of the system to 'data overload' issues, which are typical of many monitoring programmes (Lindenmayer and Likens, 2010).

A monitoring approach that has been used to systematically observe a limited set of critical variables needed to characterise change in a system has been termed 'Essential Variables' (EVs). EVs can help extract meaning from a limited set of data that is critical to build an understanding of, and characterise change in, a system of interest. Early applications of the EV concept include Essential Climate Variables (Bojinski et al., 2014a), Essential Ocean Variables (Constable et al., 2016) and Essential Biodiversity Variables (Pereira et al., 2013a). Earlier EVs had a biophysical focus and were predominantly monitored using Earth Observations. Biologically relevant variables have been documented in many EV frameworks, but social variables have been lacking and more difficult to incorporate (Reyers et al., 2017; Wu et al., 2021).

In response to the need for more integrated SES monitoring, Pacheco-Romero and others recently developed a general list and methodological routine to monitor social variables, ecological variables and social-ecological interactions in SES (Pacheco-Romero, Alcaraz-Segura, Vallejos & Cabello 2020; Pacheco-Romero et al. 2022). There is, however, still a gap in SES monitoring that focuses on the essential social-ecological interactions that drive SES dynamics. This gap could be addressed through the methodological development and application of a relational EV approach tailored for SES; a novel approach designed to focus monitoring on social-ecological data, where the social and ecological interact. This approach is based on recent literature arguing that since SES are complex adaptive systems (Preiser et al., 2018) which are constituted relationally, the focus of SES analysis should shift away from distinct, independent objects to the dynamic relationships between social and ecological objects (Reyers et al., 2022). Relationally framing EVs could contribute simultaneously to more efficient and more integrated monitoring.

1.1.2 The need for integrated social-ecological system monitoring for sustainable land management in the South African context.

In the context of South African catchments, where nature and people are closely connected, integrated monitoring approaches for assessing sustainability outcomes are particularly necessary. One of the challenges facing South Africa is sustainable land management of degraded areas within a complex governance environment. Land degradation is a social-ecological phenomenon resulting in "the reduction in the capacity of the land to provide ecosystem goods and services, over a period of time, for its beneficiaries" ((FAO) Food and Agriculture Organization of the United Nations, 2013) (p. 7).

Land degradation is a significant issue in South Africa (Hoffmann et al., 2014; Mani et al., 2021; Palmer and Bennett, 2013). There are a wide range of interrelated environmental and social factors that contribute to South Africa's susceptibility to land degradation, including its generally arid climate and history of climate variability, as well as its unique land tenure pattern as a consequence of its colonial and apartheid past (Meadows and Hoffman, 2002).

An integrated approach to monitoring the drivers of land degradation, and the way that they interact to place pressure on the landscape and communities, is crucial to develop adaptive management measures that will alter current trends towards more desirable and sustainable outcomes (le Roux & van der Waal 2020; Cowie et al. 2018). Addressing the complex issues related to South Africa's sustainable land management challenges requires an approach that acknowledges the complexity and dynamic nature of social-ecological interactions and feedbacks (Cockburn, Palmer, Biggs, and Rosenberg 2018). Taking a social-ecological systems (SES) approach is a useful here because it focusses on the integration of coupled human and natural systems, which reveals new and complex patterns and processes that are not apparent when studied by social or natural scientists separately (Liu et al., 2007).

1.1.3 The need for integrated social-ecological system monitoring for sustainable land management in Tsitsa River Catchment case study.

Between 2014 and 2023, the Tsitsa River Catchment (TRC) was home to an applied research-praxis project, called the 'Tsitsa Project' (TP), in which a transdisciplinary team of action researchers, restoration implementers, and policymakers collaborated to reduce land degradation and improve social-ecological conditions in the catchment (van der Waal et al. 2018). The TP is similar to other complex SES projects in that integrated monitoring (in

relation to the project objectives) was identified as a critical challenge (van der Waal et al. 2018).

The TRC is characterized by steep topography and erodible soils, resulting in the formation of extensive gullies (le Roux & van der Waal, 2020). There are two types of rural landholdings, private and communal. Much of communal land was cleared and tilled for cultivation during Apartheid (Rowntree et al., 2018). The communal land is where most of the catchment's population reside and coincides with more erodible soils (van der Waal et al., 2018). Residents rely, to an extent, on natural resources (Sigwela et al., 2017). Livestock holds cultural and financial value to residents (van der Waal et al., 2018).

The TRC is an appropriate case study for testing the SES and EV approaches because (i) the catchment encapsulates many of the social-ecological issues and challenges faced by other catchments in South Africa (i.e. it is rural, under-developed, faced with land degradation and high levels of poverty, residents rely on natural resources and it is situated within a complex governance environment), (ii) the TP provided the opportunity to collaborate with a broad array of transdisciplinary stakeholders who were already working towards improved SES conditions, (iii) monitoring relations between land, water and communities at the catchment scale can be used by local stakeholders and institutions to inform the management of natural resources facing the catchment (for example via integrated catchment planning).

1.2Rationale

A range of factors converge to form the rationale for this research. Firstly, the need for integrated SES monitoring approaches globally, and in South Africa in particular, are the general scientific backdrop within which this research is positioned. Secondly, this research responds to calls for the development of Essential SES Variables and indicators in the literature, as a specific response to fill gaps in integrated monitoring research and practice (Jørgensen et al. 2013 and Vugteveen, et al. 2015). Thirdly, the problem context, in this case the challenge of sustainable land management of an area with a high degradation potential in a complex governance environment, provides a scientific basis for the case study. The TP's research-praxis orientation results in an applied research agenda with a key question being 'what do we need to measure in order to understand and manage the system?'. This makes the Tsitsa catchment a suitable context to develop and pilot an SES Essential Variable monitoring approach.

The major premise of the study is to iteratively develop and apply a novel essential variable approach, known as Essential Social-Ecological System Variables (ESEVs). I develop a participatory process that draws upon various methods and conceptual approaches to explore how ESEVs can simplify integrated monitoring by tracking the key social-ecological dynamics to enhance our understanding of sustainability in SES projects at the catchment scale, using TRC in South Africa as a case study (Fig. 1). The development of the ESEV approach could be delineated into five main stages: data generated from (**1**) Participatory problem conceptualization, which was analysed to iteratively construct (**2**) Systemic Representations of Problem, which were analysed in the context of wider literature to develop a list of (**3**) Potential Variables which underwent iterative (**4**) Participatory Prioritisation of Variables to produce (**5**) Essential Social-Ecological System Variables for the Tsitsa River Catchment (Fig. 1). The ESEV approach has wider application value as it will answer the question 'How do we decide on the minimum number of variables we need to measure for integrative management of SES landscapes?'.

1.3 Aim

To iteratively develop an essential variable approach to enhance integrated monitoring in support of research, planning, and management for sustainable social-ecological systems at the catchment scale in the Tsitsa catchment, South Africa.

1.4 Objectives

1. To determine the key factors driving land degradation in the Tsitsa River Catchment in the Eastern Cape and analyze how they interact, using a participatory systems analysis approach.
2. To develop and pilot a transdisciplinary social learning process to improve integration and monitoring in social-ecological systems research, drawing on lessons from the Tsitsa River Catchment case study.
3. To develop an essential social-ecological system variable approach to prioritise the types of data inputs needed to inform evidence-based management and policy to enhance sustainability in social-ecological systems landscapes in catchment studies.

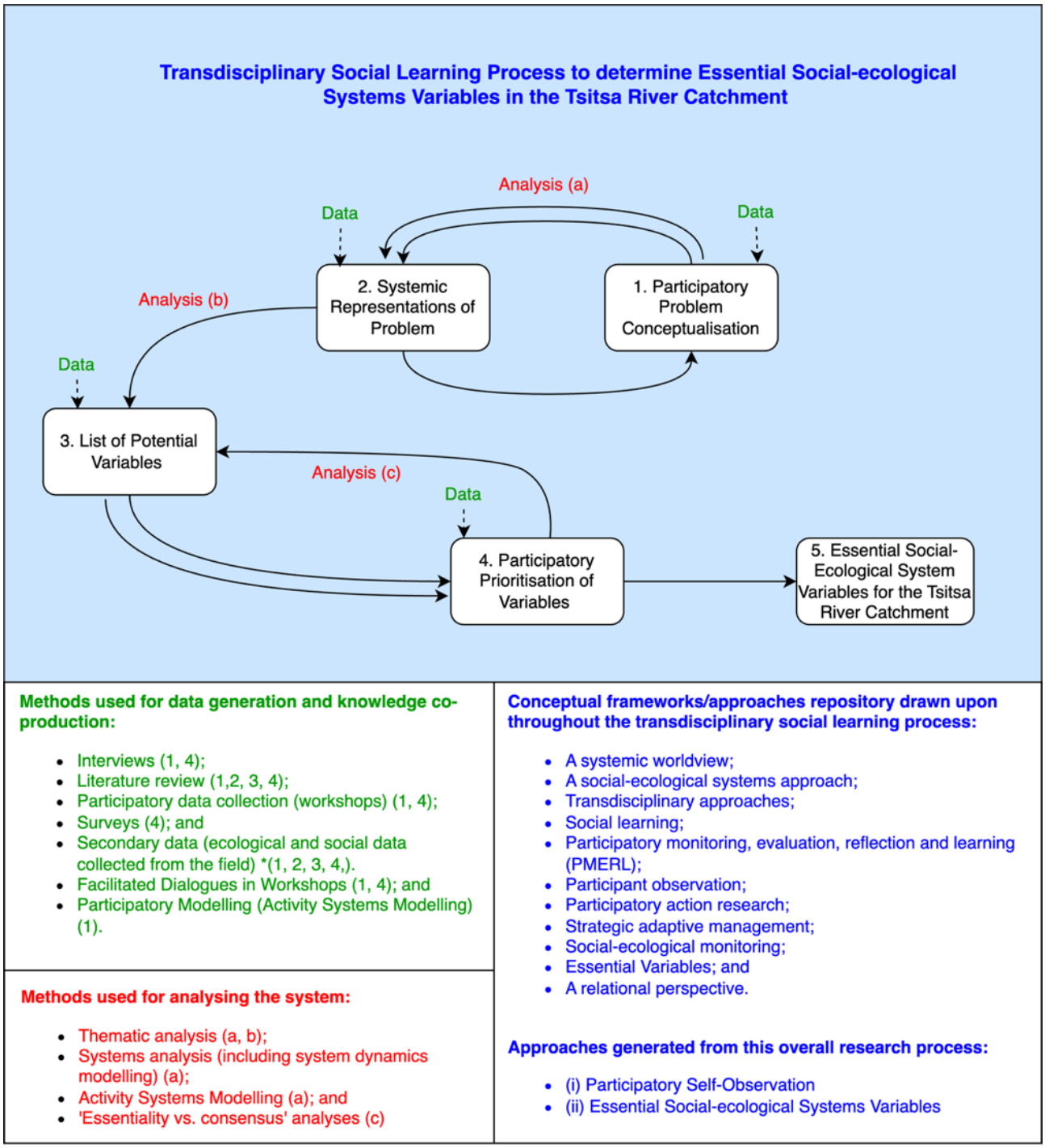


Figure 1. Colour coded overview of the process, methods and concepts underpinning the essential social-ecological system variable approach developed in this research. Double arrows are indicative of steps where feedback was gathered iteratively, with colours indicating the different types of methodological approaches applied at different steps in the sequence of data collection and data analysis. Text below the figures list the methods used. The two novel approaches generated in this research (in blue) can be applied to enhance integrated social-ecological monitoring at a catchment or landscape scale.

1.5 Contribution to Science

This research strives to cover an important gap in SES monitoring (Schlüter et al. 2021; Rosenberg & Kotschy 2020; Selomane et al. 2019), by developing and piloting an innovative transdisciplinary method for monitoring sustainability outcomes and applying it to a specific case study. Drawing upon multiple methods and approaches (Fig. 1), this thesis advances new conceptualisations of integrative, adaptive, and contextually grounded monitoring that explicitly incorporates social and ecological interdependencies and thereby offers a new lens for examining the implications of development interventions.
There are, therefore, two main areas of innovation in this research:

The first area of innovation is the development of a participatory research process, that draws on and combines various broader inter-related principles and approaches which were selected as a conceptual tool repository to help identify and address specific SES research and management challenges. Their underlying philosophies relate and contribute to the goals and principles of SES research in general, and to the TP case study in particular. The participatory process contributes towards bridging disparate research-praxis teams and their understandings of what 'the problem' is, thus providing an avenue for cognitive synthesis of data and perspectives. The system modelling products using data from the process are synthetic representations. This study thus acts in a 'synthesiser' role even while undertaking primary research. It also underscores the need to improve how we navigate tensions among the various contrasting epistemologies and methodologies that together are needed for delivering rigorous sustainability science.

The second area of innovation lies in the development of a novel approach to provide adequate information on scientific processes in a land management and restoration context and within an SES framework at the catchment scale, to inform and enable integrated planning and management. The approach is applicable to various SES landscapes where it can help overcome methodological and theoretical barriers to SES monitoring to inform decision making toward sustainable development.

1.6 Structure of the Thesis

One of the ways of presenting a PhD thesis for examination at the University of the Witwatersrand is via publication. The papers that make up the results chapters of this thesis have been submitted to peer reviewed journals. Two of the papers have been published and one is under review, however under South African Legislation a stand-alone thesis has to be submitted and examined. Since each paper has sections that are reflected in the overall thesis, this makes a certain level of repetition (albeit with using slightly different framing, or emphasis, and to meet different objectives) between chapters unavoidable. The structure of this thesis is broken into the following eight chapters.

Chapter 1 is the overall introduction to the study which describes the need for integrated social-ecological systems monitoring approaches globally and narrows down to a South African and case study context. The chapter presents the aim and objectives of the research.

Chapter 2 presents the key literature and existing knowledge on the main issues (i.e. more on the general problem context of sustainable land management in South Africa and integrated social-ecological system monitoring, before focussing on essential variables and indicators, and the various conceptual framings and approaches drawn upon to develop the ESEV approach advanced in this research), which together form the theoretical basis for the research.

Chapter 3 describes the detailed methodology used to determine the key factors driving land degradation in the Tsitsa River Catchment, to develop a transdisciplinary social learning process to improve integration and monitoring in SES research, and to develop a novel approach to enhance integrated monitoring in SES landscapes.

Chapter 4 is presented as a research article published in 2021 in the journal *Sustainability* under the section 'Social Ecology and Sustainability'. The article presents a participatory conceptualization of the problems facing the TRC, developed in collaboration with researchers, natural resource managers, and residents working to improve sustainability in the catchment. The participatory problem conceptualization phase culminates in the development of systemic models of the drivers of degradation in the catchment, from which key themes for the development of the preliminary list of candidate ESEVs and indicators for monitoring are identified, fostering an integrative approach to address land degradation and enhance

sustainability. The chapter is outlined with a preface that explains the main objective of the paper and how it aligns with objective 1 of the study followed by the article and a postscript.

Chapter 5 addresses research objective 2 and is presented as a research article published in 2022 in the journal *Land* in the collection 'Land Systems in Transition: Challenges, Approaches, and Pathways for a Sustainable Development'. This article details the insights gleaned from the iterative, complexity-sensitive social learning process, which are instrumental in shaping the development of the ESEV approach. The chapter is presented in a similar format to the preceding chapter where a preface is provided followed by the article and a postscript.

Chapter 6 is presented as a research article submitted for publication in 2024 to the journal *Environmental Development* under the special issue 'IIASA and systems analysis in Africa'. The article takes us through the development and application of the Essential Social-Ecological System Variables (ESEVs) approach to monitor progress towards improved SES sustainability in the TRC. This approach underlines the intrinsic link between 'Social' and 'Ecological' aspects of SES. The identified ESEVs, represent a robust framework for integrated monitoring of the TRC. This expanded approach takes a relational and systemic perspective, contributing to integrated social-ecological systems monitoring efforts within the catchment, and beyond. The same format for all articles presented in the thesis is used.

Chapter 7 provides a general discussion that outlines the key aspects of the research, presents the research's novel contribution, and provides recommendations for the application of the research to inform decision making as well as suggestions for future research.

Chapter 8 provides a consolidated alphabetical reference list presenting all references used in all articles in the thesis and all other references used in the thesis.

There is a separate document containing the appendices for the thesis.

CHAPTER 2 – LITERATURE REVIEW

Chapter 1 outlined the main line of argument around the need for integrated social-ecological system monitoring for sustainable land management globally (1.1.1), in the South African context (1.1.2), and in the Tsitsa River Catchment case study in particular (1.1.3). Chapter 2 reviews key literature and existing knowledge on the main issues that inform this research. The chapter begins by expanding on the history and development of integrated SES monitoring, as well as the associated approaches to monitoring, evaluation, and learning (2.1). This is followed by a section on EVs to monitor a limited set of critical variables needed to characterise change in a system (2.2), before presenting a brief review of the definitions and considerations influencing the spatial and temporal scale of social-ecological monitoring (2.3). Given the study context of a degraded South African catchment, a review of land degradation as a pressing social-ecological problem that requires integrated monitoring in South Africa, is then presented (2.4). The final section of the literature review speaks to the need for complexity-based SES research to draw on and combine multiple methods, approaches, and frameworks to advance integrated monitoring (2.5). The section provides a brief introduction to so-called 'wicked' SES problems, before reviewing how a range of inter-related approaches (SES approaches, relational SES approaches, transdisciplinary approaches, social learning in NRM contexts, participatory mapping and modelling, and finally, systems thinking and systems modelling) could promote an integrated understanding of an SES and help identify optimal variables for integrated SES monitoring.

2.1 History and development of integrated social-ecological system monitoring for sustainable land management

2.1.1 Integrated Social-Ecological System Monitoring

The need to better integrate the social and the ecological in SES research is increasingly recognised (Fischer et al., 2015; Guerrero et al., 2018). Although several analytical frameworks, methods, and approaches have been developed to achieve better integration (Biggs et al., 2021; Binder et al., 2013; Fischer et al., 2015; Schlüter et al., 2014), overall integration in social-ecological research is still lacking (Fischer et al., 2015; Lang et al., 2012). Ideally, integration should occur on several levels in the knowledge co-production process from problem conceptualisation, managing the project, collecting and analysing data, synthesising

results, and applying insights (Groß and Stauffacher, 2014; Lang et al., 2012). Integrated monitoring has been highlighted as a particularly challenging dimension of the wider undertaking of improving SES integration (Gurney et al., 2019; Schlüter et al., 2021). In theory and practice, social and ecological monitoring systems are still largely developed and implemented separately. We know that since system behaviour in complex SES comes about as a result of dynamic social-ecological relations which are determined contextually (Preiser et al., 2018), so there needs to be a shift in focus when monitoring in SES, to better capture the intertwined social-ecological interactions.

The ability to learn from, respond to, and adapt to change is a key component of resilient social-ecological systems (Kingsford, Biggs & Pollard 2011; Folke et al. 2010), and relies on effective monitoring (Thompson et al. 2019). A monitoring system includes routine observation of ecological and (or) social phenomena and analysis of these observations, to inform adaptation and mitigation decisions (Pulsifer et al., 2012). The dynamic, largely open-ended nature of SES, featuring complex feedback loops and emergent properties, requires integrated monitoring to inform real-time learning and adaptive management (Kingsford et al., 2011; Kingsford and Biggs, 2012).

SES projects' objectives are often an outcome of complex interrelated SES dynamics, necessitating an integrated SES approach to monitoring. It is recognised that issues such as natural resource and environmental issues occur at the social-ecological intersections of complex SESs (Fikret. Berkes et al., 2003). Despite this recognition, conventional approaches to environmental monitoring and management continue to follow disciplinary lines (Virapongse et al., 2016) and real-world applications of integrated monitoring of the progress of SES projects towards meeting their vision and objectives remain scarce (Gurney et al., 2019; Selomane et al., 2019). Multiple factors that may be hindering SES monitoring include (i) relatively few methods to assess the impacts of research and action in SES (AWARD, 2017; Schlüter et al., 2021) (ii) different conceptual frameworks and terminology used in different fields, including earth observation, evaluation, and social learning, all of which may characterise elements of a SES project, but prevent a common understanding, and (iii) the complexity of the SES predisposes monitoring of the system to 'data overload' issues, which are typical of many monitoring programmes (Lindenmayer and Likens, 2010).

There has been an increase in the development and application of SES monitoring focussed on ecosystem services (Balvanera et al., 2022; Firkowski et al., 2021; Kim et al., 2023). Ecosystems services represent a nexus point, inextricably connecting humans and their environment (Biggs et al., 2004; IPBES, 2019), which supports integrated monitoring.

Integrated monitoring must, however, go beyond (the 'low hanging fruit' of) ecosystem services and include other data that speak to the key social-ecological features, processes and interactions driving SES dynamics over time and space (Reyers et al., 2017).

Research to advance integrated SES monitoring has recently been focussed on SES-based environmental management approaches (Virapongse et al., 2016) , incorporating insights from SES research into monitoring (Selomane et al., 2019), social-ecological monitoring driven by community and indigenous practices (Thompson et al., 2020, 2019), connecting sustainable development goals to land degradation monitoring (Zhao et al., 2023) and developing lists of key variables and indicators for monitoring SES (Pacheco-Romero et al., 2022, 2020)

2.1.2. Monitoring, Evaluation and Learning

The dynamic, interconnected nature of SES, featuring complex feedback loops and emergent properties, requires monitoring that will enable real-time learning to inform adaptive management (Kingsford et al., 2011; Kingsford and Biggs, 2012). 'Monitoring & Evaluation' (M&E) should play a critical role in enriching the learning process (Morris and Lawrence, 2010). Although M&E tends to be discussed together as if it refers to a single research activity, refers to two distinct, albeit closely related, sets of data gathering practices. According to Morris and Lawrence (2010), the distinction between monitoring and evaluation is primarily one of analytical depth where monitoring may be nothing more than a simple recording of activities and results against plans and objectives, but evaluation probes deeper to explain why a particular outcome has occurred or failed to occur enabling the incorporation of lessons into management decision-making.

While M&E is widely recognised as being important or even essential for restoration and development initiatives, it is often implemented in ways that do not support learning, reflection and strategic adaptive management (Bornstein, 2006; Kachur et al., 2016; Mueller-Hirth, 2012). M&E systems are often developed at the start of a project and then simply "implemented" over time. This does not take into account the inevitable changes in context and learning that occur over time. By contrast, a complex M&E system requires a continuous process to test, innovate, experiment and adapt rather than rigidly follow a pre-defined plan (Simister, 2019). It is standard practice to report almost exclusively against quantitative indicators. This enables the aggregation of data on national, regional or global scales. However, when M&E is exclusively about progress against quantitative indicators, the likelihood of

learning is greatly reduced (Wals 2014). Such reports are likely to omit unexpected outcomes including failures and mistakes, whereas reflecting on such disruptions, dissonances and contradictions is vital for learning (Wals 2014).

Recognising these limitations, the field has developed monitoring, evaluation, and learning (MEL) methods to actively encourage, capture, and respond to shared learning that holds significance for SES research and projects (Schlüter et al., 2021). MEL employs qualitative techniques, informal observations, and collaborative reflection to illuminate the intricate causal processes within individual SESs (AWARD, 2017; Cockburn et al., 2018). The integration of monitoring is closely intertwined with the principles of action-oriented SES research, as it must encompass the social and ecological dimensions, both in the nature of data employed and the questions addressed (Gurney et al., 2019; Selomane et al., 2019). A lack of integrated SES monitoring inhibits our ability to assess the effectiveness of management actions on social, ecological, and social-ecological outcomes; as well as the underlying mechanisms and pathways responsible for these outcomes (Gurney et al., 2019).

The need for a more social-ecological and complex-sensitive approach to MEL led to the development of the Monitoring, Evaluation, Reflection and Learning (MERL) system by the Association for Water and Rural Development in South Africa (AWARD, 2017), which emphasises the role of 'reflection' as a practice that lays a foundation for learning and adaptive management. In complex SESs, the pathways to success need to be worked out during and through action-taking and reflection, in participation with a wide array of stakeholders.

2.2 Essential Variables and Indicators

Building upon the foundational discussions on 'integrated social-ecological monitoring' and 'monitoring, evaluation and learning', this literature review now turns its focus to Essential Variables (EVs) and indicators. One of the key challenges facing integrated monitoring listed in section 2.1.1 is that the complexity of SESs predisposes monitoring of the system to 'data overload' issues where there are large amounts of quantitative and qualitative data being monitored (Lindenmayer & Likens, 2010). In addition to being costly, an overload of data makes the tasks of analysing and integrating the data more difficult. To address these challenges, there is a need to create integrated monitoring strategies that specifically target only essential data (Fukui et al., 2021; Lehmann et al., 2020; Pacheco-Romero et al., 2020; Reyers et al., 2017). One approach to systematically monitor a limited set of critical variables needed to characterise change in a system is Essential Variables (EVs). The following sub-sections

presents literature around the conceptual development and practical applications of EVs and indicators, with a special focus on the evolution of integrated EVs, within the broader framework of social-ecological research and monitoring.

2.2.1 Essential Variables

Determining the set of EVs is, traditionally, an endeavour that aims to capture the key dimensions of a system of interest as a function of three main criteria: feasibility, relevance and cost-efficiency (Bojinski et al., 2014b; Masó et al., 2019). The first criteria, relevance, refers to the variable being effective in addressing the issue. The second criteria, feasibility, refers to the technical ability of observing or deriving the variable at the necessary scale using proven, scientifically understood methods. And finally, cost-efficiency means that generating and archiving data on the variable must be affordable, and the benefits of said data-generation must outweigh the costs.

EVs were first posited for coordinating the monitoring of global climate. The concept was used by the Global Climate Observing System (GCOS) in the 1990s for the development of Essential Climate Variables (ECVs), which have been broadly adopted in science and policy (Bojinski et al., 2014b). The EV concept has subsequently been applied to other areas including oceans (Constable et al., 2016) and biodiversity (Pereira et al., 2013b). The Essential Ocean Variables (EOVs) were defined as variables that have a high feasibility of sustained observation and high impact in responding to state scientific and societal issues, thus extending the target group beyond the scientific community (Hayes et al., 2015). In terms of biodiversity, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) has been developing and seeking consensus on setting up the Essential Biodiversity Variables (EBVs) as the basis of consistently monitoring biodiversity at national or regional scales worldwide (Pereira et al., 2013b).

Earlier EVs had a biophysical focus and were predominantly monitored using Earth Observations. Social variables have been more difficult to incorporate into EV frameworks (Reyers et al., 2017; Wu et al., 2021). However, a recent paradigm shift has underscored the necessity for more integrated Essential Variable Sets (EVS). This shift towards a more holistic approach to social-ecological systems (SES) is prominently featured in literature proposing EVs for the Sustainable Development Goals (SDGs) (Fukui et al., 2021; Kussul et al., 2020; Plag & Jules-Plag, 2020; Reyers et al., 2017). Given the comprehensive nature of the SDGs,

the development of Essential SDG Variables demands an interdisciplinary systems perspective (Reyers et al. 2017). Recommendations have also emerged for EVs relating to global change and the establishment of global boundaries within a Safe Operating Space for Humanity (Plag & Jules-Plag, 2020). Furthermore, recent efforts have been dedicated to the formulation of Integrated EVs for Sustainability (Lehmann et al., 2020a) , Essential Socio-Economic System Variables (Lehmann et al., 2020a), as well as EVs addressing the food-water-energy nexus (Mccallum et al., 2020). These endeavors have extended to Essential Drylands Variables (Wu et al., 2021) and Essential Ecosystem Variables (Balvanera et al., 2022).

The extension in the applications of EVs has been accompanied by propositions of new selection criteria. Criteria proposed to identify essential dryland ecosystem variables include capturing unique system traits, coupling nature and society, and integrating existing observation systems from space to the ground (Wu et al., 2021). Criteria for identifying variables essential to the SDGs include capturing system essence (i.e. key features, processes and interactions critical for describing and projecting the behaviour of SES over time and space), linking to system transformations, capturing key areas where coordination is needed, and being indispensable/foundational and multi- purpose for tracking sustainable development (Reyers et al. 2017).

In addition to the integrated EVs proposed for specific areas (such as SDGs, drylands and ecosystem services), Pacheco-Romero and others recently developed a general list and methodological routine to monitor social variables, ecological variables and social-ecological interactions in SES (Pacheco-Romero, Alcaraz-Segura, Vallejos & Cabello 2020; Pacheco-Romero et al. 2022). Similar to many recent endeavours in the field of integrated EVs (Fukui et al., 2021; Lehmann et al., 2020a) Pacheco-Romero et al.'s general list of variables for characterizing and monitoring social-ecological systems involves separate analyses of social system variables, ecological system variables and social-ecological key interactions (Fig. 2).

As mentioned in section 1.1.1., there is, however, still a gap in SES monitoring that specifically targets the fundamental interactions driving SES dynamics. This gap could be filled by advancing and applying a relational approach to EVs. This innovative approach directs monitoring toward socio-ecological data, emphasising the interconnectedness of social and ecological elements. The rationale behind this approach stems from recent literature asserting that SES, as complex adaptive systems (Preiser et al., 2018), are inherently relational. Consequently, the focus of SES analysis should shift from discrete, independent entities to the dynamic relationships between social and ecological components (Reyers et al., 2022).

Framing EVs in a relational context has the potential to enhance both the efficiency and integration of monitoring processes.

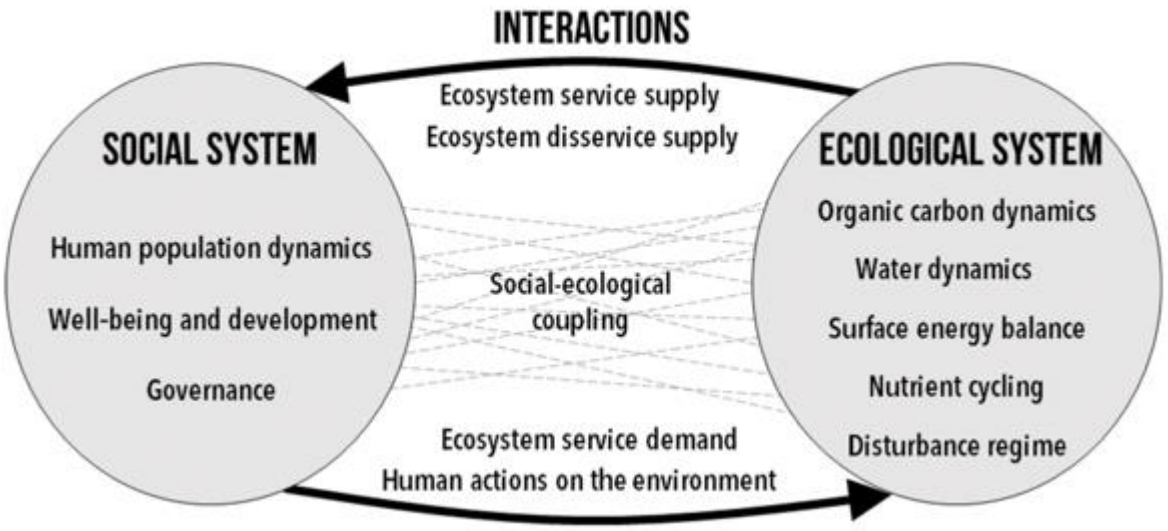


Figure 2. Conceptual framework to guide the characterization and monitoring of social-ecological systems (SESs), structured in three components namely the social system, the ecological system, and interactions between them (by Pacheco-Romero et al. 2020, modified from Resilience Alliance 2007).

2.2.2 Indicators

The primary level of an observation system consists of observations, defined here as 'directly' observed variables that can be collected by instruments, either *in situ* or remotely, or by human observers. Observations occur at a particular resolution in time and space, and should be as precise and accurate as possible. By positioning EV as the layer between observations and indicators, the observation system becomes more streamlined and defensible because the attention is focused on the minimum set of critical variables (that are clearly defined, quantitative and repeatable) needed to characterize the system under observation (Reyers et al. 2017). The next layer of the observation system is made up of indicators, which are usually statistical proxies applied to primary observation variables (Scholes and Kruger, 2011). Indicators are designed to be a reliable and interpretable tool to assess changes in some important aspect of the system under observation. Preferred indicators are the ones most closely linked to the actual observations of concern (Scholes and Kruger, 2011).

EVs are thus represented by indicators (Proença et al., 2017). For each EV more than one related indicator may be identified (Wu et al., 2021). Indicators should have certain

desirable properties. The Convention on Biological Diversity developed a set of desirable criteria for indicators of biodiversity. Summarised by Scholes & Biggs 2005 (p.45), they "should be scientifically sound, be sensitive to changes at policy-relevant spatial and temporal scales, allow for comparison with a baseline situation and policy target, be useable in models of future projections, and be amenable to aggregation and disaggregation at ecosystem, national and international levels. It should also be simple and easily understood, broadly accepted and measurable with sufficient accuracy at affordable cost." The integrative demands of the SES approach have led to calls for the development of social-ecological indicators to help identify and link the states and processes of ecological, social and economic subsystems (Jorgensen et al., 2013) and to balance different stakeholder objectives over the long-term (Vugteveen et al., 2015).

2.3 Spatial and Temporal Scale of Monitoring

The spatial and temporal scale of an observation system are considerations that inform the selection of indicators and variables for monitoring. Ecological structure and dynamics are primarily regulated by a small set of abiotic and biotic processes (including human activities) that operate across scales in time and space (Holling, 1992). Scale is thus an important consideration in collecting data about ecosystem processes and drivers. Peterson and others (Peterson, Allen & Holling 1998) (p. 11) define a scale as "a range of spatial and temporal frequencies" below which faster and smaller frequencies are considered as noise, and the above which slower and larger frequencies are considered background.

Cash and others take a more social-ecological approach and recommend that studies focussing on human-environment interactions should consider jurisdictional scales (defined as clearly bounded and organised political administrative units, e.g., towns, counties, states or provinces, and nations) as well as the scales at which relevant institutions operate (Cash et al. 2006). Complex SESs operate across a range of scales, and understanding is needed across these scales as they impact dynamics of interest at a given scale (Resilience Alliance 2007). The scales focused on in a study will determine to some degree what one learns about the problem (Resilience Alliance 2007). Selecting focal scales for SESs is challenging because in ecology there is a general relationship between spatial and temporal scales where small things generally change quickly and large things change slowly, this time and space relationship may not be true for social factors (Resilience Alliance 2010).

It is important that spatial and temporal scales of relevant processes, as well as project targets and timelines inform the selection of monitoring variables. In the case of integrated SES monitoring, it is also important to consider scales across social and ecological aspects of SES. Virapongse and others (2016) have called for the development of monitoring standards which consider scales across disciplines, to improve coupling between different disciplinary monitoring efforts.

The fact that EVs have usually been applied at the global or regional scale may be a consequence of the predominant tools to monitor EVs historically being global earth observation based (Lehmann, Masò, Nativi & Giuliani 2020a; Lehmann, Nativi, et al. 2020b; Mccallum et al. 2020; Proença et al. 2017; Constable et al. 2016). The EV concept could, however, be helpful to address SES monitoring challenges at smaller scales, such as that of the catchment.

Catchment scale monitoring is often used in relation to integrated water resource management (Katusiime & Schütt 2020; Savenije 2002). The catchment (or sub-catchment, for example quaternary catchments are hydrological delineations of sub-catchments) may be a useful spatial scale in relation to monitoring natural resource management using a wider SES approach because it. At this scale the focus is on how processes between land, water and communities drive the dynamics of a catchment. At the catchment scale or sub-catchment scale, the majority of the data to characterize the system would likely need to be collected at a spatial scale of 10-100kms and a decadal-to-century temporal scale.

2.4 Context: Using Essential Variables and Indicators to monitor Sustainable Land Management in degraded areas in South Africa

The appropriate scale, techniques and variables for monitoring are dependent on the context. Pulver et al. (2018) define context as the setting for the SES under study. Context is often beyond the control of researchers and practitioners who facilitate collaborative processes (Djenontin and Meadows 2018 in Cockburn et al 2020c). Context cannot be ignored because it is "not a passive backdrop to a system but an active agent in itself that enables or inhibits systemic agency" (Preiser 2019) (p.5). Every outcome, whether positive or negative, arises from a combination of the enabling context and a cooperative process or intervention that influences the context through different mechanisms (Cockburn et al. 2020c). The prospect exists to employ essential variables and indicators in the integrated monitoring of social-

ecological systems within the context of sustainable land management in degraded areas in South Africa.

2.4.1 Land degradation as a pressing social-ecological problem in South Africa

Land degradation has been highlighted by various South African studies as a pressing concern in South Africa (Mani et al. 2021; Hoffmann et al. 2014; Palmer & Bennett 2013). Elevated levels of land degradation in South Africa are usually the result of a complex interplay between biophysical and socio-economic factors prevalent in rural landscapes across the country (Hoffman & Todd 2000). These factors include the predominantly arid climate, a history of climate variability, and a distinctive land tenure system resulting from the colonial and apartheid history, which led to overcrowding in areas particularly susceptible to land degradation (Meadows & Hoffman 2002). Woody encroachment is a major contributor to land degradation in the rangelands of South Africa (Mani et al. 2021). The many decades of Apartheid segregation policies in South Africa, including the demarcation of 'homelands' designed for specific ethnic groups, continues to influence the country's spatial, social and economic trends (Nel & Binns 2000). Colonial and apartheid policies that dictated where people could live, work, and receive an education further entrenched poverty and disempowerment within the former homelands. These policies limited households' capacity to develop alternative livelihood strategies (Rowntree et al. 2018). The homelands, usually managed under communal land tenure systems, were significantly under-resourced compared with agricultural land managed under a commercial system (Meadows & Hoffman 2002).

Land degradation has a detrimental impact on the livelihoods of the rural communities (Sigwela et al. 2017). It not only hampers the provision of essential ecosystem services but also affects the ability of rural communities to meet their physiological, psychological, and social needs. Land degradation decreases the provision of ecosystem services that are crucial to enable rural communities to fulfill their (physiological, psychological, and social) needs (Dominati et al. 2010). Although land degradation across the country shares some common drivers, each case possesses its own unique history rooted in its specific social-ecological context. For sustainable and effective management, it is crucial to consider context-specific drivers of degradation. Case studies are instrumental in this regard as they enable researchers to gather both quantitative and qualitative data that are essential for understanding context-specific causality (Bodin et al. 2019). More on the social-ecological context of the TRC and TP case study are provided in Chapter 3 (sections 3.1., 3.2 and 3.3).

2.4.2 Frameworks for Assessing Ecosystem Health

Numerous frameworks have been developed to investigate the interplay between society and the environment, as well as the resulting outcomes, in terms of ecosystem health. These ecological health assessment frameworks have followed two main approaches.

The first approach is rooted in concepts from stress ecology, ecological risk assessments, and ecological indicators (Harwell et al. 2019; Doren, Trexler, Gottlieb & Harwell 2009; Holling 1973). It centers around the examination of causal relationships between environmental stressors, whether natural or anthropogenic, and their effect on ecosystems and their components (U.S. Environmental Protection Agency 1998; Canadian Council of Ministers of the Environment 1996).

The second approach is focussed on environmental management and is based on the Pressure-State-Response (PSR) framework and its derivative, the Driver-Pressure-State-Impact-Response (DPSIR) framework (European Environment Agency 1999). The DPSIR framework, originally developed as part of the European Environment Agency Program, has been adopted as an analytical framework by the United Nations Environmental Program and has found application in various environmental studies across Europe (Masó et al. 2019; UNEP 2007; European Environment Agency 1999). What sets DPSIR apart is its recognition of humans as integral elements within the system. It accounts for human contributions towards the generation of pressures, the assessment of impacts, and the implementation of responses (Zaldívar et al. 2008). However, it's worth noting that DPSIR has been critiqued for its implicit assumption of a baseline or 'natural state' for an ecosystem, with impacts viewed as deviations from this state (Harwell et al. 2019). In this framework, human interactions are primarily seen as adverse, with little acknowledgment of their positive contributions (Kelble et al. 2013).

A derivative of the DPSIR framework, known as the Drivers-Pressure-Stressors-Condition-Responses ($DPSCR_4$) framework, addresses this by replacing 'Impact' with 'Condition,' focusing on describing the environment's state in terms of ecological health, ecosystem services, and human well-being. It identifies four types of responses: reducing stressor sources, remediating existing stressors, engaging in ecological restoration, and facilitating ecological recovery (Harwell et al. 2019).

The Land Degradation Neutrality (LDN) framework is rooted in the Drivers-Pressure-State-Impact-Response (DPSIR) framework, but its primary objective is to counterbalance the expected loss of productive land with the recovery of degraded areas. The framework takes a

multi-pronged approach, that aims primarily to avoid and reduce new degradation of land, and then to reverse existing land degradation (Avoid >Reduce > Reverse). This hierarchy, grounded in the principle that prevention is better than cure, articulates the priorities in planning LDN interventions (Cowie et al. 2018).

What sets the LDN target apart from earlier land degradation mitigation efforts is its explicit commitment to neutrality, as measured against an established baseline, as the minimum goal. Neutrality, in this context, signifies that there should be no net loss of land-based natural capital between the initial time (time zero) and the target date (set at 2030 in the context of the Sustainable Development Goals). The framework prescribes the use of three global (biophysical) indicators, which serve as proxies for ecosystem services: land cover and land cover change (impacting water regulation and more), land productivity or Net Primary Productivity (NPP) (related to food supply), and carbon stocks or Soil Organic Carbon (SOC) (associated with nutrient cycling). These indicators are used to monitor land degradation, with the possibility of incorporating additional or complementary indicators (Orr et al. 2017).

Several characteristics make LDN suitable for application in this research and case study:

- it has been posited in relation to DPSIR and can easily be tailored to $DPSCR_4$;
- it has an explicit SES focus;
- it is intended to be implemented at local scales; and
- the mechanism for achieving the LDN vision is through participatory integrated land use planning which is the approach the TP uses.

To effectively address South Africa's sustainable land management challenges, it's imperative to recognise the intricate and dynamic interactions between human activities and ecosystems, as highlighted by Cockburn, Palmer, Biggs, and Rosenberg in 2018 (Cockburn et al. 2018). This complexity underscores the need for an integrated approach that monitors the various drivers of land degradation and how they collectively exert pressure on landscapes and communities. Such an approach is vital for crafting adaptive management strategies capable of redirecting current trends toward more favourable and sustainable outcomes (le Roux & van der Waal 2020; Cowie et al. 2018). In the context of this study's problem conceptualization phase, the guiding framework is a composite model that embeds Land Degradation Neutrality (LDN) within the Drivers-Pressure-Stressors-Condition-Responses ($DPSCR_4$) framework, presented as a systems model. This approach draws from systems analysis principles, (as depicted in Fig. 2 by Itzkin et al. in 2021 in Chapter 4).

2.5 Combining multiple methods, approaches and frameworks to advance integrated monitoring

Given the limited extent to which singular methods can be used to comprehensively understand SES dynamics (Preiser et al. 2018; Poteete, Janssen & Ostrom 2010), research initiatives and processes of co-producing knowledge frequently necessitate the utilization of multiple methods, approaches and frameworks to fulfil their objectives (Murray, D'Anna & MacDonald 2016). Multiple methods are, thus, often used in combination or built on one another to achieve a particular purpose in SES research (Biggs et al. 2021). Multi-method research refers to the use of more than one method to understand given phenomena (Anguera, Blanco-Villaseñor, Losada, Sánchez-Algarra & Onwuegbuzie 2018). Using multiple methods in combination can also be used to fulfil different objectives such as to increase participant engagement, to improve understanding of different aspects of the system, or to improve understanding of the same aspect from different perspectives (Biggs et al. 2021).

A review of potentially relevant literature is needed to inform the selection of specific methods, approaches and frameworks that could be used in combination to promote an integrated understanding of an SES and to identify optimal variables for integrated SES monitoring. The following sub-sections provide detailed backgrounds on a number of inter-related and overlapping approaches elucidating the rationale for their incorporation. Sub-section 2.5.1 provides a brief overview of wicked SES problems, before reviewing the literature on SES approaches in general (2.5.2), and a relational SES approach in particular (2.5.3). This is followed by a review of transdisciplinary approaches in the context of wicked SES problems (2.5.4). A synthesis of literature on the role of social learning in natural resource management contexts is then presented (2.5.5), followed by sections on participatory mapping and modelling (2.5.6), and systems thinking and modelling (2.5.7).

2.5.1 Wicked social-ecological system problems

The concept of "wicked problems" was introduced by Rittel and Webber (1973). Wicked problems, often associated with the complexity of SES, defy conventional problem-solving approaches due to their complex and interconnected nature (Davies, Fisher, Dickson, Thrush & Le Heron 2015). SES problems resist straightforward articulation and lack definitive

solutions, as they involve numerous interdependent factors (Herrero-Jáuregui et al. 2018). Addressing wicked problems demands a departure from traditional problem-solving techniques because standard methods fall short when confronted with the complex causality and the need for a nuanced understanding of the people involved. To navigate these challenges, approaches that delve deeper into the intricacies of SES dynamics are necessary (Klein 2014).

2.5.2 Social-ecological systems approaches

Overcoming wicked SES challenges requires an integrated social-ecological approach that acknowledges the inextricable links between people and nature (Liu et al. 2007). Over the past two decades, the transdisciplinary field of sustainability science has provided a space in which to generate approaches that transcend modernist paradigms by conceiving of humans and nature as interconnected within complex, hybrid systems (West, Haider, Stålhammar & Woroniecki 2020). This has included the use of complex coupled systems perspectives, including social-ecological, socioecological, human-environment, and coupled human and natural systems (de Vries 2013; Kates 2010; Kates et al. 2001).

SES research is an interdisciplinary and transdisciplinary domain (see 2.5.4 for more on transdisciplinary approaches) in which an integrated understanding of the social and ecological aspects of environmental issues is seen as essential to address complex sustainability challenges (Schlüter et al. 2021; Guerrero et al. 2018; Brandt et al. 2013; Ostrom 2007). The growing utility of an SES approach is demonstrated by a threefold increase in the number of SES research publications between 2010 and 2015 (Guerrero et al. 2018). As a relatively new and fast-growing field, the development of a handbook synthesising methods for SES was recently published (Biggs et al. 2021), and the development of methods for SES research is ongoing.

The conceptual foundation of SES research is that SES are complex adaptive systems (Preiser et al. 2018, 2021; Berkes, Colding & Folke 2003a). Acknowledging the complex and adaptive nature of living systems introduces a mind shift in how we understand the nature of the world, and what tools and methods we can use to study and understand SES (Preiser et al. 2021). SES research proposes a more integrated approach for studying and engaging with the intertwined nature of social-ecological relations. SES approaches aim to unveil intricate patterns and processes that might otherwise remain hidden when studying these systems separately, offering a comprehensive understanding of the intricate dynamics at play. However, there are growing concerns among sustainability researchers that complex systems perspectives

remain constrained by underlying paradigmatic assumptions that implicitly perpetuate a fundamental separation between humans and nature (West et al. 2020; Sala & Torchio 2019; Hukkinen 2014; Raymond et al. 2013). Despite emphasis on interconnectedness in social-ecological systems (SES) perspectives, these approaches often maintain the distinct categorization of 'social' and 'ecological,' reinforcing the idea that these are fundamentally separate entities (West et al. 2020).

2.5.3 A relational social-ecological systems approach

Relationality is a key feature of SES (Cockburn, Rosenberg, et al. 2020; Preiser et al. 2018). This means that SESs are inherently formed through numerous, dynamic connections or interrelations that bind the elements of a system together. Simply put, the structure and function of SESs are significantly influenced by the intricate network of relationships within each system. While the significance of individual elements is acknowledged, it emphasises that the system's dynamics arise from the interplay of both the elements and the relationships among them (Preiser 2019). It has been argued that a way to increase interconnectivity and better understand SESs is, therefore, to shift SES analysis away from distinct, independent objects to the dynamic relationships between social and ecological objects (Reyers et al. 2022). A coevolutionary approach depicting the social and environmental in relation to one another and in constant interplay helps redefine development processes as dynamically interdependent (Haider, Schlüter, Folke & Reyers 2021). This conceptualization shifts from a perspective that focuses on the distinct parts of a system, to a relational/interactional perspective where the dynamic relations between system components are seen as the drivers of emergent patterns and behaviours (Reyers et al. 2022; Garcia, Hertz & Schlüter 2020; West et al. 2020). A relational SES perspective, thus, places emphasis on the integration of interconnected human-natural systems. West and others (2020) suggest that relational approaches can contribute to more holistic accounts of human-nature connectedness; more situated and diverse knowledges for decision-making; and new domains and methods of intervention that nurture relationships in place and practice.

2.5.4 Transdisciplinary approaches to address wicked social-ecological system problems

The inherent diversity in perspectives when addressing wicked problems, such as SES problems, means that there is never just one explanation due to the varying viewpoints of individuals involved (Agramont, Craps, Balderrama & Huysmans 2019). Incorporating diverse perspectives requires participatory and collaborative approaches to research. Traversing the terrain of collaborative research approaches, multidisciplinarity, interdisciplinarity, and transdisciplinarity represent distinct strategies in integrating knowledge across diverse domains. Multidisciplinarity involves bringing together insights and methodologies from different disciplines while maintaining their individual boundaries (Klein 2010). Interdisciplinarity goes a step further by integrating and synthesising contributions from multiple disciplines to create a more holistic understanding, breaking down some of the barriers between them (Klein 2010). Transdisciplinarity transcends interdisciplinarity by fostering (interdisciplinary) collaboration together with the active input of stakeholders from outside academia, to understand and address shared problems collaboratively (Brandt et al. 2013). A broad definition of transdisciplinarity applied by Lang et al. (2012) reads as follows: "Transdisciplinarity is a reflexive, integrative, method-driven scientific principle aiming at the solution or transition of societal problems and concurrently of related scientific problems by differentiating and integrating knowledge from various scientific and societal bodies of knowledge." (p. 26-27). Navigating SESs toward a more sustainable trajectory is an inherently transdisciplinary problem, necessitating collaboration among diverse scientific domains and society as a whole. By bringing together diverse forms of knowledge to better understand and tackle complex sustainability challenges, stakeholders can learn together through iterative cycles of questioning and knowledge co-production (Cundill, Roux & Parker 2015).

Although transdisciplinary research is necessary, it faces a number of challenges. A review of 236 articles between 1996 and 2011 resulted in the identification of 5 key challenges in transdisciplinary projects: coherent framing; method integration; research process and knowledge production; practitioner involvement; and generating impact (Brandt et al. 2013).

The processes of knowledge co-production (Nel et al. 2016) and knowledge integration (Godemann 2008) are key to the added value of transdisciplinary research. In this context, transdisciplinarity is a research approach involving multiple scientific disciplines (interdisciplinarity) centred around shared problems, with active engagement from practitioners and other stakeholders outside academia (Brandt et al. 2013). Interdisciplinarity

focuses mainly on knowledge integration across academic disciplines, whereas transdisciplinarity goes beyond to integrate societal knowledge (Cundill et al. 2015; Hirsch Hadorn, Pohl & Bammer 2010). The participation of societal stakeholders allows transdisciplinary research to provide constructive contributions from diverse knowledge communities, towards the integration of insights from the perspectives of various groups. Transdisciplinary research is thus a participatory approach that aims to fulfil requirements for knowledge co-production in SES (Gurney et al. 2019). Collaborative partnerships between researchers and non-academic stakeholders also offer the potential to enhance the legitimacy, ownership, and accountability associated with both the problem and the proposed solutions (Lang et al. 2012).

Transdisciplinary research fits within the broad category of participatory and collaborative research approaches. There are different methods and approaches for facilitating interdisciplinary and transdisciplinary processes. In 2012, Lang and others drew on previous work to synthesise an overall transdisciplinary research approach which includes three phases: (a) collaborative problem framing, (b) conducting participatory and collaborative research together, and then (c) re-integrating the co-created knowledge outcomes of the process into academic and societal practice (Fig. 3). This approach, which inherently encompasses social learning, has since been adapted and applied in different contexts (for example, Cockburn et al. 2016).

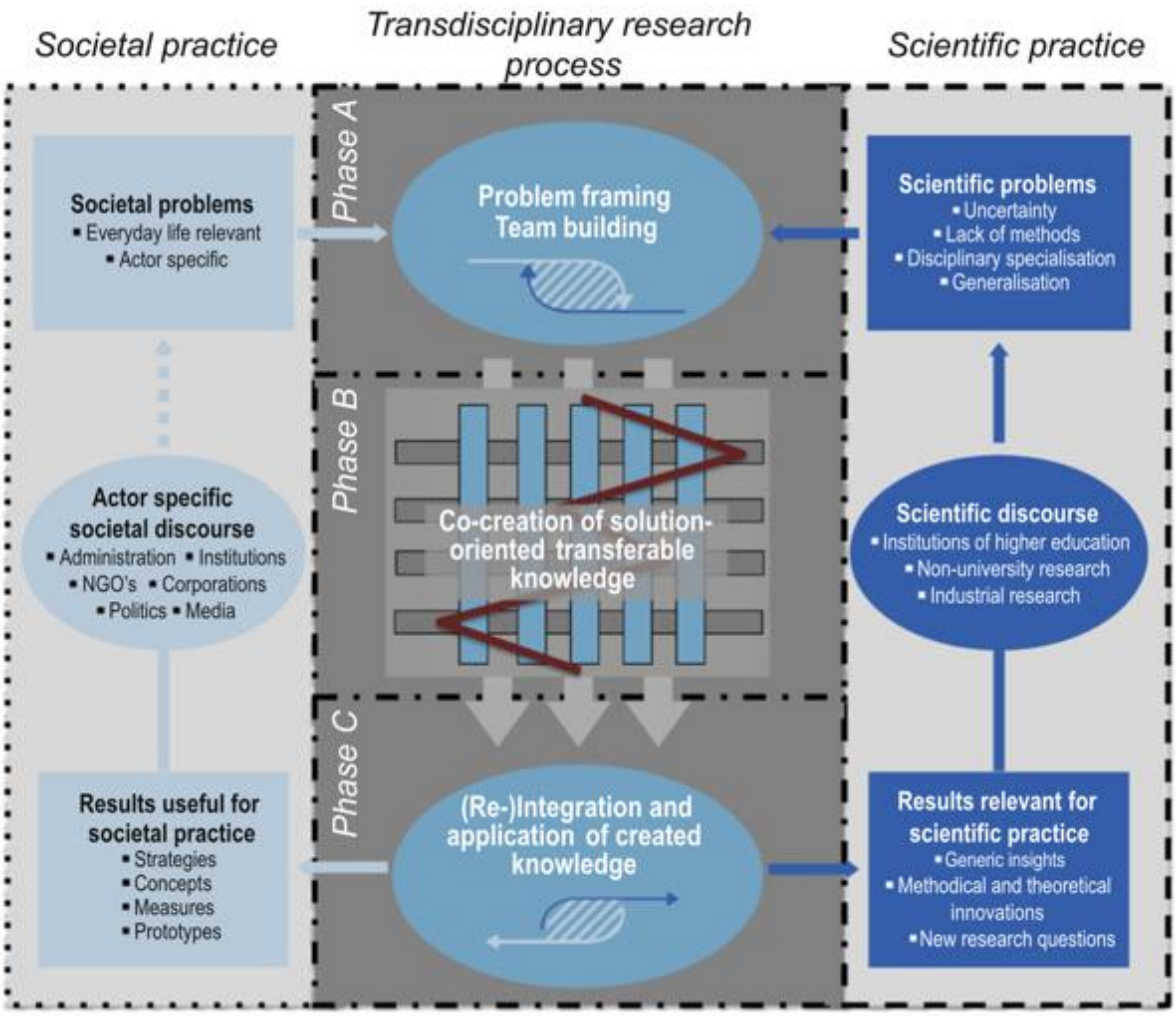


Figure 3. Conceptual model of an ideal–typical transdisciplinary research process (Lang et al. 2012).

2.5.5 Social learning in natural resource management contexts.

Social learning is a crucial element of interdisciplinary and transdisciplinary work in NRM (Nel et al. 2016; Reed et al. 2010). The nature of knowledge as generated in social processes of interaction, learning, work, research, and thus as situated and dependent on the relations between social actors, has long been a subject of investigation within the field of the sociology of knowledge (Bruckmeier & Tovey 2008). Social learning processes are pathways to enable collaboration for NRM to be more flexible and adaptable. A social learning process should: "(1) demonstrate that a change in understanding has taken place in the individuals involved; (2) demonstrate that this change goes beyond the individual and becomes situated within wider social units or communities of practice; and (3) occur through social interactions and processes between actors within a social network" (Reed et al. 2010) (p. 1). Social learning

is inherently participatory and reflexive. It is a relational approach to knowledge generation in complex SES where the nature of knowledge as generated in social processes of interaction, learning, work, research, is dependent on the relations between social actors (Cockburn, Rosenberg, et al. 2020; Cockburn, Schoon, et al. 2020; Preiser et al. 2018). Social learning is widely considered to improve the success of transdisciplinary efforts through the integration of different actors in reflexive, iterative research-praxis (Cheruvelil et al. 2014; Fiore et al. 2010; Stokols, Misra, Moser, Hall & Taylor 2008).

Natural resource management and sustainable development issues are complex, contextual and often contested (Wals 2007). They requires responses that acknowledge the complexities of the situation, and include the diverse values, interests, experiences, and knowledge of people involved, while also affording participants opportunities to deliberate on conflicting perspectives from a basis of information and experience. Social learning theories provide frameworks for facilitating and mediating processes to build collective understandings of ideas, norms, and practices towards sustainability (Wals 2007). Social learning has become a key focus in adaptive approaches to NRM. Adaptive approaches are often advocated to improve our understanding and management of complexity in social-ecological systems (Fabricius & Cundill 2014).

Recognising shared objectives is an important early phase of a social learning process (Lave & Wenger 1991), but it is also important to bear in mind that the objectives may change as the process unfolds, necessitating collaborative learning processes that are reflexive and adaptable to discerning evolving needs and responding to emerging knowledge. Moreover, the precise steps required to attain the stated objectives are not always predictable. Social learning facilitators must therefore be both responsive and guiding, simultaneously, recognising that social learning can lead in unforeseen directions (Fabricius & Cundill 2014). Facilitating social learning for transformative action is about supporting both individual change and systems change, and the ongoing interaction between them (Kwauk & Casey 2021).

Several participatory research methods incorporate social learning features. Social learning is a central feature in MEL, which was previously introduced as an approach for monitoring SESs in Section 2.1.2 (Woodhill 2007). Positioned at the intersection of monitoring and social learning approaches, MEL plays a pivotal role in integrating these aspects. Social learning is also at the foundation of interdisciplinary and transdisciplinary processes discussed in the previous section (2.5.4), as well as participatory mapping and modelling, which are discussed further below.

2.5.6 Participatory mapping and modelling

Participatory mapping and modelling manifest in many forms and go by many names (including cooperative modelling, collaborative modelling, mediated modelling, and group model-building) all of which emphasise the importance of modelling with stakeholders (Henly-Shepard, Gray & Cox 2015). Participatory modelling processes and the resulting models can serve different purposes. They can be used as a social-learning tool to facilitate interdisciplinary or transdisciplinary communication and integration (Henly-Shepard et al. 2015); as a thinking tool to support reflection about different views of processes of interest and their consequences for system behaviour (Schlüter, Müller & Frank 2019); as an analytical tool to explore, explain or predict SES behaviour and outcomes (Edmonds 2017); or as a tool for assessing the effects of policies and interventions (Schlüter et al. 2019b). The process of building the model can be as valuable as the resultant model, as it challenges participants to articulate their assumptions and comprehension of the SES or the focal problem. Ideally, this process unfolds collaboratively, engaging a diverse array of both scientific and non-scientific participants who draw from distinct knowledge systems (Schlüter et al. 2019b). Collaborative model development, particularly with stakeholders, stands out for its capacity to foster the establishment of a shared understanding and learning. Iterative participatory modelling and evaluating change or development in model representations can serve as empirical evidence of social learning (Henly-Shepard et al. 2015).

2.5.6.1 Activity System Analysis

Participatory modelling can also support a form of social learning called expansive learning, which focuses specifically on expanding our knowledge by learning what is not yet there (Engeström 1987) . Activity System Analysis (Engeström 1987, 2001) is an example of a participatory modelling method developed to support expansive learning. Developed within the cultural-historical activity theory (CHAT) school of thought, activity systems analysis provides a conceptual model for participatory system analysis. This model offers facilitators and participants guidance on how to collectively engage with collaborative relations and contradictions within and between people and the tools they use in relation to a shared object (or goal) for a specific context. It also assists in collectively envisioning pathways towards sustainable solutions (Engeström 1987, 2001). The development of agency (capacity and capability) to learn new ideas, develop new tools, and implement new actions is a crucial part of expansive learning (Engeström 1987). An important outcome of expansive learning

processes (such as activity systems analysis) in situations of complex change is thus the development of transformative agency of participants which is a key enabler of sustainability transformations (Lotz-Sisitka, Mukute, Chikunda, Baloi & Pesanayi 2017).

2.5.7 Systems thinking and systems modelling

Tackling wicked or complex problems requires a systemic approach (Burton 2017). Systems thinking has been defined as "a set of synergistic analytic skills used to improve the capability of identifying and understanding systems, predicting their behaviours, and devising modifications to them in order to produce desired effects" (Arnold & Wade 2015) (p. 7). Systems thinking consists of three components elements (variables or characteristics), interconnections (the way these characteristics relate to and/or feed back into each other), and a function or purpose (Meadows 2009). S**ince systems thinking** is the process of understanding how elements of a system influence each other as well as other systems, it can be a well-suited approach for wicked SES problems.

The leverage points perspective, which emerged from complex systems thinking (Meadows 1999) to identify potential points for adaptive management interventions, has recently been rearticulated (Abson et al. 2016) as a distinct framework in sustainability science. Within this framework, human-nature connectedness has been proposed as a crucial research area and 'domain of leverage' for achieving sustainability transformations (Fischer & Riechers 2019).

System dynamics and systems dynamic modelling are, respectively, an approach and a tool for comprehending a system's structure across disciplines by modelling complex social and ecological events, patterns, and processes along with their key feedback loops, using systems thinking principles (Elsawah et al. 2017). The founder of system dynamics, Jay W. Forrester, reasoned that the way in which humans interact with technical and natural systems is contained in their practices (Jay Wright Forrester 1968). The system dynamics modelling approach offers a SES-centred method for exploring these practices and the resultant problems, by focusing on interaction points and feedbacks in social-ecological systems. System dynamics allows for complex social and ecological events, patterns and processes along with their key feedback loops to be modelled and thus better understood, even in systems characterised by some uncertainty (Elsawah et al. 2017). Systems thinking and modelling transcends disciplinary boundaries by taking a systemic view of sustainability issues, which has led to

"fundamental discoveries and sustainability actions that are not possible by using conventional disciplinary, reductionist, and compartmentalized approaches" (Cheruvelil et al. 2014) (p. 963).

One of the most powerful aspects of the system dynamics modelling approach is the breadth of information sources that can be drawn from (Brent, Simelane & Clifford-Holmes 2017). According to Forrester (1980) modellers draw information for their models from three types of databases, namely numerical, written, and mental. (Brent et al. 2017) categorise Forrester's three types of databases in relation to so-called 'hard' sources of information (including physical laws and controlled and uncontrolled experiments), and 'soft' sources of information (including the judgement of experts, and experiential/institutional system knowledge and personal intuition of participating stakeholders). The quantity of content that could potentially be used as model inputs increases from 'hard' to 'soft' databases (Fig. 4).

Participatory systems dynamics is a process that accounts for dynamic connections between social and ecological systems, integrates stakeholder deliberation with scientific analysis, incorporates diverse stakeholder knowledge, increases trust and consensus and improves transdisciplinary collaboration to solve complex problems (Rieder, Larson, 't Sas-Rolfes & Kopainsky 2021; Stave 2010). It also supports learning about the system and the perspectives of other stakeholders (Stave 2010). The level of involvement of participants in different phases of systems model development varies.

Systems Dynamics models are simplified representations of a more complex reality and, like all models, are limited by the data available with which to populate them. They serve as visual tools to communicate and illustrate the causal interrelations among various variables within a system (Luna-Reyes & Andersen 2003). There are different types of systems models. Stock-and-flow diagrams depend on 'hard' quantitative data to generate feedback models, but causal loop diagrams (CLDs) and other types of system diagrams use softer, qualitative data (Luna-Reyes & Andersen 2003). Systems models contribute to hypothesising system behaviour by revealing balancing and reinforcing feedback loops. Balancing feedback loops, also called stabilising loops, counteract any changes imposed on the system, seeking stability. Reinforcing feedback loops, also called runaway loops, enhance whatever direction of change is imposed on it to cause vicious or virtuous cycles (Meadows 2009).

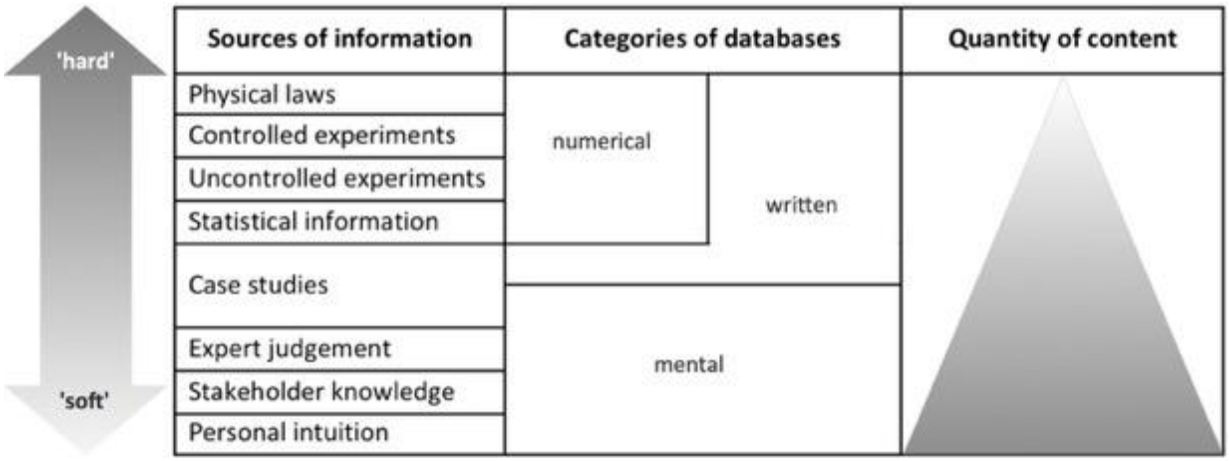


Figure 4. Continuum of information from so-called 'hard' sources through to so-called 'soft' sources. Conceptualised and designed by Jai Clifford-Holmes drawing from the work of Forrester (1980) and Ford (2009), and published in Brent, Simelane and Clifford-Holmes (2017).

2.6 Concluding remark

This chapter serves as a comprehensive exploration of the literature on identifying critical variables for integrated SES monitoring for sustainable land management. It covers the evolution of integrated monitoring methods, Essential Variables, spatial-temporal considerations, and the need for integrated monitoring in addressing the social-ecological challenge of land degradation. Furthermore, the literature review highlights the necessity for complexity-based SES research to integrate diverse methods, approaches, and frameworks, underscoring the holistic understanding required for integrated SES monitoring.

CHAPTER 3 - OVERALL METHODOLOGY

Chapter 3 presents the overall methodology of the study, starting with a description of the study area and case study. This is followed by an overview of the methods and analysis featuring several approaches, concepts and methods introduced in this literature review. Furthermore, the review acts as a foundation to augment the literature which has been used in the individual papers in chapters four, five and six.

3.1 Description of the study area - Tsitsa River Catchment, Eastern Cape Province, South Africa

Situated in the Eastern Cape Province of South Africa, the Tsitsa River Catchment (TRC) is characterised by steep topography, erodible soils, and the presence of extensive gullies (Du Plessis, Van Zijl, Van Tol & Manyevere 2020; Schlegel & Huchzermeyer 2018; Huchzermeyer 2017). The catchment encompasses both communal land, managed by traditional leaders under customary law, and private land (Fig. 5) (Rowntree, Conde-Aller, Fox & Duma 2018).

Historical legacies, shaped by colonial and apartheid policies pre-1994, have had a lasting impact on the social-ecological landscape of communal lands within the catchment. These policies, influencing residency and employment, have contributed to disempowerment, unemployment, poverty, and ongoing degradation (Rowntree et al. 2018). The majority of the catchment's population reside in the communal land, primarily located in the middle and lower parts of the catchment, coinciding with more erodible soils (van der Waal et al. 2018). There is significant out-migration (Hodgson & Fox 2017). Residents still rely, to an extent, on natural resources (Sigwela, Elbakidze, Powell & Angelstam 2017) and livestock remain of cultural and financial value to residents (Rowntree et al. 2018). Grazing management systems in the catchment differ, with a more sustainable rotational grazing model on privately owned land and a less sustainable continuous grazing model on communal land (van der Waal et al. 2018). Land degradation in the catchment is driven by a complex interplay of the contextual ecological and social factors. A synthesis of the key drivers of degradation and how they interact would help to inform efforts towards sustainable land management.

While recognising the importance of context in social-ecological systems (SES) studies, it is evident that many environmental challenges faced by the TRC are not entirely unique but reflect core issues recurring across various cases and contexts (Bodin et al. 2019). The catchment's rural, underdeveloped nature, coupled with land degradation, high poverty

levels, and a complex governance environment, mirrors challenges experienced by other catchments in the developing world (Cockburn, Palmer, Biggs & Rosenberg 2018).

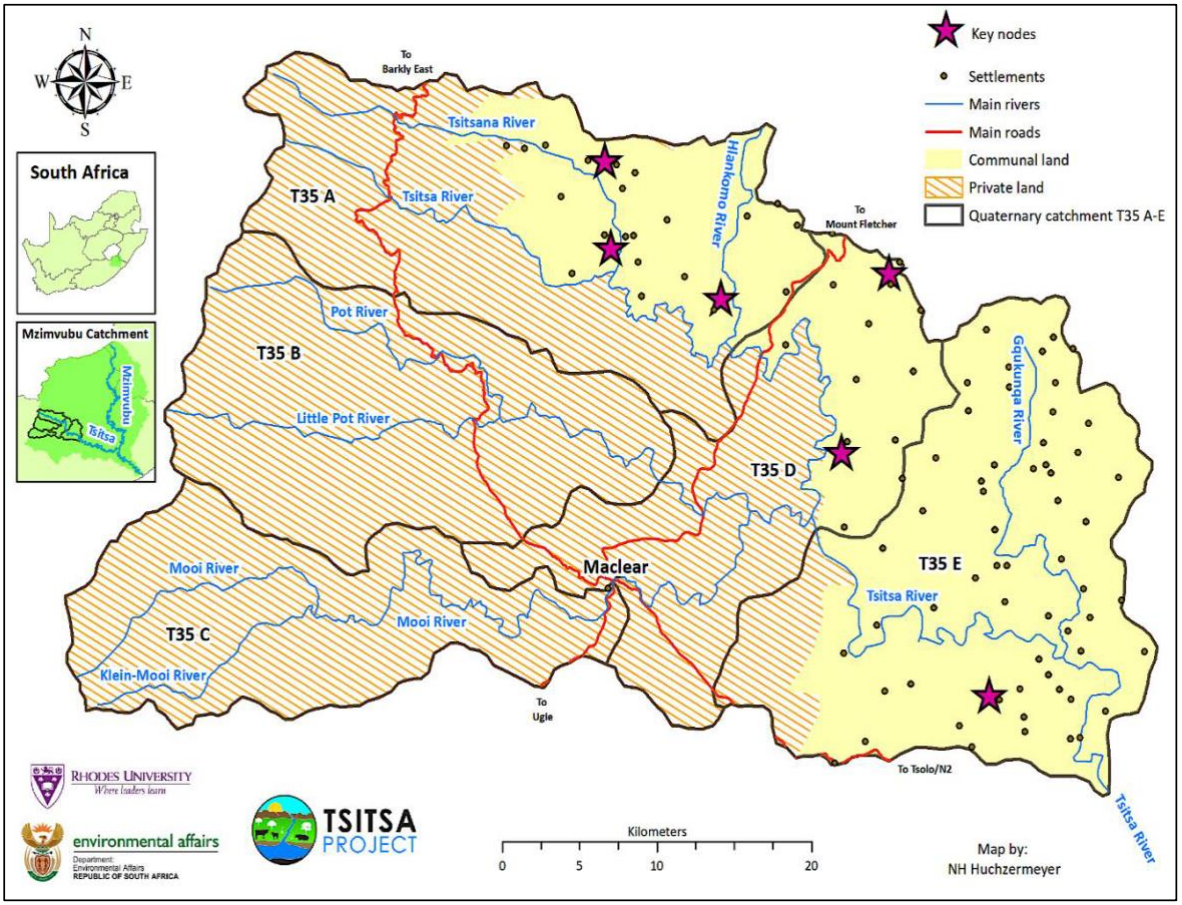


Figure 5. Map of the Tsitsa River Catchment by N.H. Huchzermeyer. The Tsitsa Project focused on the upper catchment, which coincides with the communal land where most of the catchment population resides and where soil erosion and land degradation are most severe.

3.2 The Tsitsa Project Case Study: Enhancing Sustainability in the Tsitsa River Catchment

The Tsitsa River Catchment, served as the backdrop for a transformative social-ecological project known as the Tsitsa Project (TP). Funded by the South African Department of Forestry, Fisheries, and the Environment (DFFE) between 2014 and 2023, the TP brought together interdisciplinary researchers, natural resource managers, and local residents. Their shared goal, as articulated by van der Waal et al. (2018) (p.18), was to "support sustainable livelihoods for local people through integrated landscape management that strives for resilient social-ecological systems and fosters equity in access to ecosystem services." The TP's activities are focussed on the upper catchment, where most of communal land is located. The approach of the Tsitsa Project incorporates five core components that are woven together to

foster sustainable land management. These components include avoided degradation, sustainable land management and rehabilitation; strengthening participatory governance including integrated village-level planning; green economy, rural livelihoods and climate change innovations; local monitoring, evaluation, learning and adapting; capacity and capability development (Tsitsa Project 2021).

Adopting an SES approach to integrated landscape management in developing regions, such as the Tsitsa River Catchment, involves addressing challenges related to eroded governance systems, historical disempowerment of resource users, high poverty rates, and natural resource degradation. The TP emphasised the importance of the two-way link between research and practice, known as praxis, which requires integration (Biggs et al. 2019; Ison 2018).

Within the TP, transdisciplinary collaboration among researchers, natural resource managers, and residents has been instrumental in applying an SES approach (Tsitsa Project 2021). This approach was aimed to support sustainable livelihoods and enhance landscape management, recognising the interdependence of social and ecological sustainability (Herrero-Jáuregui et al. 2018). The project sought to bridge the gap between social and natural sciences, practitioners, and communities, addressing integration and learning challenges that often hindered similar SES research settings (Cockburn, Palmer, Biggs & Rosenberg 2018).

The TP structured its research efforts around six themed Communities of Practice (CoPs) focused on research-praxis themes — 'Sediment and Restoration,' 'Governance,' 'Livelihoods,' 'Fire and Grazing,' 'Knowledge and Learning,' and 'Systems Praxis'. This framework, updated from (Botha, Rosenberg, Biggs, Kotschy & Conde-Aller 2017) in consultation with the Tsitsa Project Manager (personal communication 2022), guided the project's community monitoring initiatives. Community Liaison Officers (CLOs), Citizen Technicians (CTs), and Environmental Monitors (EMs) played crucial roles as conduits of information at the grassroots level. The presence of a Catchment Coordinator further facilitated connections between researchers, community members, monitors, government departments, and other stakeholders.

The TP's unique position as a SES 'praxis project' funded by the DFFE, has provided an experimental space, offering valuable insights not only for its own objectives but also for informing broader processes and projects, making it a good case study to inform other projects interested in using similar approaches.

3.3 Monitoring in the Tsitsa Project

Similar to other complex SES projects, the TP grapples with substantial challenges related to integration and monitoring (Cockburn et al. 2020a). The transdisciplinary approach of the Tsitsa Project necessitates a collective mental model, emphasising the need for integrated sustainability research, management, and governance rooted in the recognition of humans as actors embedded within natural systems (Cockburn et al. 2018). Stakeholders engaged in the project bring diverse disciplinary, community, and practitioner backgrounds. The integration of data and mental models across the transdisciplinary TP stakeholders is central in the TP vision "to support sustainable livelihoods for local people through integrated landscape management that strives for resilient social-ecological systems and which fosters equity in access to ecosystem services" (van der Waal et al. 2018; Fabricious, Biggs & Powell 2016).

The TP places strong emphasis on the importance of learning to promote collaboration amongst the different stakeholders involved and to enhance an adaptive approach within the project activities. In 2017 TP leadership engaged with experts who had experience in designing a complexity-sensitive MEL system for another catchment-based programme implemented by the Association for Water and Rural Development in the Limpopo-Olifants Basin (AWARD (Association for Water and Rural Development) 2017). The experience from implementing and refining AWARD's system informed the participatory monitoring, evaluation, reflection and learning (PMERL) system for the TP which is situated in the TP's Knowledge and Learning CoP (Cockburn et al. 2018, 2020a; Kotschy & Mvulane 2020a,b; Kotschy, Mvulane & Cockburn 2020; Botha et al. 2017).

The PMERL approach places a strong emphasis on participation, reflection and learning, as part of and supported by integrated monitoring and evaluation processes. These design features are linked to the TP's strategic objectives, transdisciplinary and adaptive approach, and its intentions to build agency and innovate (Kotschy, Cockburn, Biggs & Rosenberg 2021). It is also linked to the understanding of restoration programmes as taking place in and through complex SES, where the pathways to success need to be worked out *during and through* action-taking and reflection innovate (Kotschy et al. 2021).

The PMERL team collaborated with other TP CoPs in participatory processes to develop indicator protocols for six biophysical themes (Kotschy & Mvulane 2020b) and seventeen social indicators (Human 2019). This involved deliberations within and between project groups to define objectives and establish strategies for their attainment, essentially creating theories of change at the sub-project level. Work was also in progress to develop indicators related to a 'women's capability index' (Cockburn et al. 2020a) and climate change

indicators were proposed (Rowntree 2020), but not finalized. There is a need for monitoring data that speaks to the integrative (social-ecological) nature of SES (Botha et al. 2017). TP members expressed the need to find ways to further integrate monitoring (Itzkin, Clifford-Holmes, Scholes & Coetzer 2022).

3.4 Justification of the Tsitsa River Catchment and Tsitsa Project as a case study

The selection of the TRC as the study area for this research to develop an EV approach for integrated SES monitoring was based on three main factors. Firstly, many characteristics of the catchment reflect similar challenges encountered by other catchments in the developing world (Cockburn, Palmer, Biggs & Rosenberg 2018) which make the research approach and findings widely applicable in other contexts. Secondly, the TP's SES and PMERL approaches where researchers, natural resource managers, and residents were given an experimental space to collaborate in towards a shared goal of improving social-ecological systems sustainability, provided a unique opportunity for transdisciplinary social learning to address challenges and foster sustainability. The TP's emphasis on SES praxis towards improved natural resource management (NRM) further underscores the integration of research and practice, essential for the development of an essential variable approach. And finally, the identification of integration and monitoring as critical challenges in the TP, which are similarly reflected in wider SES literature, make it an appropriate case study for the topic.

In conclusion, the Tsitsa River Catchment and the Tsitsa Project together offer a rich and relevant study area for this research, providing insights into the complex dynamics of SES and contributing to the development of an integrated essential monitoring approach for achieving sustainability in the South African context and beyond.

3.5 Overview of Methods and Analysis

The specifics of methodology for each of the study's objectives are detailed in chapters 4 (objective 1), 5 (objective 2) & 6 (objective 3) respectively. An overview and summary of the general process are provided in Figure 6 and the text that follows, below.

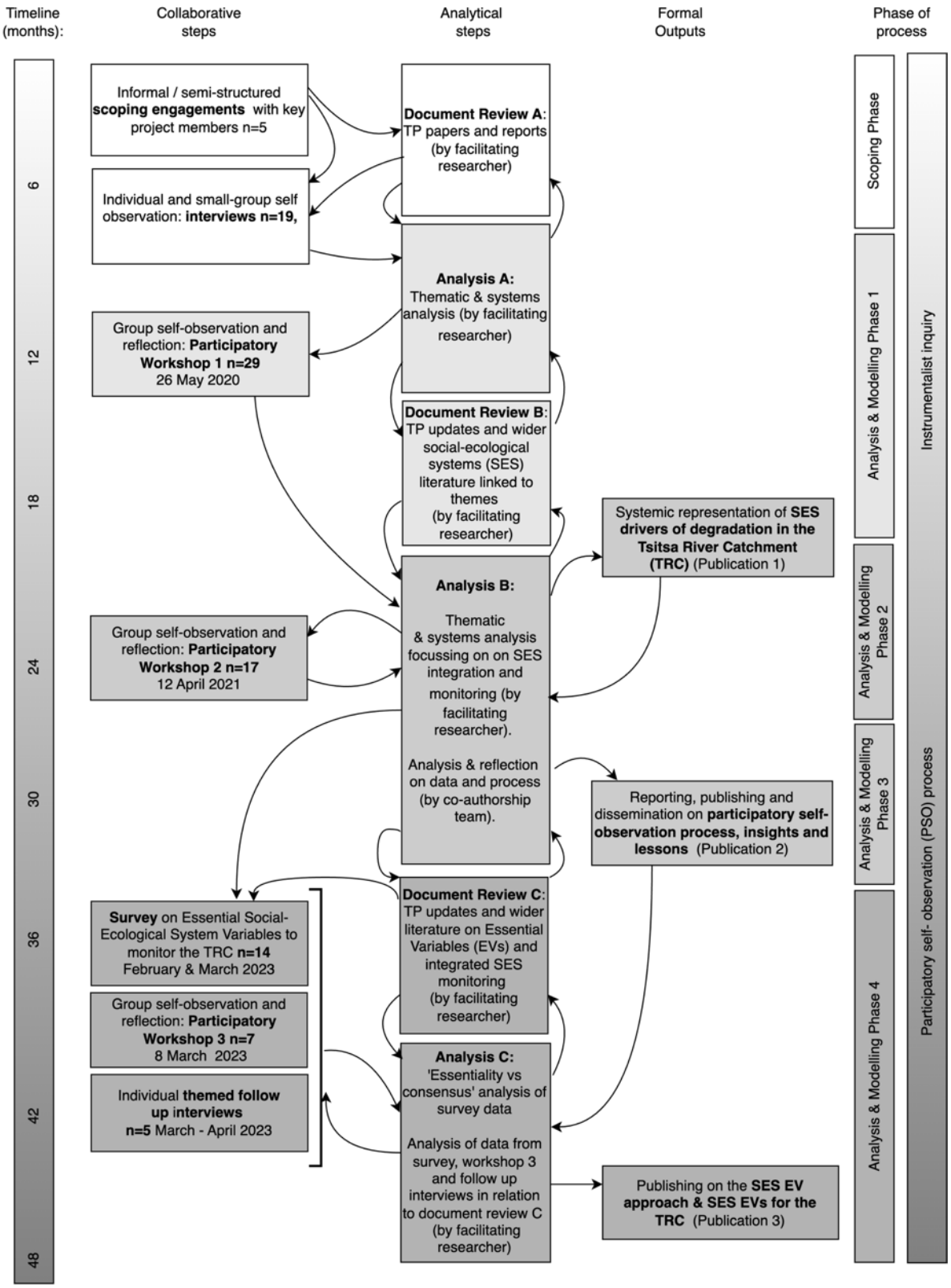


Figure 6. Overview of the research process to improve social-ecological system integration and integrated monitoring in the Tsitsa River Catchment and beyond. The transdisciplinary social learning process, called participatory self-observation, included iterative rounds of collaborative self-observation and reflection by participants, interspersed with rounds of analysis by the facilitating researcher. Relevant parts of this overall process are presented in the methods sections of the publications in chapters 4, 5 & 6.

The study utilized both primary and secondary data, employing an iterative data collection process. Primary data were gathered through scoping and key informant interviews (n=29), participatory workshops (n=3, labelled as 'W1,' 'W2,' & 'W3' with corresponding reports in the appendices), and surveys (n=14). Secondary data were sourced from internal project documents created for DFFE, as well as various types of literature. This literature included:

a) background literature contextualizing the TRC and TP,
b) supporting literature addressing issues akin to the TRC and TP but not exclusively centred on the catchment, and
c) literature discussing the approaches employed in this study.

The research process was undertaken in five main phases, beginning with a scoping phase and followed by four phases of analysis and modelling (Fig. 6).

Scoping Phase

The initial scoping phase was undertaken with various members of the TP research team and achieved an understanding of the key issues from various perspectives (Kingsford & Biggs 2012). The scoping engagements provided a starting point for 'Document Review A' of TP documentation and publications (Fig. 6). The scoping engagements and document review informed the development of interview questions which were used to conduct 19 key informant interviews. The interviews aimed to identify key variables of the system and how they connect, and the level of the interconnectivity of data in the TP as a transdisciplinary endeavour. Interview participants were selected based on their skills and position in the TP, through which they have specialist knowledge of the TP and TRC that is more extensive, detailed, or privileged than the general public, making them expert or key informants (Payne & Payne 2004). Collectively these stakeholders consisted of the heads of the various communities of practice in the project and representatives of the project management team, forming the transdisciplinary research-praxis base of the Tsitsa Project.

Analysis and Modelling Phase 1

During 'Analysis A', the interview and project documentation data were thematically analysed by the facilitating researcher as described by Braun and Clark (Clarke & Braun 2014; Braun & Clarke 2006) with codes emerging on the basis of the information collected from participants (Creswell & Creswell 2018). Data were used to create systems models (Elsawah

et al. 2017; Forrester 1968) that paint a systemic picture of how the Tsitsa Project team sees the key issues playing out in the system. The predominant themes that emerged from the analysis, as well as the systems models, were presented, verified and discussed at a social learning workshop ('Participatory Workshop 1' online), to which the interview participants and broader stakeholders identified during the interviews were invited. This workshop was attended by representatives from all the Tsitsa Project research-praxis communities of practice and various transdisciplinary stakeholder organisations including research institutions, implementers, NGOs and government funders (n = 29). Following W1, further verification and updates were gathered from project documents and reports compiled by the PMERL team. 'Document Review B' of SES literature on the themes that emerged from the process was done. Further analysis ('Analysis B') including a hierarchical analysis derived from the classic Analytic Hierarchy Process method (Saaty 2008) of the top drivers of degradation that emerged from W1 were incorporated to the thematic and systems models. This led to the development of Publication 1, systems models synthesising the SES drivers of degradation in the TRC.

Analysis and Modelling Phase 2

'Analysis B' of the data that went beyond Publication 1 identified *SES integration* and *integrated SES monitoring* as critical needs in the project, and in wider SES research. 'Participatory workshop 2' (n = 17) concentrated on exploring and addressing integration and monitoring challenges. During this workshop, open-ended discussions took place, and activity systems analysis (Engeström 1987, 2001) served as a tool for co-creating a model of socio-ecological system (SES) monitoring in the Tsitsa Project. Contributions were incorporated into the framework in real-time, fostering discussions based on the concept of contradictions within and between individuals and the tools they employed for integrated monitoring (Engeström 2001). In this context, contradictions are understood as historically evolving tensions or underlying issues that may impede progress (Ploettner, Tresseras & Llull 2016). The identification and resolution of these contradictions within the activity can enhance the overall functioning of the system.

Analysis and Modelling Phase 3

'Analysis B' also included reflective practice engagements by the facilitating researcher with publication 2 co-authors and the TP PMERL team to guide the analysis of the data and

process in relation to issues of paradigm, power, and positionality (Moon 2004). Research was done on the specific aspects of integration and monitoring challenges identified in the research, and recommendations were made based on both the social learning process and wider literature. Publication 2, detailing the insights and lessons to enhance integration and monitoring for SES, was drawn up for dissemination.

Analysis and Modelling Phase 4

The data that emerged on potentially important monitoring variables from phases 1-3 (including both the data gathered through this participatory transdisciplinary process, and the indicators that were already selected through expert-driven disciplinary processes within the project) were critically reviewed in light of the wider literature on EVs (including their selection criteria) and integrated SES, 'Document Review C', to produce a list of candidate ESEVs and indicators for integrated monitoring of the TRC. A google form survey was developed incorporating potential selection criteria and candidate social-ecological variables and indicators that emerged from phase one of the research process. Participants were directed to assign scores ranging from 0 (non-essential) to 5 (highly essential) to each potential selection criterion, assessing its importance for integrated monitoring in the TRC. They were also encouraged to suggest any additional criteria that might have been omitted. Likewise, participants were asked to score each social-ecological variable and indicator on a scale of 0 to 5, providing comments and suggestions in a manner similar to the evaluation of selection criteria.

The survey (n=14) results were utilized for two "essentiality vs. consensus" analyses (as part of 'Analysis C'), inspired by Pacheco-Romero, Alcaraz-Segura, Vallejos & Cabello's (2020) "relevance vs. consensus" approach. 'Essentiality' in this context denotes the importance assigned by participants to variables and indicators concerning ESEV selection criteria. The first analysis focused on the selection criteria for ESEVs in the TRC ('essentiality vs. consensus' a), and the second on variables and indicators for monitoring the TRC ('essentiality vs. consensus' b). Essentiality was determined by the mean scores, while consensus was assessed by the difference between the maximum standard deviation and the standard deviation of scores for each criterion, variable, or indicator. Rankings were assigned based on percentiles, resulting in five priority levels (1 being top priority and non-priority for those below the 50th percentile). To identify potential biases and gaps, the researcher analyzed additional suggestions and comments from the survey, categorizing recurrent themes as potential additional ESEVs. The

findings were discussed in participatory workshop 3 (n=7), and follow-up expert interviews n=5) were conducted for themes requiring further input. Further analysis and synthesis of these findings culminated in the development of publication 3, developing the ESEV approach as an innovative transdisciplinary method for integrated SES monitoring and piloting it in the TRC.

3.6 Concluding remark

The chapter has provided a detailed description of the main methodological tools and approaches used in the study, namely transdisciplinary knowledge co-production, thematic analyses, systems analysis through the use of CLDs, participatory activity systems analysis, and 'essentiality vs. consensus' analyses. The methodology of this study is premised on the idea that incorporating a plurality of tools and approaches to elicit data at different stages of the research process enables different aspects of the integration and monitoring challenges to be analysed and addressed. The following chapter will address how the study's first objective, i.e., determining the social-ecological system drivers of degradation in the TRC, was approached.

CHAPTER 4 – A SYNTHESIS OF THE DRIVERS OF DEGRADATION IN THE TSITSA RIVER CATCHMENT

4.1 Preface

Effective and efficient monitoring of degraded SES requires an understanding of the key drivers of degradation. In determining the drivers of degradation and evaluating the extent to which they impact communities and the landscape, a better understanding of how context-specific SES drivers are interlinked and how they interact with one another is achievable. This paper uses a participatory systems analysis approach to determine the key factors driving land degradation in the TRC in the Eastern Cape and to analyse how they interact. The paper provides a systemic synthesis which is important for the identification of effective and sustainable leverage points, interventions and monitoring variables that speak to the drivers of degradation rather than the symptoms. The publication is available online at: https://www.mdpi.com/2071-1050/13/2/516

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Article

A Social-Ecological Systems Understanding of Drivers of Degradation in the Tsitsa River Catchment to Inform Sustainable Land Management

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Abstract: Understanding the interactions of the social and biophysical drivers of land degradation is crucial for developing adaptive management actions for future sustainability. A research-praxis project, the 'Tsitsa Project' (TP), applies a social-ecological systems (SES) approach where researchers, natural resource managers, and residents collaborate to support sustainable livelihoods and improved natural resource management for the degraded Tsitsa River Catchment (TRC) in South Africa. A system diagramming approach was coupled with findings from interviews, workshops, literature, and two conceptual frameworks. Data inputs were qualitatively integrated to provide a systemic snapshot of how the context-specific social and biophysical drivers are interlinked and how they interact, revealing multiple processes that operate simultaneously to cause and exacerbate land degradation. Physical and climatic variables, changes in land use and cover, and overgrazing were identified as key factors leading to degradation. Additionally, poverty and disempowerment were also important. While little can be done to influence the physical aspects (steep topography and duplex soils) and climatic variables (extreme rainfall and drought), carefully planned changes in land use and management could produce dual-benefits for improving landscape conditions and sustainable livelihoods. This analysis will inform integrated planning processes to monitor, avoid, reduce and reverse land degradation.

Keywords: land degradation; social-ecological systems; systems thinking; sustainable land management

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Citation: Itzkin, A.; Scholes, M.C.; Clifford-Holmes, J.K.; Rowntree, K.; van der Waal, B.; Coetzer, K. A Social-Ecological Systems Understanding of Drivers of Degradation in the Tsitsa River Catchment to Inform Sustainable Land Management. *Sustainability* **2021**, *13*, 516. https://doi.org/10.3390/su13020516

Received: 9 December 2020
Accepted: 31 December 2020
Published: 7 January 2021

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1. Introduction

Social-ecological systems (SESs) are characterized by complexity, high connectivity, and the presence of positive and negative feedback loops involving social and biophysical variables which can have desirable or undesirable outcomes [1,2]. Land degradation is a process with undesirable social and ecological outcomes that can be especially devastating for the world's poorest people living in dryland areas. Land degradation is classified into soil degradation and vegetation degradation, both of which are important and often interrelated [3]. The definition of land degradation traditionally focused on the biophysical aspects (i.e., vegetation change and soil loss), but has more recently been framed as a social-ecological phenomenon resulting in "the reduction in the capacity of the land to provide ecosystem goods and services, over a period of time, for its beneficiaries" [4] (p. 7). The major factors leading to land degradation globally are land use changes and unsustainable land management practices; changes in land use and management are often driven by system shocks (abrupt change), trends (long-term changes), or seasonality

(short-term variability) [5]. Addressing issues around land degradation is fundamental to achieving the Sustainable Development Goal (SDG) target 15.3, "to combat desertification, restore degraded land and soil, including land affected by desertification, drought, and floods, and strive to achieve a land degradation-neutral world" by 2030 [6]. A systemic approach to land degradation can also support other SDGs related to climate change, poverty eradication, food security, environmental protection, and the sustainable use of natural resources [7,8]. In recognition of the urgent need to restore degraded ecosystems, 2021–2030 has been declared the UN Decade on Ecosystem Restoration with the mission of preventing, halting, and reversing the degradation of ecosystems worldwide [8].

Land degradation is one of South Africa's most critical environmental issues [9,10] and negatively impacts the livelihoods of the rural communities [11]. Land degradation decreases the provision of ecosystem services crucial to enable rural communities to fulfill their (physiological, psychological, and social) needs [12]. The drivers of land degradation are the fundamental forces causing the degradation of the coupled social-ecological system (e.g., climate change, policies, and physical aspects). Understanding both the social and biophysical drivers, and the way that they interact to place pressure on the landscape, changing its condition, is crucial to develop adaptive management measures that will alter current trends towards more desirable and sustainable outcomes [7,13].

While context-dependency is a key determinant of the land degradation impacts of drivers, the nature of an environmental problem in any given case is not entirely unique [14]. Instead, it reflects a series of core challenges that occur repeatedly across many different cases and contexts. In the case of South Africa, high levels of land degradation are associated with both biophysical and socio-economic factors that are apparent throughout the country's rural landscapes [3]. Many land degradation outcomes in South Africa can be traced back to the historical land tenure policies of the country where the formation of homelands led to over-crowding [15]. Colonial and Apartheid policies controlling where people could live, work, and school also contributed to the entrenchment of poverty and disempowerment in the former homelands, which reduced the capacity of households to develop alternative livelihood coping strategies, and contributed to continued degradation [16].

Yet while case studies of environmental problems like land degradation share some global, regional, or national 'core challenges', each has its own history, rooted in its own specific social and ecological context that must be taken into consideration for sustainable and effective management. Case studies are valuable because they allow researchers to gather complementary quantitative data and rich qualitative data that helps to contextualize the study and to infer causality [14]. The Tsitsa River Catchment (TRC) is such a case study. It is home to a unique, ongoing research-praxis project, the Tsitsa Project (TP, formerly the Ntabelanga-Laleni Ecological Infrastructure Project), which began in 2014 and is the South African Government's flagship restoration project [17]. The TP has an explicit SES framing that is based on applied transdisciplinary research (in the space between implementation and academic research) to improve the landscape and sustainable livelihoods of the degraded, rural TRC. The TP aims to improve social and ecological sustainability using an SES approach that combines knowledge and expertise from social and natural sciences, practitioners, and communities. The TP has put effort into building trust with and the capacity within the communities, foremost through several years of continued participatory engagement and the employment of community members to participate in social and biophysical monitoring activities [18]. Adaptive management in a degraded SES like the TRC requires an understanding of the key social and biophysical drivers of degradation for that system. The TP recognizes that taking social-ecological drivers of degradation into account is crucial to the project's chances of success [19].

This paper will provide a synthesis of the drivers of degradation in the TRC case study through an integrated SES approach. This is a unique case study and approach in the South African context that adds value to our understanding of the drivers of land degradation by integrating transdisciplinary perspectives that can be used to identify potential leverage

points for adaptive management interventions. The TP's social-biophysical approach to understanding the environmental, social, economic, and governance factors which drive the system, and importantly the particular linkages between them, provides an opening to conduct 'degradation research' in novel ways, such as through systems thinking. Defined as "a set of synergistic analytic skills used to improve the capability of identifying and understanding systems, predicting their behaviors, and devising modifications to them in order to produce desired effects" [20] (p. 7), systems thinking consists of three kinds of things: elements (in this case, the drivers, pressures and stressors and responses that affect the condition of the TRC), interconnections (the way these characteristics relate to and/or feed back into each other), and a function or purpose (in this case, to systemically understand land degradation to inform sustainable land management of the TRC). Since real-world phenomena are typically not explained through a single, clear, unidirectional path linking a cause to an effect, systems diagramming drawing on data about the drivers of degradation gathered from within the TP will elucidate some key ways that the context-specific drivers interact to result in multiple processes that operate simultaneously to cause and exacerbate the land degradation in the TRC. The paper will then make a theoretical case for the use of a system's application of Drivers-Pressure-Stressors-Condition-Responses ($DPSCR_4$) and Land Degradation Neutrality (LDN) frameworks with regards to better degradation intervention outcomes.

1.1. The Study Area: The Tsitsa River Catchment

The Tsitsa River Catchment (focus area of 200,000 ha, as per Figure 1) lies in the Eastern Cape province of South Africa. The catchment is considered sub-humid and is characterized by areas of steep topography [21,22]. Soils are generally erodible, especially in the lower catchment, as seen by the formation of extensive gullies [23,24]. The catchment is comprised of two types of rural landholdings (private and communal) with similar ownership patterns as under the pre-1994 Apartheid regime [25]. The communal land, where the majority of the catchment's population resides, is found mostly in the middle and lower parts of the catchment, which coincides with more erodible soils [25]. Historically, Apartheid policies and actions (including the political and administrative separation of the Transkei homeland from the Republic of South Africa, laws restricting black ownership of land, urban labor controls, limited investment in education, social grants, and betterment) impacted the social-ecological landscape of the TRC, increasing disempowerment and poverty, and changing land use and land cover patterns [16].

The ultimate aim of the TP research is twofold. Firstly, to provide and synthesize relevant scientific and local knowledge to evaluate the natural and social capital of the TRC, with regards to whether it is or is not progressing toward desired long-term goals. Secondly, to link this understanding to management and implementation processes needed to achieve sustainability of the TRC. Land degradation in the Tsitsa catchment can be seen through the dissection by deeply incised gullies ('*dongas*'), the loss of grassy vegetation cover and associated soil erosion and loss of soil fertility, as well as encroachment of degraded grasslands by woody vegetation (largely by invasive alien plants) [25]. These processes reduce the productivity of the land, making it less able to support the people who live on it. The complex SES framing of the TP has a strong focus on livelihoods and governance in the area because through livelihoods people benefit and through good governance the SES can be sustained. This is a departure from the South African Department of the Environment, Forestry and Fisheries' (DEFF) business-as-usual management activities to counter land degradation by reducing soil loss through restoring degraded ecological infrastructure, with limited investment in long-term livelihood benefits and governance institutions that support sustainability. The TP's singular nature as a research-praxis project (with praxis being the interaction between research and practice), funded by DEFF who are using it as an experimental space to inform their own processes and projects, provides exciting learning opportunities that can be extended to other projects interested in using a similar approach.

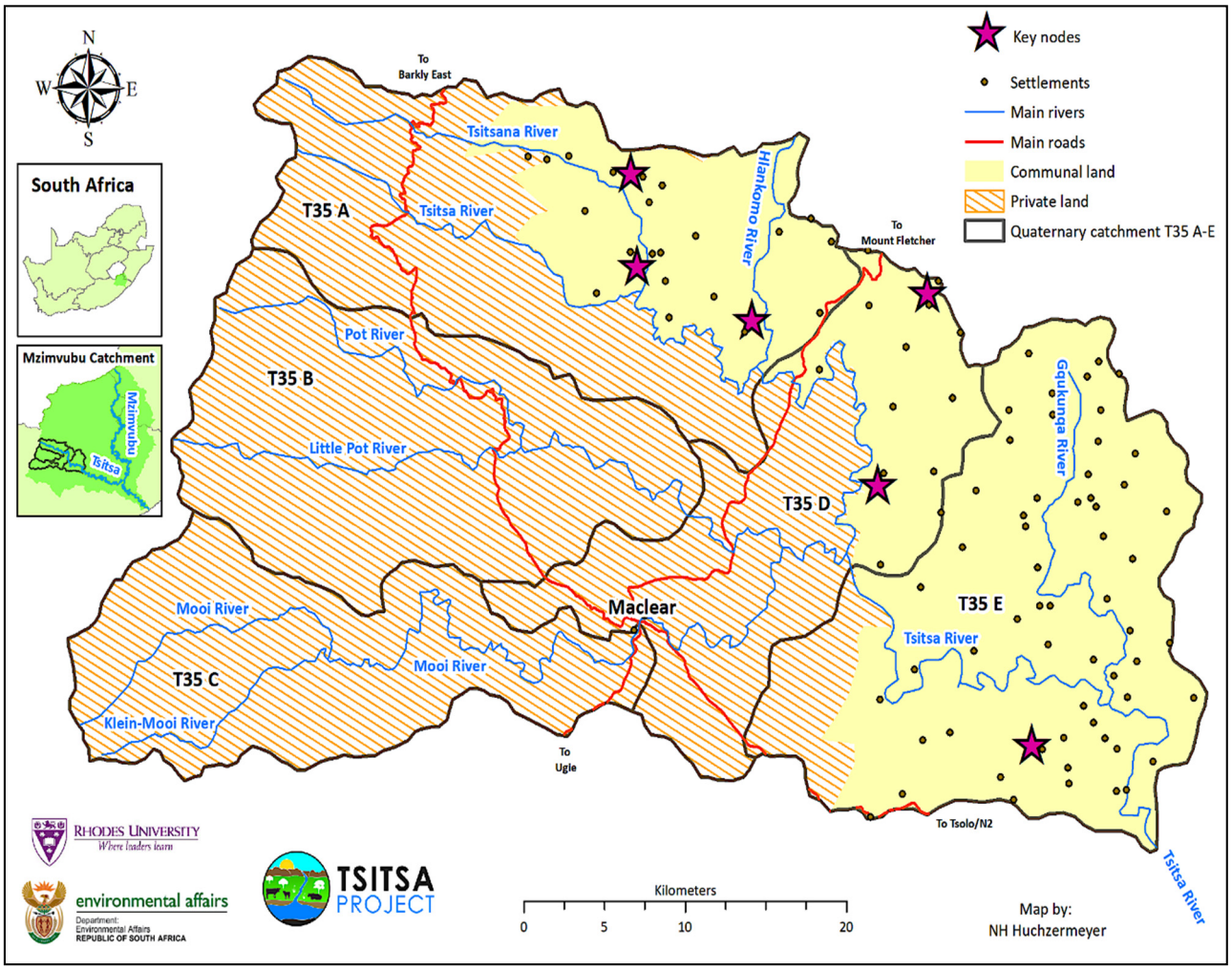


Figure 1. Map of the Tsitsa River Catchment. Quaternary catchments are hydrological delineations of sub-catchments (numbered by the South African system of T35A-E); and key nodes refer to focal areas for the Tsitsa Project's engaged research and restoration work. Map by N.H. Huchzermeyer.

A desktop review of key documents from the Tsitsa Project [19,25–28] and the responses at a workshop with the heads of all the TP research-praxis communities of practice (CoPs) as well as various key stakeholder organizations, held in May 2020, highlighted the need for a synthesis of the drivers of degradation in this system. Such a systemic synthesis would help build a common understanding of the problem context, which is important for the identification of suitable (effective and sustainable) leverage points and interventions that address the drivers of degradation rather than the symptoms. The synthesis builds on an earlier review of the environmental, social, and historic processes contributing to degradation provided through the Water Research Commission funded "Green Village Project" [16].

1.2. Framework

One of the ways to explore the interactions between society and the environment and their consequences is the use of frameworks for assessing ecosystem health. Ecological health assessment frameworks have followed two main approaches. The first one is derived from concepts within stress ecology, ecological risk assessments, and ecological indicators [29]. These frameworks are closely related to hypothesis-driven scientific studies on causal relationships between environmental stressors (whether natural or anthropogenic) and their effect on ecosystems and their components [29]. The second approach is focused on environmental-management, based on the Pressure-State-Response (PSR) framework

and its derivative, the Driver-Pressure-State-Impact-Response (DPSIR) framework [30]. First developed as part of the European Environment Agency Programme, DPSIR has been adopted as an analytical framework by UNEP and has been applied to various environmental studies in Europe [30–32]. A strength of the DPSIR framework is that it considers humans an integral part of the system generating pressures, sensing the impact, and applying responses [33]. A deficiency of DPSIR, according to Harwell and others [29], is that in distinguishing between impacts and state, it implies that there exists some baseline or 'natural state' for an ecosystem and that impacts constitute some deviation from that state. Human interactions are thus positioned only as adverse without accounting for positive contributions.

The Drivers-Pressure-Stressors-Condition-Responses ($DPSCR_4$) is a derivative of the DPSIR framework, which replaces 'Impact' with 'Condition', where condition describes the state of the environment (in terms of ecological health, ecosystem services, and human well-being) and four types of responses are identified: reduction of stressor sources, remediation of existing stressors, ecological restoration, and ecological recovery [29]. Researchers from the TP have used the $DPSCR_4$ as an integrated monitoring framework [24]. The TP defines 'drivers' as the fundamental forces driving the coupled human-environment system, leading to 'pressures' (i.e., human activities and natural processes e.g., natural resource use), which cause chemical, physical, or biological 'stressors' (e.g., toxic chemicals, habitat alteration, invasive species) that affect the 'condition' of ecological structure, processes, and/or diversity and ecosystem services that link ecological systems, societal systems and human well-being [24]. Management actions can feed back to the system through the four types of societal and ecological responses.

The Land Degradation Neutrality (LDN) framework draws on the Driving Force-Pressure-State-Impact-Response (DPSIR) framework, but with the overarching aim to counterbalance the expected loss of productive land with the recovery of degraded areas. The framework takes a multi-pronged approach, that aims primarily to avoid and reduce new degradation of land, and then to reverse existing land degradation (Avoid > Reduce > Reverse). This hierarchy, based on the recognition that prevention is better than cure, articulates the priorities in planning LDN interventions [7]. The novel aspect of the LDN target that sets it apart from earlier efforts to tackle land degradation is the specific adoption of neutrality (against an established baseline) as the minimum goal. Neutrality requires that there is no net loss of land-based natural capital between time zero and the target date (2030, for the SDGs). The framework has prescribed three global (biophysical) indicators serving as proxies for ecosystem services: land cover/land cover change (water regulation and others), land productivity/NPP (food supply), and carbon stocks/SOC (nutrient cycling) against which the land degradation is monitored while being open to additional/complementary indicators [5]. A number of characteristics make LDN suitable for application in this case study:

- it has been posited in relation to DPSIR and can easily be tailored to $DPSCR_4$;
- it has an explicit SES focus;
- it is intended to be implemented at local scales; and
- the mechanism for achieving the LDN vision is through participatory integrated land use planning which is the approach the TP uses.

The guiding framework for this study is a simple composite model embedding LDN within $DPSCR_4$ presented as a systems model (Figure 2).

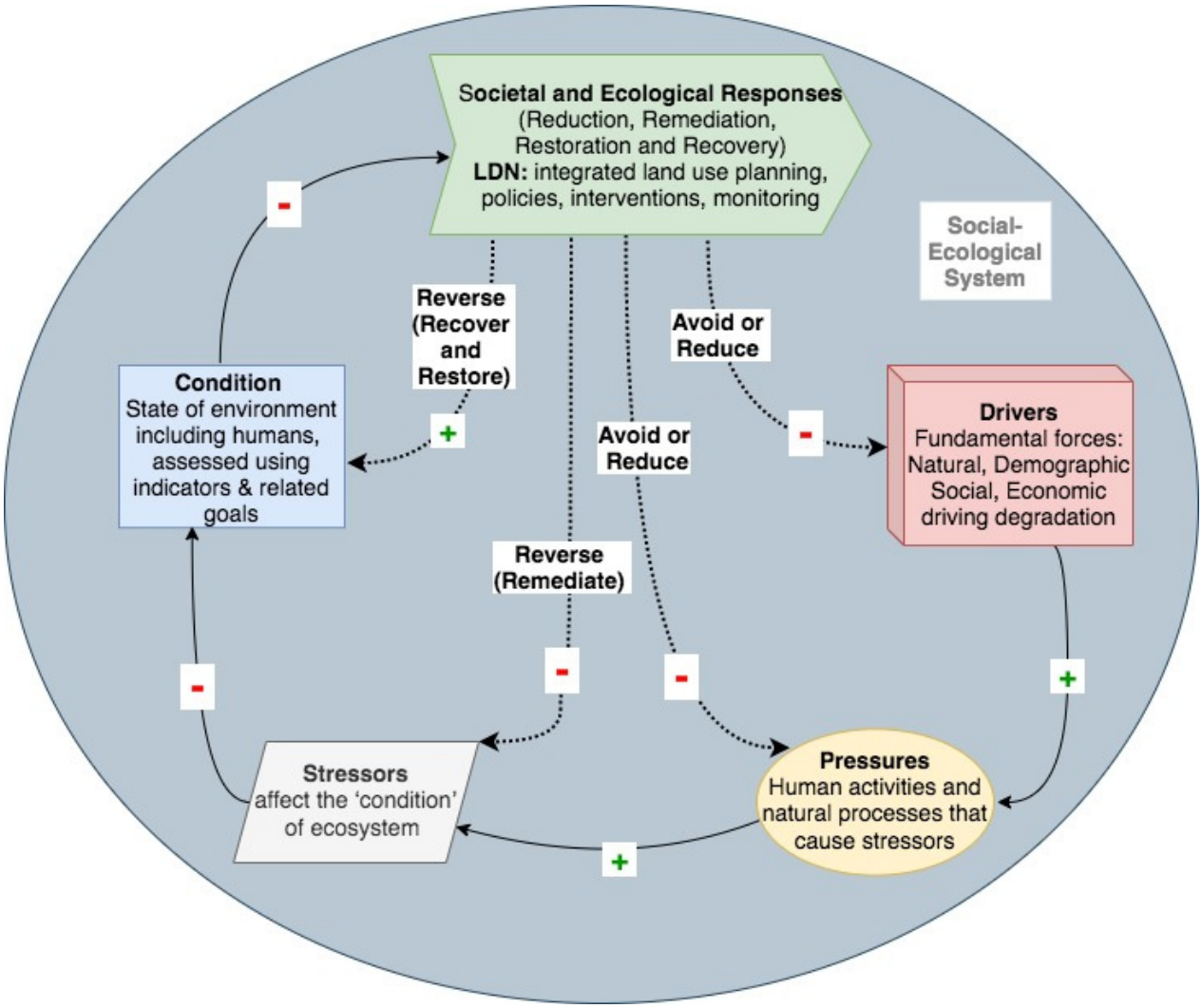


Figure 2. Conceptualizing the role of Land Degradation Neutrality within the Drivers-Pressure-Stressors-Condition-Responses ($DPSCR_4$) framework (used in the Tsitsa Project (TP)) to combat land degradation using a social-ecological systems approach. Solid arrows indicate cause-effect relationships, and dotted arrows indicate response relationships. The green '+' signs on the arrows show relations where a change in the cause creates a change in the effect in the same direction, the red '−' signs on the arrows show inverse relationships (modified from [7,29]).

2. Materials and Methods

Data about the drivers of degradation in the TRC were generated from three sources: key informant interviews, a workshop session, and project documentation. There are two areas of innovation in the methodology of this research. The first area of innovation is the combined general strategy of the interviews followed by more specific analysis from the workshop and project documentation, from which it emerged that there was substantive new evidence about drivers of degradation that had not been synthesized before. The second area of innovation is the use of the systems analysis approach to synthesize information from sources Sections 2.1–2.3. (outlined below) to build systems diagrams.

2.1. Interviews

Interview participants were selected based on their skills and position in the TP, through which they have specialist knowledge of the TP (and TRC) that is more extensive, detailed, or privileged than the general public, making them expert or key informants [34]. A list of nineteen key informants, including the researchers leading all the existing TP communities of practice (CoPs) at the time, as well as TP (research and project) manage-

ment, were interviewed (two group interviews and fifteen individual interviews). The key informant interviews were aimed at identifying key variables of the system and how they connect, and the level of the interconnectivity of data in the TP as a transdisciplinary endeavor. Interviews were undertaken between July 2019 and January 2020 with some follow-up discussions taking place in May 2020. The interviews were intended to provide a broad overview of the key issues facing the catchment and to identify the progress and gaps of the TP to date. The need for a synthesis of the drivers of degradation in the system emerged as a gap during analysis across the key issues which was raised in the interview data and in a further review of internal project documentation.

2.2. Workshop

A virtual follow-up workshop, held in May 2020, was attended by 29 participants including 15 of the 19 original interviewees as well as additional representatives from various stakeholder organizations. Participants answered multiple-choice and open-ended questions around the drivers of degradation in the system, and suggested additional documents including journal articles, strategic planning documents, and internal reports, for subsequent review. There were four questions focused on drivers of degradation in the system. The first question was if and how (or where) the TP's understanding of the drivers of degradation in the TRC had been synthesized. This was followed by participants individually listing drivers of degradation in the TRC. In question 3, participants chose the three most important drivers of degradation from the combined list, and in question 4 they selected any factors that they thought should not be on the list. A derivative of the classic Analytic Hierarchy Process (AHP) method [35] was used by asking participants to assign values of importance to each of the drivers of degradation. These values informed a hierarchical analysis, out of which the top drivers were selected for further development in this paper.

2.3. Document Review

Data were drawn from a variety of different sources. These include:

(a) relevant internal project documents prepared for DEFF, which were identified during the interview and workshop processes (a summary of these documents and their relevance in the study is provided in Appendix A, Table A1);
(b) published literature on the Tsitsa; and
(c) supporting literature, made up of published and "grey" literature that addressed issues similar to that of the TP/TRC, but are not solely focused on the catchment. This could be literature that speaks to the wider region (e.g., [3]) neighbouring areas (e.g., [36,37]), or areas facing similar degradation contexts (e.g., [38,39]).

2.4. Systemic Analysis

System dynamics and systems dynamic modeling are, respectively, an approach and a tool for comprehending a system's structure across disciplines by modeling complex social and ecological events, patterns, and processes along with their key feedback loops, using systems thinking principles [40]. System dynamics helps to better represent, analyze, and understand systems, including those characterized by some uncertainty. Jay Forrester [41], known as the founder of System Dynamics, argued that one of the most powerful aspects of the system dynamics modeling approach is the breadth of data sources that can be used—namely numerical, written, and mental. The triangulation of key informant interviews, the workshop, and the combination of documents reviewed, together with integration, formed the basis of systemic analysis of the drivers of degradation in the TRC. Causal loop diagrams (CLDs) that hypothesize system behavior and identify balancing and reinforcing feedbacks were developed (Figure A1 of Appendix B), but more readable systems diagrams presented in the paper itself are not strictly according to CLD conventions; rather they use a format that is more appropriate for the $DPSCR_4$ LDN framework (Figure 2). The diagrams

thus provide a systemic snapshot of expert knowledge on the key drivers of degradation in the system.

Research ethics clearance was obtained from the Wits University Ethics Committee (Clearance certificate: H19/09/13).

3. Results

The results are presented here in three sub-sections. Firstly, the interview and workshop results describe the data gathered from key informant descriptions of the drivers of degradation in the system. Secondly, the document analysis focuses on synthesizing data from TP documents and published literature on three emphasis points (natural drivers, land use change, and grazing management) that emerged from the interview and workshop results. Lastly, the systemic analysis presents and describes systems diagrams to improve our understanding of the interconnected social and ecological variables driving land degradation in the system, which will inform sustainable land management.

3.1. Interview and Workshop Results

This section presents results from the workshop which helped validate, verify, and further unpack a summary of data regarding land degradation that emerged from the key informant interviews. When participants were asked at a workshop if and how the TP's understanding of the drivers of degradation in the Tsitsa River Catchment had been synthesized, it became apparent that many were not aware of any such work having been undertaken. Six out of the fifteen respondents acknowledged that while the drivers are mentioned and shared in various ways and at various forums, they did not know of a single synthesis, as shown in this narrative thread:

> *"Although the drivers of degradation have been pointed out in various other forms, I can't, from the top of my head, point towards a simple and readily available document to use as a reference when planning for interventions over and above those typically employed in the project".*

Other feedback noted that the project has:

> *"neglected this aspect to some extent. We are relying on 'received wisdom' and literature/theory e.g., on overgrazing, soil erosion, etc. and don't fully understand how these drivers work in the Tsitsa catchment context", and that, "the process of synthesizing has only started happening in the last 18 months as the CoPs and the partners start working more closely together. The more we share information the more likely it is that the synthesis will happen".*

Another six out of the fifteen responses pointed to various reports, plans, and papers that spoke to the drivers of degradation in the TRC. A review of these sources is included in this synthesis.

Participants were then asked to list 'drivers of degradation in the TRC'; there were no restrictions on the number to be listed. There were 19 respondents to this question. Responses were thematically categorized, leading to some respondents bringing up two issues within the same theme, for example, if both grazing management and overgrazing were mentioned by a participant, that was counted as two responses within the theme 'grazing management/overgrazing'. 'Grazing management/overgrazing', 'physical factors', and 'governance issues' were the most frequently listed 'driver' themes (Table 1). These 'drivers' span across several categorizations within the $DPSCR_4$ framing and will be described in $DPSCR_4$ terms in the systems diagrams. It was noted that a number of these 'drivers' are interrelated, which will also be further described in the systems diagrams.

Participants selected the three most important drivers of degradation from the list in Table 1 in the TRC (Figure 3); the top choices were: physical factors such as steep terrain and erodible soils (selected by 12 of the 22; 54.54% of participants), land use or land cover change (selected by 10 of the 22; 45.5% of participants), overgrazing (selected by 9 of the 22; 40.9% of participants), and disempowerment and poverty (selected by 8 of the 22 or 36.4%

of participants). Other drivers considered to be in the top 3 were 'extreme weather' and 'fire patterns and management' (selected by 6 of the 22 or 27.3% of participants respectively). One participant commented:

"I don't think there are a top 3! They are all interconnected. But I tried".

Table 1. Drivers of degradation in the Tsitsa River Catchment listed by 19 Tsitsa Project participants.

Drivers of Degradation in the TRC	Number of Mentions
Gazing Management/Overgrazing	20
Physical Factors (steep terrain, erodible soils)	12
Governance Issues	11
Climate and Extreme weather (droughts, storms)	7
Agricultural Practices	6
Infrastructure (poorly designed, built, or maintained)	6
Rural-urban linkages & Migration	6
Fire patterns and management	5
Alien invasive species	5
Land use or land cover	4
Livelihoods	3
Climate change	2
Disempowerment, poverty	2
Historical socio-political factors	2
Livestock food availability	1
Deforestation	1
Land tenure	1
Path dependency of past erosion dynamics	1
Fuelwood collection	-

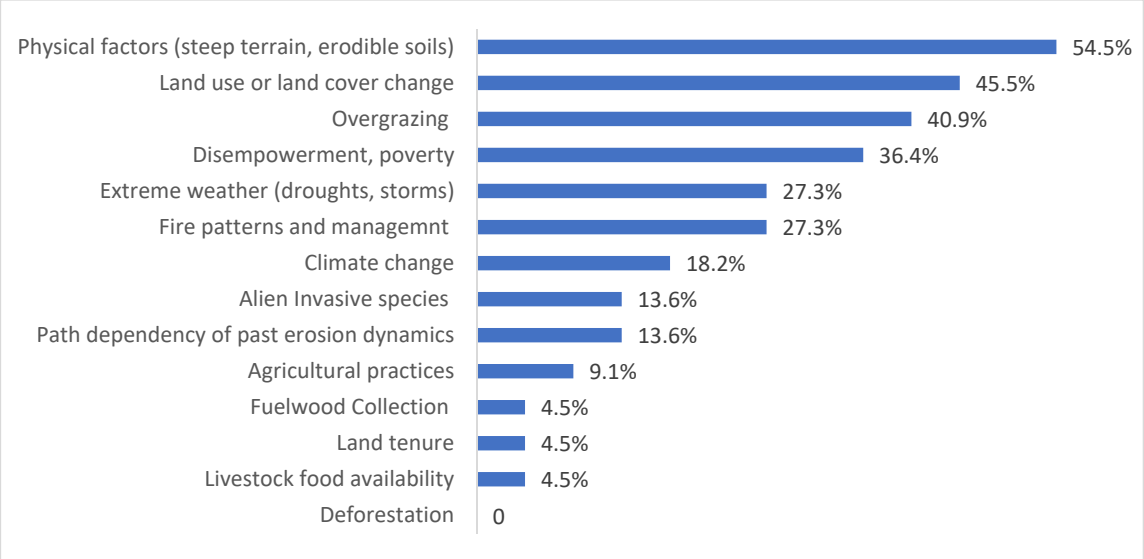


Figure 3. Selection of the three most important drivers of degradation in the Tsitsa River Catchment (TRC) from the list in Table 1 (22 participants).

When asked to select any factors that participants thought should not be on the list of drivers of degradation for the TRC, a number of participants (9 of the 23; 39.1%) felt that all drivers must remain on the list (Figure 4). The drivers that were, however, deemed least applicable to the TRC by other participants were deforestation and fuelwood collection.

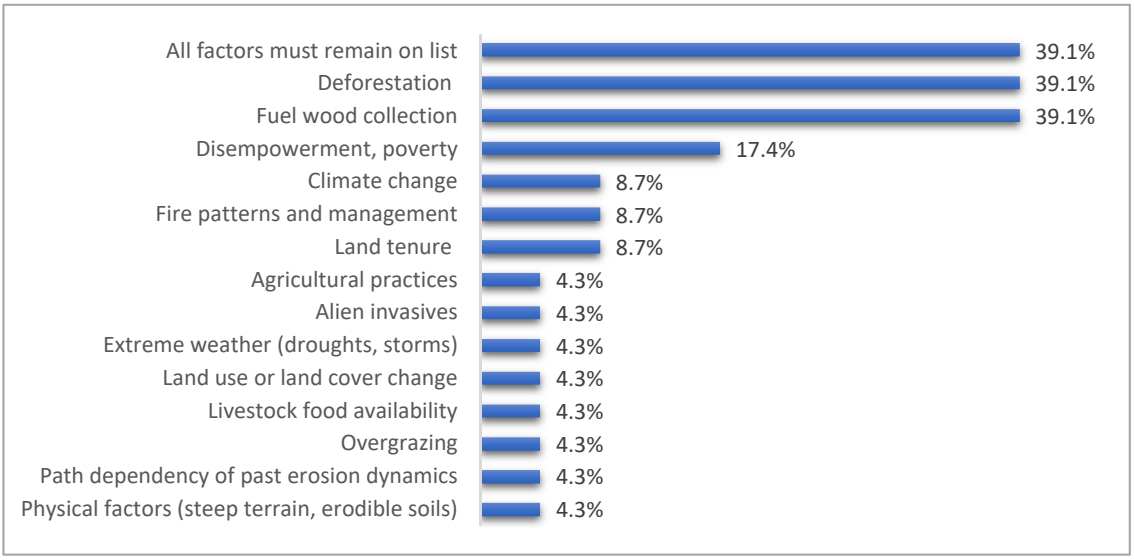


Figure 4. Selection of factors from Table 1 that participants believe should not be on the list of drivers of degradation in the TRC (23 participants).

Looking at the results from Table 1, Figures 3 and 4, according to the workshop participants, the most important factors driving degradation in the TRC were grazing management/overgrazing, physical factors such as steep terrain and erodible soils, climate and extreme weather events (droughts, storms), land use or land cover change, disempowerment and poverty, governance issues, and fire patterns and management.

3.2. Document Analysis Results

The workshop and interview results identified natural drivers, land use and land cover change, and uncontrolled/overgrazing as key factors leading to degradation in the TRC. These three emphasis points were explored further below through integration of relevant data from internal project documents, published literature on the TRC, and general supporting literature. These were used to inform the systemic analysis that follows.

3.2.1. Emphasis Point 1: Natural Drivers

Soil erosion is an important form of land degradation and is one of South Africa's most critical environmental issues [10]. Physical characteristics influencing land degradation through soil erosion include altitude, slope, runoff, soil erodibility, and soil fertility [3]. Steep topography and dispersive soils with duplex profiles predispose the TRC to soil erosion and gully formation [13,23,25]. There are limited options when it comes to changing the physical characteristics of a landscape and existing strategies for rehabilitating duplex soils are based mainly on experiences of working in Australia [42,43]. These strategies aim to enhance water movement and infiltration between the A–B horizon boundaries of the duplex soil profiles via the addition of clay to the sandy topsoils through two different approaches: clay spreading or clay delving [44]. Since these interventions require significant investment in labor and resources, they may be inappropriate for catchment-scale application [36].

Climatic variables have also been found to be drivers of land degradation across South Africa [3]. Gully initiation and intensification in communal lands of the Eastern Cape were found to coincide with a period of extreme rainfall events in the 1970s [43]. Workshops with communities from two villages in the catchment reported that the largest 'dongas' (deep gullies) had been present for the lifetime of the oldest residents, but the erosion in their part of the catchment was thought to have worsened from the 1960s and to be continuing today [16]. Extreme weather featured predominantly in their list of drivers of degradation, with thirteen events from the 1940s till the current decade (droughts n = 6,

floods n = 4, and tornados n = 3) [16]. Climate change futures for the region predict higher temperatures, decreased rainfall over the growing season, increased variability, more extreme weather events, and longer dry spells [45]. Fine-scale analysis of the TRC rainfall [46] also suggests a possible increase in rainfall intensity [16]. Increases in rainfall intensity would lead to increased runoff, reduced water retention, erosion, and flooding. Loss of vegetation cover due to drought would, likewise, increase erosion potential. There is therefore a strong likelihood that the catchment's susceptibility to erosion will increase in the future in response to climate change [26].

There is little that can be done to directly influence the physical aspects and climatic variables of a landscape; these can be considered inherent properties at the scale of the study area. These properties must. However. be understood because they affect the efficacy of potential responses. The TP posits that, in light of the study area's underlying natural drivers, dense vegetation cover will provide the best protection against degradation as surface runoff and splash erosion are limited and the flow of subsurface water is reduced. Dispersive soils are prone to water saturation and piping erosion and this should be prevented [16,23]. Land use practices, especially those related to grazing and cultivation, influence ground cover in the catchment and may be potential leverage points, but more data are needed.

3.2.2. Emphasis Point 2: Land Use and Land Cover History and Futures (Driven by Economic, Demographic and Social Factors)

The land cover distribution for the focus area of the TRC in this case study is comprised mostly of grassland (71.8%) with some plantations (7.0% exotic pine and eucalyptus species) and cultivated fields (8.8%: subsistence 5.3%; commercial 3.5%) [47]. The two main types of landholdings are communal and private land. The larger portion (62% or 124,000 ha) of the middle and upper catchment is private land mainly under white ownership, comprised of larger commercial farms, and plantations; scattered urban and semi-urban centers [24].

Landscapes and livelihoods change over time in response to local and external drivers, including changing modalities of state interventions in the rural domain. According to Hebinck and others [37] (p. 324), "this necessitates conceptually and empirically infusing a time dimension and a robust historical framing in any analysis of land use change". Forced removals and resettlement implemented by the Apartheid regime from the 1960s onwards contributed to rapid population growth in the communal land [16,48]. The Transkei's population increased threefold from 800,000 in 1904 to 1,300,000 in the mid-1950s to 2,600,000 by 1981 [48]. The majority of the catchment's population currently reside in low-density rural villages on 76,000 ha of communal land (of the former Transkei homeland) which is held on behalf of the National Government under the authority of Tribal chiefs [24]. The communal land, found mostly in the middle and lower parts of the catchment, is co-located with the more erodible soils [25]. A review of land degradation in South Africa showed considerably worse land degradation in communal areas than in commercial farming areas and, while the rate of degradation in communal areas was increasing, the rate in commercial areas was decreasing [3]. The results for the TRC concur with findings elsewhere in South Africa that land use types and land tenure systems are important predictors of soil erosion (though not necessarily the direct cause) [3].

Land use in the communal areas of the TRC is dominated by rural subsistence farming [24]. Cultivation was once widespread, but a study of two villages in the catchment found that field cultivation has almost entirely ceased and is now confined to gardens next to the homesteads [16]. Village residents gave the main reasons for this as drought, lack of manpower to plow, lack of access to tractors and machinery, theft of fences, soil erosion and reduced fertility, and a lessened need to grow crops due to the introduction of child subsidies in 1999 [16]. This illustrates how the linked social and ecological aspects of the system have contributed to the disuse of fields, which was found to be one of the main (direct and indirect) drivers of severe erosion and land degradation in most parts of the Eastern Cape Province [43].

Demographically the villages are in a state of flux, which influences land use. Freedom of movement after the 1994 democratic elections enabled a large out-migration as individuals and families moved to urban areas in search of better opportunities. Freedom of movement has also allowed more learners to join their families in urban centers for high school education. These factors have contributed to a clear decline in population numbers, which in turn has reduced the areas cultivated [16]. The study area is experiencing significant out-migration, resulting in a population decrease of 19% (from 55,797 to 45,043 people) between 2001 and 2011 [49], further exacerbating the disuse of fields as the potential labor force decreases. The disuse of crop fields by smallholder farmers in the communal areas is part of a wider trend across South Africa [37,39]. De-agrarianisation is, however, not a linear process. Crops are sometimes planted opportunistically on 'deactivated' fields when it rains. Hebinck and others [37] argue that having the option to farm at any time remains important to local identity and sense of belonging as well as a livelihood safety net for people retrenched or retiring from urban employment. The range of linked social and ecological factors discussed above make a return to large scale field agriculture unlikely to be a viable intervention for communal villages. The lack of field-scale irrigation in the communal areas of the TRC also means that crops are subject to severe weather events such as the ongoing drought [16].

Land use change can be monitored at a particular resolution both currently and historically and offers a valuable tool to obtain various types of information about drivers of degradation in the catchment.

3.2.3. Emphasis Point 3: Uncontrolled/over Grazing in the Catchment

Theories, models, and approaches to grazing and fire management have varied over time from very controlled, to more adaptable and "natural" approaches, but some commonalities across models are that stocking rates matter and that plants need rest to survive over time [26]. The TRC represents a microcosm of land management in South Africa in that there are currently two primary grazing management systems in place: a more sustainable rotational grazing model on privately owned land and an unsustainable continuous grazing model on communal land [25]. Overgrazing came through very strongly in the workshop as a perceived driver of degradation in the system. The Webster Dictionary defines the term overgraze as: "to allow animals to graze (as a pasture) to the point of damaging vegetational cover" (Merriam Webster Dictionary available at http://www.m-w.com/cgi-bin/dictionary). The term 'overgrazing' implies grazing at a higher level than required to meet a specific management objective [50], whilst the term is strictly defined it is used in a variety of ways depending on the perception of the people.

For population ecologists, overgrazing is often associated with carrying capacity (K), which has been defined as the population stocking numbers above that which the population will grow [50]. In the TP and TRC where the objective is the sustainable management and utilization of the natural resources by livestock, grazing capacity, defined as 'the land area required to support a single large stock unit (LSU) for an extended period of time without resulting in declines in condition of the resource' [51] (online), is a more useful measure in relation to overgrazing. Grazing capacity indicates how many hectares are needed per large stock unit (ha/LSU). The long-term grazing norms for the Grassland biome provided by the former Department of Agriculture, Forestry, and Fisheries (DAFF) is set at 4–6 ha/LSU [52]. A study on grazing capacities based on MODIS (250 m spatial resolution) forage production long-term, means five sites across the study area were found to have long-term grazing capacities of 4–4.9 hectares per large stock unit (ha/LSU) in lower catchment sites, but significantly lower grazing capacities of 7.7–7.8 ha/LSU were found in the upper catchment sites due to lower forage quality in a more acidic environment [53].

Livestock numbers declined during the 'betterment planning' (rural development planning implemented in the former homelands) from 1965 [54], but current numbers and trends are unknown. Some households interviewed perceived that livestock numbers have decreased over time while others suggested that livestock numbers had increased due to

the breakdown of controls on the number that can be owned [54]. There is no intentional aim to manage stock numbers which are thought to fluctuate around the maximum number that can survive on natural grazing and can vary with drought, theft, and disease [25]. During winter, grass availability and quality are very poor and the feeding of animals is limited due to high feed costs [25]. Data on actual stocking numbers across the catchment are needed to determine whether the livestock numbers are within or above the grazing capacity. If the stocking numbers are within the long-term grazing capacity, this could point to a livestock management problem rather than an overstocking problem. Livestock in the communal land is left free to graze in and around the village on a daily basis with little management beyond being brought back to the village at night for safety [54]. This results in no recovery period for the rangelands. Following the change in government in 1994, the migration to the cities has left fewer people to look after stock [16].

Democratic changes after 1994 caused tension between traditional leadership, who lost some authority to govern natural resource use, and elected councilors, which has resulted in a perceived breakdown of local governance systems leading to increased theft of fences and livestock [16]. Theft is a disincentive to farming in both the communal and commercial areas. The lack of fences changes the way that grazing is managed, and the land is used. There is also an absence of rangeland institutions in this area [54]. This lack of control results in livestock grazing on abandoned fields which, due to the nature of the soils, are particularly susceptible to sheet erosion.

3.3. Systemic Analysis Results

3.3.1. The Drivers, Pressures, and Stressors Causing Land Degradation in the Tsitsa River Catchment

The factors that were identified through the interviews, the workshop, and document review as having causal links to land degradation were categorized in terms of $DPSCR_4$, with special consideration to their impact at the relatively small scale of the study area (Table 2). At larger scales, climate change is an outcome of human activities (or pressures) that stress the landscape, and a change in human activities could relieve the impacts of climate change. Likewise, land degradation at large scales acts as a driver of climate change through the emission of greenhouse gases and reduced rates of carbon uptake [55]. At the scale of this study area, however, climate change would be considered a fundamental force or driver, and land degradation is the undesirable resulting condition.

The $DRSCR_4$ from Table 2 are arranged into two systems diagrams. Figure 5 illustrates how the drivers, pressures, and stressors are interrelated, and would not have the same outcomes if they were acting independently of one another. Figure 6 highlights the entry points and systemic pathways through which potential responses are hypothesized to impact the system. The variables are categorized in the diagrams below, as noted in the key at the bottom of the figures, as follows:

- the light red boxes show fundamental drivers of degradation (which could be natural or anthropogenic);
- the orange ovals show pressures (which are defined here as human activities and processes that cause stressors);
- the grey parallelograms show stressors (which could be natural or anthropogenic);
- the blue rectangles show the condition (in this case, the resulting condition of interest is land degradation); and lastly,
- the green arrows show interventions (which do not fall into the other variable categories).

Figure 5 maps the relationships between some of the key variables driving land degradation in the Tsitsa River catchment, showing why coordinated, integrated, and cross-sectoral interventions are required to reduce degradation and improve sustainable livelihoods in the area.

Table 2. Drivers Pressures Stressors Condition and Responses ($DPSCR_4$) for the Tsitsa River Catchment (TRC).

Drivers (Fundamental Forces, Natural and Anthropogenic)	**Pressures (Human Activities and Natural Processes That Cause Stressors)**	**Stressors (Natural and Anthropogenic)**	**Condition (Assessed Using Indicators & Related Goals)**	**Responses (Societal and Ecological: Reduction, Remediation, Restoration and Recovery)**
Natural: Physical aspects: Soil type Topography Climate	Unstable governance	Woody vegetation (largely invasive species)	Goal: Reduce land degradation	Reduction: Environmental Education (Learning words & TP workshops) Market Access initiatives Land-use management (rangeland associations) Policies and Regulations
Demographic, Social and Economic:	Disuse of fields (land use changes)	Low ground cover	Goal: Improve Sustainable livelihoods	Restoration: Remove invasive species Rehabilitation of eroded land
Past and present (colonial, apartheid and post-apartheid) policies Poverty and disempowerment	Livestock numbers	Soil erosion		Recovery: Rest landscape to enable ecological recovery
Traditional values re. livestock Climate change	Free or over-grazing Out-migration	Gully formation Grassland condition	Goal: Poverty alleviation	All R_4s: LDN integrated land use planning

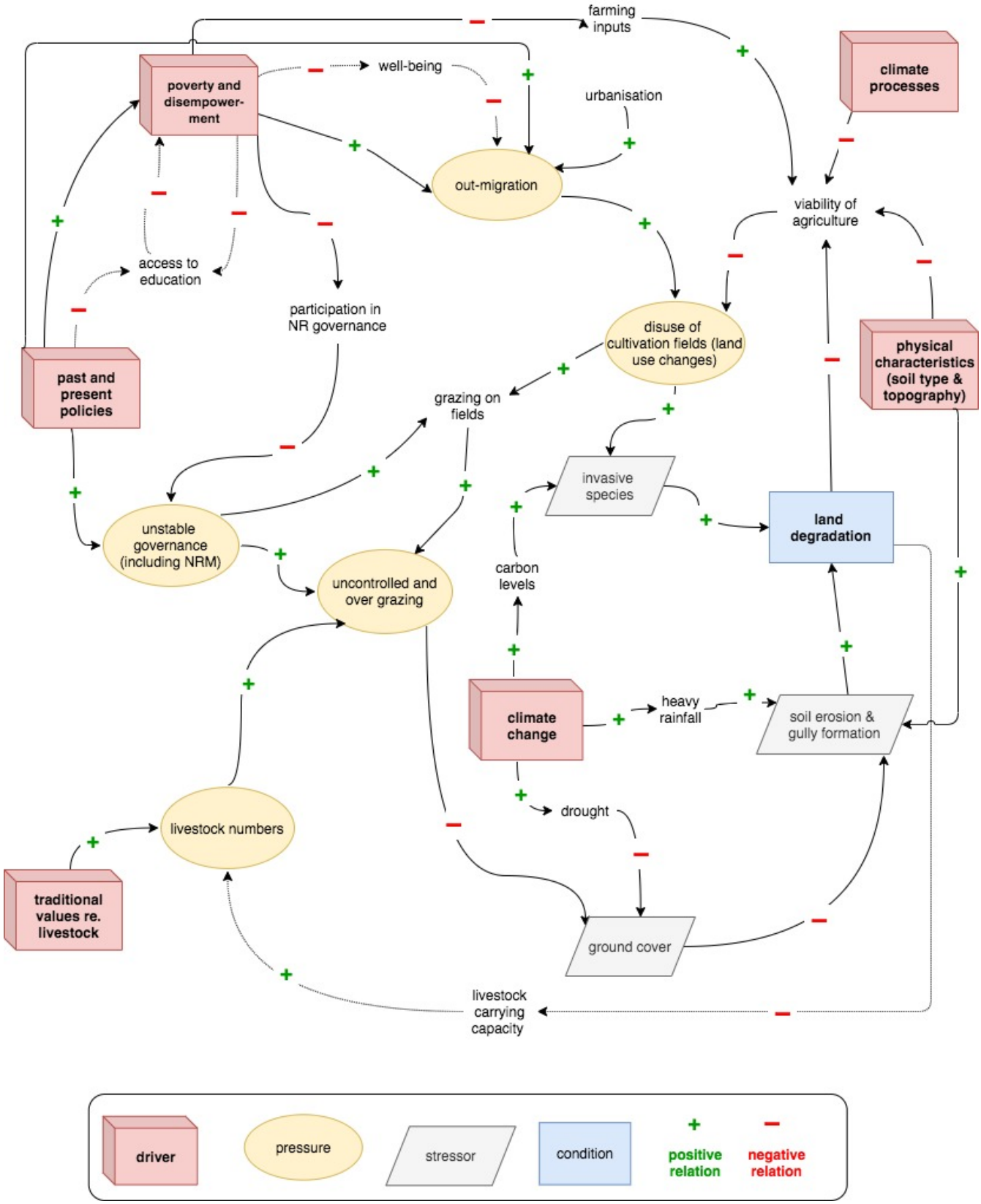


Figure 5. Drivers, Pressures, and Stressors that cause land degradation in the Tsitsa River Catchment (TRC).

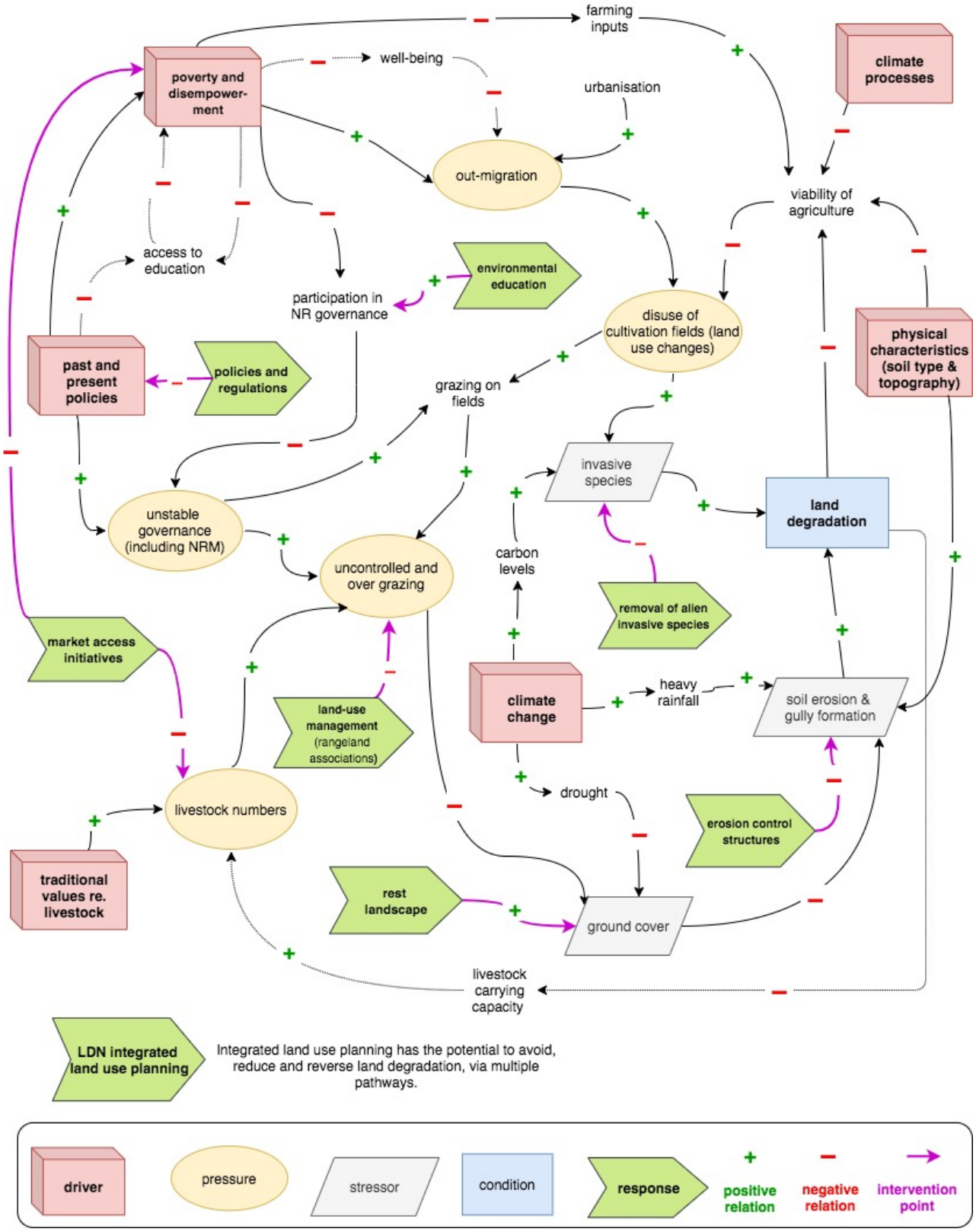


Figure 6. Drivers of degradation and potential responses being considered by the Tsitsa Project (TP) to reduce degradation and improve sustainable livelihoods in the Tsista River Catchment (TRC).

In the lower right side of the diagram is the (undesirable) condition of interest, *land degradation*, which is exacerbated by soil erosion, gully formation, and invasive species (the green '+' signs on the arrows show relations where a change in the cause creates a change

in the effect in the same direction—for e.g., the more *climate change*, the more *soil erosion and gully formation*, causing more *land degradation*; the red '−' signs on the arrows show inverse relations, where a change in the cause creates a change in the effect in the opposite direction—for e.g., as *drought* increases, *ground cover* decreases).

If we shift our focus to the fundamental drivers of degradation in the diagram, we see that *past and present policies* (such as Apartheid policies which forced large numbers of indigenous people on to the Transkei, and restricted their access to education) fuelled a reinforcing cycle of *poverty and disempowerment* of the population in the communal lands which made the prospect of *out-migration* appealing. Post-1994 policies (such as freedom of movement) enabled widespread *out-migration* as people moved out of the catchment in search of opportunities.

Out-migration contributes to the *disuse of cultivation fields*. The *physical characteristics* (such as soil type and topography), *climate processes*, and existing *land degradation* of the catchment necessitate farming inputs for the *viability of agriculture*; but *poverty and disempowerment* preclude farmers from acquiring these inputs. These barriers to viable agriculture further drive *the disuse of cultivation fields*. With increasing disuse of fields, the number of *invasive species* growing on fields increases, contributing to *land degradation*, which reduces the *viability of agriculture* thus leading to further *disuse of cultivation fields* in a reinforcing cycle. *Climate change* increases atmospheric *carbon levels* which increases *invasive species* plant growth. *Climate change* also increases the likelihood of both *heavy rainfall* (which directly increases soil erosion and gully formation that the physical characteristics predispose the landscape to) and *drought* (which decreases ground cover, in turn increasing soil erosion and gully formation) to cause further *land degradation*.

Past and present policies (driven by broader national issues and the breakdown of local governance systems) have resulted in *unstable governance. Poverty and disempowerment* have a negative effect on *participation in NR governance,* reinforcing the *unstable governance,* which enables *uncontrolled and overgrazing. Uncontrolled and overgrazing* reduces *ground cover*, increasing *soil erosion and gully formation* driving *land degradation. Land degradation* reduces the *livestock carrying capacity* of the area, resulting in increased *livestock deaths* which decreases *stock numbers, thus* allowing the landscape to recover and reduce *land degradation.*

Increasing *disuse of cultivation fields* together with *unstable natural resource management (NRM) governance*, leads to *grazing on fields*, which is part of a wider issue of *uncontrolled and overgrazing*, also driven by *traditional values* that emphasize the desirability of high *livestock numbers*.

3.3.2. The Tsitsa Project Response to Land Degradation

One of the ways that the TP is different from other state-funded restoration projects that typically focus on technical solutions to degradation, such as physical erosion control structures, is its explicit transdisciplinary SES approach. This includes ensuring that community perspectives and knowledge are integrated within the project, which is considered key to its long-term sustainability. Livestock numbers are culturally important to the community with less focus on their productivity which drives range degradation and low cash income [25]. Participants at a 2015 workshop in the Sinxaku villages in the catchment did not believe livestock to be a cause of erosion [16], though perceptions may have since changed. Despite livestock and grazing controls being a sensitive issue, the community responded positively to the idea of a ranger system that allows a rotational rest period of rangelands, similar to the one that existed in the past [16]. Such a ranger system would work with an agreed set of rules, developed by the community with the help of researchers, to monitor and limit activities that start or increase erosion [16].

The Tsitsa Project supports DEFF's interventions through: advice on where different measures should be applied (based on biophysical monitoring data and participatory community mapping); identifying areas at risk of erosion but not yet degraded; growing vetiver in household gardens for use in the rehabilitation (thus creating income for households); supporting livestock associations, giving advice on livestock management and facilitating

links to marketing opportunities; biophysical and social monitoring; building capacity of community members to participate in these activities and to become involved in NRM governance; building internal and external networks; and bringing these together in an integrated plan applied at the village or village group level [26]. These activities are already happening. The systems diagram (Figure 6, below) positions the TP's responses within their systemic context to demonstrate how they are linked. It shows the pathways (drivers, pressures, and stressors) through which the responses are hypothesized to affect the system. The analysis provides a basis for integrated planning. Deeper individual analysis of each potential response can identify alternate potential pathways and impacts, but part of intervening in complex systems is accepting that responses may have unforeseen or unintended consequences.

The dynamic approach of the TP has enabled the implementation of *responses* to target various *drivers* and *pressures* placed on the landscape as follows (displayed graphically in Figure 6):

- *Environmental education* envisioned to improve the capabilities of communities *to participate in natural resource governance*.
- *Market access initiatives* such as 'Meat Naturally' incentivize livestock owners to maintain livestock quality (as opposed to focussing mainly on quantity) by providing an avenue to sell healthy livestock at a good price, which would decrease active *livestock numbers*. This would be an indirect way of managing land use to improve the viability of livestock as a sustainable livelihood and could lower *poverty and disempowerment.*
- *Policies and regulations* should be explicitly designed to reverse the negative impacts of *past and present policies* on the social-ecological condition of the area.
- *Land use management* such as rangeland associations would decrease *uncontrolled and overgrazing*.
- The *removal of alien invasive species* directly decreases the number of *invasive species* on the landscape.
- Efforts to *rest the landscape* would allow necessary plant growth to increase ground cover.
- *LDN integrated land use planning* has the potential to avoid, reduce, and reverse land degradation, via multiple pathways.
- DEFF has also invested considerably in direct rehabilitation using *erosion control structures* to reduce *soil erosion and gully formation*.

In addition to responses managed by the TP listed above, the project must consider the impacts of other activities and plans on the area, and the project. For instance, there is a Forestry Master Plan to plant seven-hundred-thousand trees in the Eastern Cape in the near future [56]. The TP must consider whether the TRC will be affected and the impact of such an intervention on land degradation, sustainable livelihoods, and poverty alleviation.

4. Discussion

4.1. Synthesizing Drivers, Pressure, and Stressors Contributing to Degradation in the TRC

The application of a systems analysis as presented in this paper highlights how the environmental problems facing the TRC result from a set of interrelated core challenges (centered around biophysical aspects, overgrazing, and land use) that manifest through the interplay between various social and biophysical factors. Achieving effective, sustainable environmental governance requires a good understanding of the system drivers and consequences in the form of the complex patterns of interdependencies connecting people and ecosystems within and across scales [5]. Figures 5 and 6 present a systems perspective in terms of the $DPSCR_4$ that influence land degradation in the TRC, highlighting some key SES linkages relevant for sustainable land management. While the physical characteristics, such as dispersive duplex soils, are natural drivers that predispose the TRC to soil erosion and gully formation (stressors), it is the interplay between natural and human drivers and pressures, including forced resettlements, clearing and subsequent disuse of fields, and uncontrolled grazing (all of which exist in a socio-economic context characterized by poverty and poor governance)—that cause the resulting widespread erosion and land

degradation. This aligns with Kakembo and Rowntree's [43] finding that the main drivers of severe erosion in other parts of the rural Eastern Cape Province are the erodible soils in combination with overgrazing and disuse of fields linked to poor governance and poverty.

The historical context also has a bearing on the current social and ecological state and drivers of degradation in the catchment. A synthesis of some of the historical and current South African policies that could be drivers of either degradation or rehabilitation in the TRC can be found in Rowntree and others [16] (pp. 37–44). Poor natural resource governance and management exacerbated by the reduction of the authority of traditional leaders in the democratic era have resulted in few grazing controls and grazing on abandoned fields, which exacerbates soil erosion. It is interesting that 'disempowerment and poverty' (the two variables were coupled for this study because of their close reinforcing relationship, but can also be uncoupled) was selected by eight participants at the workshop as being in the top three drivers of degradation in the system but it was considered by four as not belonging on the list of drivers at all. The two-way relationship in which poverty causes environmental degradation and environmental degradation exacerbates poverty, termed the Poverty-Environment Nexus (PEN), has been described for other degraded developing contexts in Africa [57–59]. The over-simplification of the PEN that resulted in the poor being blamed for degradation [57,58] has been challenged, recognizing the complexity of this nexus in relation to sustainable development [60]. From a systemic point of view, the systems diagram (Figure 5, further elaborated in Appendix B) shows how poverty and disempowerment became entrenched and play a role in driving degradation through multiple reinforcing pathways. Cycles of poverty and disempowerment make catchment residents vulnerable and limit their coping strategies and ability to participate in local governance processes. In addition, the underdeveloped rural context makes poverty alleviation a (government) priority.

There is growing recognition within the TP and beyond of the role traditional knowledge and practices can play to sustainably combat degradation and improve people's lives in the long term. The TP emphasizes the importance of input and buy-in of communities and, given its applied praxis focus, the project will need to reconcile/address the disconnect between scientific and community beliefs. This is especially relevant with regards to overgrazing and grazing management, which was the most prevalent driver listed by workshop participants, but which communities surveyed do not necessarily see as a cause of land degradation; rather they wish for increased livestock numbers [16]. There is some evidence that communal grazing systems and associated 'overgrazing' do not necessarily degrade the range condition relative to management systems based on a notional carrying capacity. An Eastern Cape case study showed that communal grazing lands, considered 'overgrazed', had only slightly higher erosion rates than those from the land under 'optimal' grazing, that is grazed at a level considered not to exceed the carrying capacity of the land [61]. The question of whether stock numbers or management practices play a bigger role in the condition of the landscape remains a key debate [62,63]. There is an argument that by using management practices such as rotational grazing, greater stock numbers can be supported [64]. This is the underlying principle being advocated through rangeland associations [16], the formation of which the TP is facilitating.

Furthermore, there is no consensus among scientists on the role of overgrazing as a key driver of degradation, with some ecologists arguing that erosion and degradation in the Eastern Cape grazing systems (such as the TRC) are driven more by rainfall events and other factors than by overgrazing [61]. The Residual Trends (RESTREND) method [65] may be useful for controlling the effects of rainfall in order to detect human-induced land degradation at a regional scale by identifying areas where there has been a reduction in production per unit rainfall. The exact cause of the negative trend, e.g., overgrazing by livestock, must be more closely investigated. More data on perceived overgrazing are needed to assess its role as a driver of degradation in the system. Recent soil studies show that relatively small areas are very sensitive to erosion and can benefit significantly from increased vegetation cover [13,23].

While subsistence fields currently make up only 5.3% of the land use in the study area [47], the impact of field disuse on degradation should be explored further because duplex soils are particularly susceptible to land degradation when cleared [42]. A case study of historical land-use change and erosion in a communal Eastern Cape area showed that the most severe erosion was associated with cultivated land that had been abandoned and reverted to grazing land from the 1960s, and not from land that had been under grazing since the 1930s [61].

The drivers of land degradation in the TRC reflects certain core challenges that occur repeatedly across landscapes with similar social-ecological contexts. Other former homelands in South Africa, such as Venda in current day Limpopo, have similar socio-political histories and face similar challenges as the TRC with regards to poverty and land degradation [59]. There are, however, some ways that the drivers of degradation in the TRC contrast with other communal areas in South Africa. Fuelwood is the dominant source of energy and a major contributor to woodland degradation in other communal areas in South Africa [38]. In contrast, fuelwood collection did not feature strongly as a driver of degradation in TRC in either the workshop responses or the document review, suggesting that it may not play a prominent role as a driver of degradation in the system. This corresponds with the finding that the number of households with access to electricity in the catchment more than tripled from 2026 to 6663 between 2000 and 2011 [49]. Survey results from the Sinxaku villages, however, suggests that even when electricity is used for lighting, wood is still a preferred energy source for cooking and heating [16], corresponding with the majority of rural households in southern Africa [66]. When asked about their use of natural ecosystem resources, firewood collection was an overwhelming response in Sinxaku villages but little wood is in fact collected from the local area as most that are used in households on an everyday basis is purchased from a plantation and brought in by the small truckload [16]. Wood for ceremonial purposes is collected from the local environment [16]. The impact of fuelwood collection on livelihoods and degradation in the area is worth exploring further. Encroachment of grassland by woody vegetation (thorn trees) is seen as one sign of degradation, so removal of fuelwood from alien clearing and woody encroachment could be a positive intervention.

4.2. Responses to Avoid, Reduce, or Reverse Land Degradation in the TRC

Restoration practices in Africa must be carefully tailored to the local context. The South African DEFF's provision of funding and involvement in the TP is an important step beyond business-as-usual management responses that counter land degradation through the restoration of ecological infrastructure. Arnold and Wade's [20] characterization of systems thinking guided the process of characterizing the drivers, pressures, and stressors that affect the condition of the TRC, as well as the way these characteristics feed back into each other to systemically understand land degradation to inform sustainable land management (responses) in the TRC. This synthesis will inform the TP as DEFF's flagship restoration research-praxis project by enabling the project to systemically position and analyze a range of existing and potential future responses within the $DPSCR_4$ framework. This synthesis also highlights the importance of tailoring responses in the TRC to meet the goals of restoration and income generation/poverty alleviation simultaneously.

Responses could be targeted toward LDN. The TP's commitment to work with communities to implement appropriate and sustainable interventions has led the project to start developing multiple integrated restoration plans at a nodal scale, which could be designed to feed into LDN planning at sub-catchment and catchment scales. There has been some integration in an initial 2018 rehabilitation plan that was drawn up for the project [25]. Some key aspects of the plan include attention to social-ecological linkages, capacity development, avoided degradation and monitoring, evaluation, reflection, and learning. Further work on integrated rehabilitation plans for three specific nodes that are pilots within the catchment is currently underway (TP draft document: 'Elangeni node—Integrated implementation plan 2020').

The LDN approach within the responses category comprises the counter-balancing of anticipated losses in land-based natural capital with planned gains. The LDN hierarchy aims to avoid, reduce, and then to reverse land degradation. Many parts of the TRC are already degraded, but the options in terms of LDN responses should be geared towards avoiding the degradation of currently functioning systems, followed by reducing future degradation and reversing existing degradation. Incorporating land degradation neutrality into existing planning processes can shift land management in the TP from a reactive space into a proactive sustainable space. In addition to having an understanding of the current situation, LDN planning must consider potential future scenarios for development that could affect land degradation in the study area. In this regard, there is expected to be significant afforestation in the Eastern Cape in the near future. Seven-hundred-thousand trees are planned to be planted to meet the fifteen-year global wood shortage and for poverty alleviation [56]. The planting of trees ties into global and regional restoration initiatives such as AFR100, which targets 100 million hectares (Mha) of land in Africa for 'reforestation' by 2030, and within which South Africa has committed 3.6 Mha [67]. This extensive tree planting is framed as 'reforestation' to reduce atmospheric CO_2, but most targeted areas in Africa are grassland and savanna biomes, and the social, economic, and ecological effects of converting such areas to plantations are not well understood [68,69]. Critics of such initiatives argue that while the restoration of pre-existing forests is effective in terms of climate change mitigation, plantation forestry is not [68]. Furthermore, the top-down implementation of plantation forestry ignores local concerns over land tenure, competition with agriculture, and conservation, and imposes a single dominant land use for generations to come [68]. A systemic analysis of the effectiveness of tree planting to alleviate degradation and as an avenue for sustainable livelihood creation in the TRC needs to be conducted.

Land degradation severely impacts the livelihoods of rural communities in South Africa more broadly, and in the TRC specifically. Recognizing that land degradation is a social-ecological phenomenon that reduces, over a period of time, the capacity of the land to provide ecosystem goods and services to its beneficiaries, the systemic analysis in this paper has shown the importance of understanding both the social and biophysical drivers of degradation and the way that these drivers interact to place pressure on the landscape. The TRC is an example of a region where carefully planned changes in land use and management could produce dual benefits of improving landscape conditions and sustainable livelihood opportunities. As such, the region is illustrative of the potential of integrated planning processes to support achieving land degradation neutrality targets within the context of the UN Decade on Ecosystem Restoration and the 2030 SDG agenda.

5. Conclusions

Land degradation in rural South Africa is a major threat to livelihoods with people being vulnerable due to poverty and a lack of integrated natural resource planning. A social-ecological system of understanding the drivers of degradation in the Tsitsa River Catchment (TRC) is essential for informing sustainable land management. A systems approach was used in this study together with two frameworks, the Drivers-Pressures-Stressors-Condition-Responses (DPSCR) and Land Degradation Neutrality (LDN) frameworks. Innovative data collection techniques of coupling interviews with workshops and systems diagramming resulted in the identification of the key drivers of degradation, and the linkages between them, some of which would likely have been overlooked using only a single approach. Physical and climatic variables, changes in land use and land cover, and overgrazing were identified as key factors leading to degradation. An integrated sociological and ecological study provided a basis for planning changes in land use and management that could produce dual benefits of improving landscape conditions and sustainable livelihood opportunities.

Author Contributions: This research article has several authors; their individual contributions are specified below: Conceptualization and methodology, A.I., M.C.S. and J.K.C.-H.; investigation, data

curation, and validation, A.I.; foundational analytical work within the broader Tsitsa Project that this paper builds from K.R. and B.v.d.W.; broader literature and project documentation contributions A.I., K.R. and B.v.d.W.; formal analysis, A.I., and J.K.C.-H.; writing—original draft preparation, A.I.; writing—review and editing, M.C.S., J.K.C.-H., K.C., K.R. and B.v.d.W.; supervision, M.C.S., J.K.C.-H., and K.C.; & funding acquisition, M.C.S. All authors have read and agreed to the published version of the manuscript.

Funding: Funding for this study, (PhD scholarship and research costs) has been provided to Mary Scholes through her DST-NRF research chair in System Dynamics. The research and implementation of the broader Tsitsa Project has been funded by the Department of Environment, Forestry and Fisheries (DEFF), Chief Directorate: Natural Resource Management Programmes (NRM), Directorate: Operational Support and Planning. The contents of this paper do not necessarily reflect the views and the policies of DEFF, Chief Directorate: NRM, nor does the mention of trade names or commercial products constitute endorsement or recommendation for use.

Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Ethics Committee of the University of the Witwatersrand (protocol code H19/09/13, date of approval 13 September 2019).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data collected by the authors of this study are available on request from the corresponding author. The data are not publicly available due to the need to comply with the ethics clearance certificate obtained, from the University of the Witwatersrand, for this study. Restrictions may apply to the availability of third-party data. Data obtained through Tsitsa Project reports and documentation are available upon request from info.tsitsaproject@ru.ac.za with the permission of the project manager.

Acknowledgments: The Rhodes Restoration Research group (within the Department of Environmental Science), the Institute for Water Research and the Geography Department at Rhodes University for providing access to project documents for analysis. The Department of Forestry, Fisheries and the Environment (DFFE), for being an active research participant and partner to the Tsitsa Project. Funding for this research was provided by my research supervisor, Mary Scholes, who holds a Research Chair at the University of the Witwatersrand Johannesburg. Her Research Chair is funded by the Department of Science and Innovation and the National Research Foundation of South Africa.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Appendix A

Table A1. Internal project documents that were used, together with key informant data and published literature, to develop the synthesis of drivers of degradation in the TRC. These documents are available from the Tsitsa Project, either on the website (https://www.ru.ac.za/tsitsaproject/) or upon request (info.tsitsaproject@ru.ac.za).

Author(s)	Date	Title	Type & Relevance of Document
Botha, L., Rosenberg, E., Biggs, H., Kotschy, K. and Conde-Aller, L.	2017	Ntabelanga-Lalini Ecological Infrastructure Project (NLEIP) Participatory Monitoring, Evaluation, Reflection & Learning (PMERL) Framework	Internal TP report, articulates the project's intention to integrate the interests of people and nature, communities and landscapes, in a social-ecological systems framework, and explains the PMERL approach to monitoring and evaluation.
Biggs, H., Clifford-Holmes, J., Conde-Aller, L., Lunderstedt, K., Mtati, N., Palmer, T., Powell, M., Rosenberg, E.,Rowntree, K., Van Der Waal, B. and Wolff, M.	2019	The Tsitsa Project Research Investment Strategy (vol 2) expanding into praxis: a resource library (Vol. 2).	Presents a revised set of coherent praxis-related objectives, Trans-disciplinary 'stitching together' or unifying activity between the Tsitsa Project's communities of practice, whose coordinators were key authors of parts of the report. Includes a number of relevant appendices from other TP processes and meetings.

Table A1. *Cont.*

Author(s)	Date	Title	Type & Relevance of Document
Fabricious, C., Biggs, H. C. and Powell, M.	2016	Research Investment Strategy: Ntabelanga and Laleni Ecological Infrastructure Project.	Internal TP report, initial research investment strategy for what developed later into the Tsitsa Project.
Herd-Hoare, S.	2015	Understanding local institutions as a basis for ecological restoration efforts in communal areas: the case of Sinxaku Village, Eastern Cape.	Honours dissertation focusing on the underlying social causes of land degradation in the TRC.
Hodgson, D.	2016	Demographic Change in the Upper Tsitsa Catchment: The Integration of Census and Remote Sensed Data for 2001 and 2011	MSc dissertation, provides demographic profile using South Africa National Population Censuses for 2001 and 2011 and the National Land Cover (NLC) data sets for 2000 and 2013/14.
Huchzermeyer, N.	2017	A baseline survey of channel geomorphology with particular reference to the effects of sediment characteristics on ecosystem health in the Tsitsa River, Eastern Cape, South Africa.	MSc dissertation of the effects of sediment characteristics on ecosystem health in the TRC.
Huchzermeyer, N., Schlegel, P., and van der Waal, B.	2019	Biophysical Monitoring Methods in the Upper Tsitsa River Catchment (T35 A-E).	Internal TP report that outlines results from 8 Veld Condition Monitoring sites across T35 A, D & E. Also outlines rangeland performance and forage production.
Rowntree, K., Conde-Aller, L., Fox, H., Duma, M., and Ntshudu, M.	2018	Improving socio-economic conditions through landscape greening, a case study from the Tsitsa River catchment, uMzimvubu basin. Vol 1 of The Green Village Project-Improving socio-economic conditions of the Tsitsa River catchment and Okhombe communities through landscape greening and integrated green innovations.	Water Research Commission Report TT 777/1/18, the Green Village Project took a participatory action research approach to identify drivers of poverty, and opportunities to improve socio-economic conditions of communities through landscape greening.
Schlegel, P., and Huchzermeyer, N.	2018	Biophysical Monitoring Plan Tsitsa River T35A-E, Methodological Outline Report.	Internal TP report, outlines location, geology, soils, topography, rainfall, vegetation, land use & land cover (Maps and data of Land cover (1990, 2001 & 2013/2014-DEA EGIS). Introduces $DPSCR_4$ as the integrated monitoring framework for the Tsitsa Project
van der Waal, B., Rowntree, K., Le Roux, J., Buckle, J., Biggs, H., Braack, M., Kawa, M., Wolff, M., Palmer, T., Sisitka, L., Powell, M., Clark, R., Ntshudu, M., Mtati, N., van Tol, J., and van Zijl, G.	2018	The Tsitsa Project Restoration and Sustainable Land Management Plan Infrastructure for Improved Livelihoods and Futures T35A-E (Phase 1 of TP).	TP Report to: Department of Environmental Affairs: NRM Programmes. Directorate-Operational Support and Planning.

Appendix B

The description of the causal loop diagram (CLD) below focusses on the reinforcing and balancing feedback loops that were omitted from the paper in favor of simpler systems diagrams (Figures 5 and 6) using a format that is more appropriate for the $DPSCR_4$ LDN framework. See the narrative around Figures 5 and 6 in the paper for a fuller description of the systemic hypothesis of drivers of degradation in the Tsitsa River Catchment.

R1 historical policies driving poverty and disempowerment

Prior to 1994, *apartheid policies* forced large numbers of indigenous people on to the Transkei (current communal lands of the catchment), and restricted *access to education*. These policies fuelled a reinforcing cycle of *poverty* and *disempowerment* of the population in the communal lands (R1).

R2 field abandonment driving degradation

During the post-1994 democratic era, freedom of movement has enabled widespread migration decreasing the population of the communal lands as people move in search of opportunities and *access to education*, thus contributing to the *disuse of fields*. With increasing *disuse of fields,* the number of *invasive alien plants* growing on fields increases, contributing to *land degradation,* which reduces the *viability of agriculture* thus leading to further *disuse of fields in a reinforcing cycle (R2).* Increasing *disuse of fields* together with a lack of *grazing and fire controls* leads to *grazing on abandoned fields* which reduces *ground cover* on the fields which, combined with the *physical characteristics* and *heavy rainfall* lead to *soil erosion, sheet erosion, surface runoff and gully formation* contributing to *land degradation and joining reinforcing cycle (R2) to* reduce the *viability of agriculture* and lead to further *disuse of fields.*

R3 poverty driving poor stock quality

Poverty decreases the livestock inputs that people can afford, thus drives poor stock quality (health) which reduces livestock products, livestock sale opportunities and livestock value as an asset thus more deeply entrenching poverty in a reinforcing cycle (R3).

R4 poverty driving field abandonment

Poverty decreases people's ability to buy *farming inputs* which decreases the *viability of agriculture*, thus increasing the *disuse of fields*, increasing *grazing on abandoned fields* which decreases *ground cover,* further damaging *stock quality*, which negatively impacts *livestock products, livestock sale opportunities* and *livestock value as an asset*, thus more deeply entrenching poverty in a reinforcing cycle (R4).

R5 poverty affecting participation in natural resource (NR) governance

Poverty negatives affects *participation in NR governance* (it is a barrier to people being able to attend meetings due to transport costs etc.), which is a *NR governance factor* necessary for *natural resource governance.* Poor *natural resource governance* results in a lack of *rangeland management* with no *grazing and fire controls*, which reinforces *poverty* and a *lack of participation in NR governance* through livestock and field abandonment pathways (R5). Poor *natural resource governance* as a consequence of the *breakdown of local governance systems* and other broader *national drivers* has resulted in poor *rangeland management* without *grazing and fire controls* such as *rotational grazing*. This means that *stocking numbers* are only controlled through balancing loops B1 and B2.

B1 Food cover and diversity balancing livestock numbers

Traditional values emphasize livestock *stocking numbers* (with less focus on their productivity) (van der Waal et al., 2018). As *stocking numbers* go up and continuous grazing takes place, *ground cover* and *graminoid and non-graminoid diversity* go down, thus impacting negatively on *stock quality (health)* leading to *livestock deaths* which reduces *stocking numbers* in a balancing loop (B1).

B2 land degradation balancing livestock numbers

Land degradation reduces the *livestock carrying capacity* of the area, resulting in increased *livestock deaths* which decreases *stocking numbers, thus* allowing the landscape to recover and reducing *land degradation* in a balancing loop (B2).

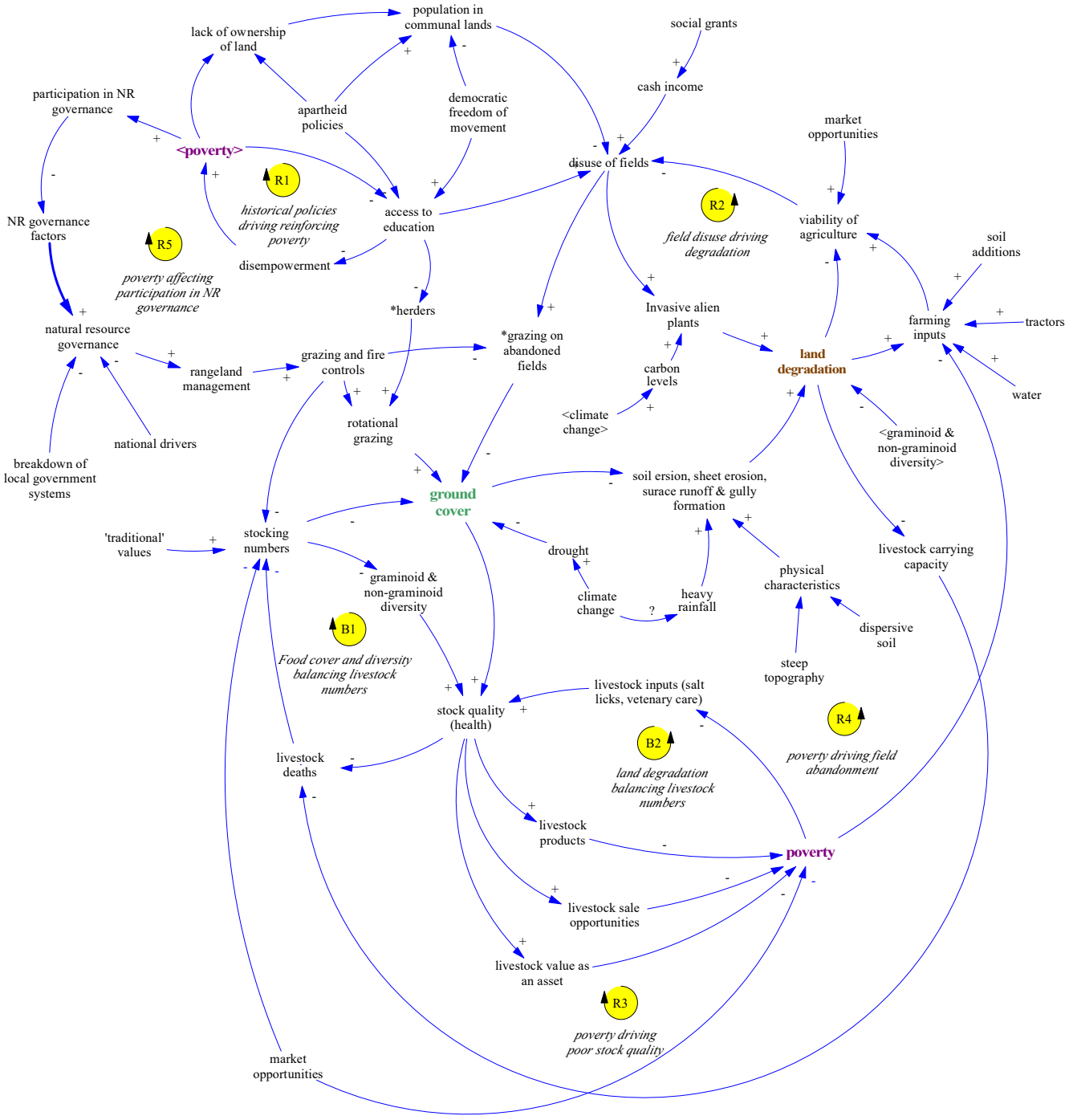


Figure A1. The interview and workshop data as well as a literature and document review were used to draw up a causal loop diagram (CLD) of the linked social-ecological systems (SES) drivers of land degradation in the Tsitsa River Catchment (TRC). The CLD numerically identifies reinforcing loops 'R' and balancing feedback loops 'B' (highlighted in yellow).

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4.2 Postscript

The paper provides a synthesis of the current state of understanding on the drivers of degradation in the TRC of South Africa using a social-ecological systems approach. A unique aspect of this paper is the development and application of a composite framework embedding the concept of land degradation neutrality within the 'drivers, pressures, stressors, condition responses' (DPSCR4) model, presented as a systems model. Taking this approach to understand the environmental, social, economic, and governance factors which drive the system, and importantly the particular linkages between them, provides an opening to conduct 'degradation research' in novel ways, such as through systems thinking and modelling.. The application of the approach presented in this paper highlights how the environmental problems facing the TRC result from a set of interrelated core challenges (centred around biophysical aspects, overgrazing, and land use) that manifest through the interplay between various social and biophysical factors; and impact both landscape conditions and sustainable livelihoods. The participatory nature of the research process for this paper helped to integrate transdisciplinary perspectives and build a common understanding of the problem context. Core challenges that emerged from the participatory process, which go beyond the scope of this paper, were further developed in the next chapter, which speaks to the development of a social learning process that explores approaches to enhance integration and monitoring in SES. The drivers, pressures, and stressors identified in this paper form the basis of a provisional list of potential monitoring variables for further assessment in Chapter Six.

CHAPTER 5 – A SOCIAL LEARNING PROCESS TO ENHANCE INTEGRATION AND MONITORING OF SOCIAL-ECOLOGICAL SYSTEMS

5.1 Preface

In the preceding chapter, it was established via the participatory research process that the environmental problems facing the TRC result from a set of interrelated SES factors. Therefore, an integrated approach, rooted in SES principles, would be essential for monitoring the TP's progress in relation to its vision and objectives. Integration and monitoring are pressing conceptual and methodological challenges in SES research more broadly, as well as in the TP case study. The participatory research process that began instrumentally (to meet objective one in the previous chapter) was extended into a more deliberate social learning process where the emergent challenges and opportunities around SES integration and integrated monitoring in the TP, and wider SES research, were collaboratively explored. This paper serves as a means of documenting the social learning process, called participatory self-observation (PSO), piloted by a group of action-researchers to improve SES integration and monitoring, using the TRC in South Africa as a case study. The lessons learnt are analysed as a basis to provide insights and recommendations to improve integration and monitoring in social-ecological systems research. The publication is available at: https://www.mdpi.com/2073-445X/11/10/1848

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Approaches to Enhance Integration and Monitoring for Social-Ecological Systems

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Abstract: Integration and monitoring are pressing conceptual and methodological challenges in social-ecological systems (SES) research. This paper follows a social learning process, called participatory self-observation, piloted by a group of action-researchers to improve SES integration and monitoring, using the Tsitsa River Catchment in South Africa as a case study. The participatory self-observation process reflected on lessons to enhance integration and integrated monitoring of biophysical, social, and social-ecological data in SES projects; for adaptive planning and management. Three focal points emerged for improving the challenges of SES integration: the need for participatory people-based processes, the importance of applied praxis tasks to catalyze meaningful integration, and the need for transdisciplinary teams to value non-biophysical research. Five focal areas emerged as major challenges for SES monitoring: the integration of qualitative and quantitative data, data overload, the scale of SES monitoring, the need to center SES monitoring around learning, and good working relationships to enable data flow. Recommendations to further develop integrated monitoring and management of SESs include (i) using people-based approaches that focus on applied work which includes rigorous collection of quantitative, biophysical data, (ii) identifying essential data needs through an essential variable approach, and (iii) combining quantitative monitoring with participatory people-based processes.

Keywords: social-ecological systems integration; integrated monitoring; participatory self-observation; social learning

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Citation: Itzkin, A.; Clifford-Holmes, J.K.; Scholes, M.; Coetzer, K. Approaches to Enhance Integration and Monitoring for Social-Ecological Systems. *Land* **2022**, *11*, 1848. https://doi.org/10.3390/land11101848

Academic Editors: Ileana Pătru-Stupariu and Christine Fürst

Received: 14 September 2022
Accepted: 18 October 2022
Published: 20 October 2022

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1. Introduction

Integrated landscape studies have for decades been focussed on a characterization of biophysical parameters thought to be the drivers of ecosystem function. It has been increasingly recognised that ecosystem function is affected by both sociological and biophysical issues which occur within social-ecological systems (SES) in which they are embedded [1]. These SESs are complex due to a number of processes that are non-linear and unpredictable [2]. There is a growing awareness that understanding and managing complex systems, which involve numerous stakeholders, a range of land uses and different governance systems, requires an SES approach [2–4]. While progress has been made to advance aspects of SES research and management, including the development of various methods [5,6] and frameworks [7–9] which account to different extents for the various features of SESs [6], many conceptual and methodological challenges remain [5].

Integration across social and ecological disciplines, and integration between science and society, are widely recognized as being crucial, yet challenging, aspects of SES research and management [5,10,11]. SES integration is a precursor to integrated monitoring, which is another essential, but challenging, part of SES research and management [5,8,10,12]. This paper shares insights gathered from a transdisciplinary social learning process called

participatory self-observation (PSO) where researchers collaborated to improve SES integration and monitoring. The PSO process was developed for a group of action-researchers involved in an SES project, the Tsitsa Project, in the Tsitsa River Catchment, South Africa, to collectively conduct a transdisciplinary analysis of their project and the SES in which it is embedded. The PSO process's participatory approach draws on the biophysical and sociological data, methods and knowledge in the Tsitsa Project, and applies thematic and systems analysis. The advantage of a data integrative and people-driven approach, as used in the PSO, is that it allows for greater understanding of contextual interactions (such as feedback loops) between system components of both biophysical and social elements, to make better sense of the system, and to develop approaches to fill gaps identified by researchers during the process [6]. The insights and recommendations that emerged from this project can enhance SES integration and monitoring in other SES projects.

Integration and Monitoring Challenges in Social-Ecological Systems

SES research is an interdisciplinary and transdisciplinary domain in which an integrated understanding of both social and ecological aspects of environmental issues is seen as essential to address complex sustainability challenges [5,11,13,14]. The number of SES research publications has risen significantly since 2010 [11] and the need to better integrate the social and the ecological in SES research is increasingly recognised [10,11]. Integration is widely regarded as the primary methodology of interdisciplinarity [15], and has been called "the core methodology underpinning the transdisciplinary research process" [16]. SES research requires knowledge co-production and participatory approaches [12], and the process of knowledge integration has been identified as key to the added value of transdisciplinary research [17]. Integration, here defined as "the desire to assimilate heterogeneous knowledge (via data, analysis, or claims) through processes of co-production" ([18], p. 160), has been described as "the main cognitive challenge of the transdisciplinary research process" ([19], p. 4). A body of literature has developed on some of the aspects which make integration between and beyond scientific disciplines complex [5,20]. Furthermore, the dynamic interactions of SESs can lead to emergent properties and unintended consequences [2], thus increasing the complexity of SES integration.

Ideally, integration should occur on several levels in the knowledge co-production process: framing the problem, managing the project, including team members and stakeholders, collecting and analyzing data, synthesizing results, and applying insights [21,22]. Yet, there are well-documented methodological challenges in integrating the social and the ecological in SES research [22]. Although a number of analytical frameworks, methods, and approaches have been developed to achieve better integration and to overcome these methodological challenges [10,23–25], overall integration in social-ecological research is still lacking [10].

Another dimension that has been highlighted as a particular challenge in SES research is monitoring [5,12]. Although it is crucial to monitor the progress of an SES project towards meeting its vision and objectives, real-world applications remain scarce [12,26]. This could, in part, be because there are relatively few methods to assess the impacts of research and action in SES [5,20]. A second part of the challenge is the different conceptual frameworks and terminology used in relevant fields, including earth observation, evaluation, and social learning, all of which may characterise elements of a SES project, but prevent a common understanding. Thirdly, the complexity of the SES predisposes monitoring of the system to 'data overload' issues, which are typical of many monitoring programmes [27]. This requires monitoring strategies that focus on only data deemed essential [28], with what is deemed 'essential' in itself challenging to a priori identify. In addition, observation systems, which form the basis of monitoring in the earth sciences, are typically quantitative and biophysically focussed (e.g., biodiversity, climate, ocean, global earth observation), and thus may not adequately take into account the impact of social and social-ecological drivers. The dynamic, largely open-ended nature of SES, featuring complex feedback loops and emergent properties, requires real-time learning to inform adaptive management [29,30].

The way that M&E is conventionally implemented does not typically support the required learning, reflection and adaptive management to respond to this challenge [31–33]. In response to this limitation, monitoring, evaluation and learning (MEL) methods have been developed to stimulate, capture and respond to shared learning that is relevant to SES research and programmes [5]. MEL can use qualitative methods, less formal observations, and shared reflection to shed light on complex causal processes in individual SESs [20,33].

Integration and monitoring are interrelated in that monitoring approaches in action-oriented SES research need to be integrative of the social and ecological systems, both in the types of data they are using and the types of questions they are addressing [12,26]. A lack of integrated SES monitoring inhibits understanding of: (a) whether management actions improve social and/or ecological outcomes; (b) the mechanisms or pathways underpinning these outcomes; and (c) the non-linear relationships between these outcomes [12].

2. Materials and Methods

2.1. Case Study Context

The SES and complexity-based literature emphasizes the importance of problem context [2,29]. Located in the Eastern Cape Province of South Africa, the Tsitsa River Catchment is characterized by steep topography [34] and consists of sedimentary layers of the Triassic age, including Adelaide mudrock succeeded by mud-stones of the Tarkastad, Molteno and Elliot Formations [35,36]). Soils in the catchment vary but those from the mudstone parent material in the central part of the catchment are associated with duplex soils that are highly erodible, contributing to the formation of extensive gullies [36]. The climate is sub-humid with mean annual rainfall ranging from 625 mm in the lower plains to 1327 mm in the mountains [36]. The catchment falls mainly within the Grassland biome [37]. A moderate to poor grazing grass, *Sporobolus africanus*, which is an indicator of overgrazing, was found to be the dominant grass species at five out of eight monitoring sites [38]. Other dominant grass species found at monitoring sites in catchment have been tabulated ([38] pp. 46–47). The integrity and functionality of the grassland biome is threatened by unsustainable land use and the encroachment of alien vegetation by both woody invasive alien species (such as the Australian wattle spp., *Acacia* species), and shrubs (such as bramble, *Rubus* species) [38]. The catchment comprises of a combination of communal land managed by traditional leaders under customary law [39], and private land (Figure 1) [40]. Colonial and apartheid policies which controlled where people could live and work prior to 1994 have had a lasting impact on the social-ecological landscape of the communal lands, contributing to disempowerment and poverty, and to continued degradation [40]. The communal land, where the majority of the catchment's population reside, is found mostly in the middle and lower parts of the catchment, which coincides with more erodible soils [41]. There is significant out-migration [42]. Residents still rely, to an extent, on natural resources [43], and livestock hold cultural and financial value to residents [40]. There are two primary grazing management systems in place: a more sustainable rotational grazing model on privately owned land and an unsustainable continuous grazing model on communal land [40]. The land degradation in the catchment is driven by a complex interplay of the ecological and social factors discussed above [44].

While context is a key consideration in SES studies, the nature of many environmental problems are not entirely unique [45]. Instead, they reflect a series of core challenges that occur repeatedly across many different cases and contexts. The catchment is typical of many challenges faced by other catchments in the developing world in that it is rural, under-developed, faced with land degradation and high levels of poverty, and is situated within a complex governance environment [4,38–41]. The Tsitsa River Catchment case study was used because it has many features representative of a complex rural SES landscape, and because there is a transdisciplinary array of stakeholders actively working on a government-funded praxis [46] project to improve SES sustainability [4,38–44]. In the Tsitsa Project, interdisciplinary researchers, natural resource managers and residents collaborate to apply an SES approach to support sustainable livelihoods and improve landscape management [4].

The Tsitsa Project is a praxis project funded by the South African Department of Forestry, Fisheries and the Environment (DFFE), who are using it as an experimental space to inform their natural resource management (NRM) processes and projects. The unique positioning of the project provides exciting learning opportunities that can be used not only in this project but also for other projects interested in using similar approaches. Research in the Tsitsa Project is approached through six themed communities of practice along research-praxis themes: 'Sediment and Restoration', 'Governance', 'Livelihoods', 'Grass and Fire', 'Knowledge and Learning', and 'Systems Praxis' [47]. The Tsitsa project focuses its efforts on quaternary catchment T35A-E (Figure 1). A Quaternary catchment is a hydrological delineation for fourth order catchments in the South African classification system, in which a primary catchment is the major unit [48]. Quaternary catchments are the principal units for water resource management in South Africa [48].

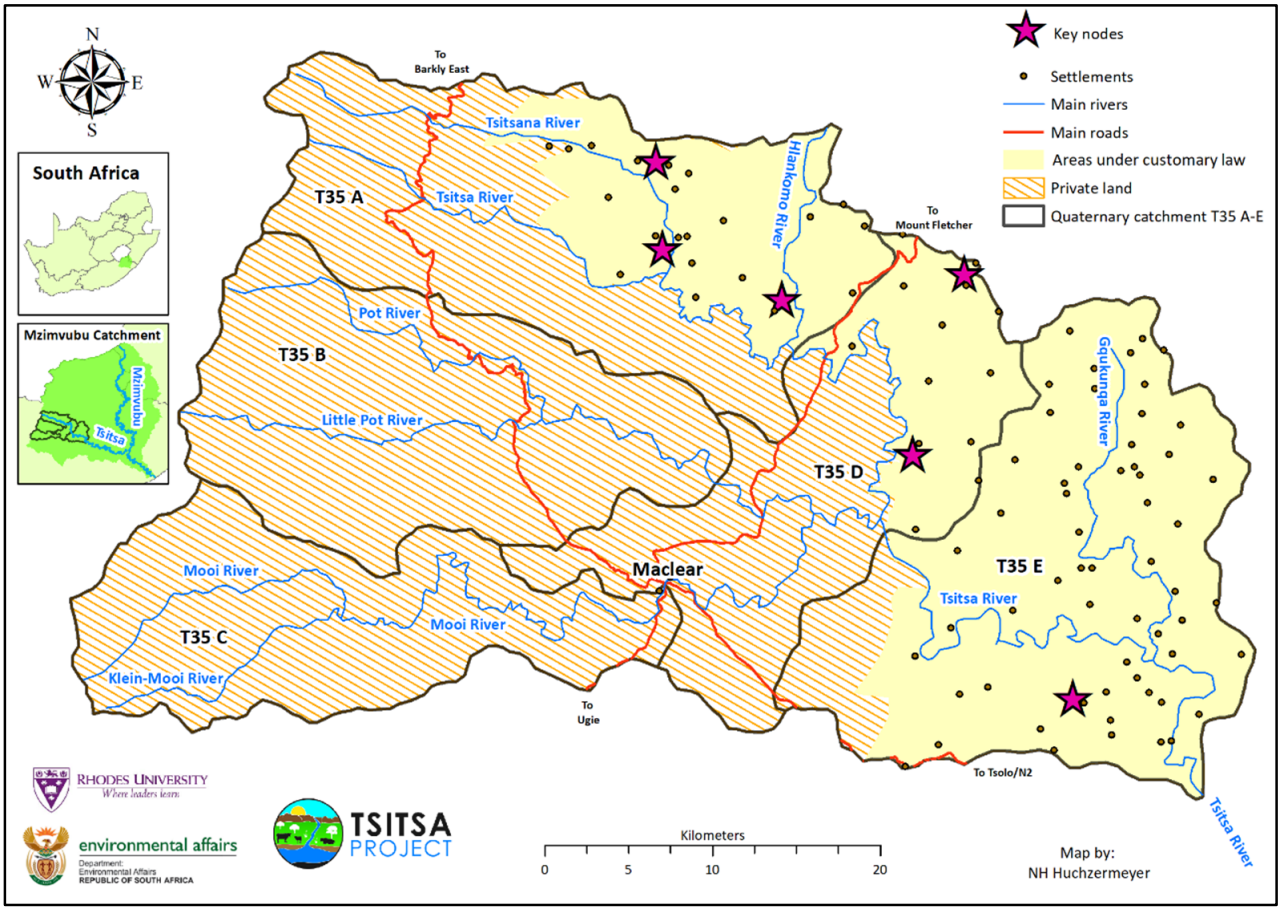


Figure 1. Map of the Tsitsa River Catchment. Quaternary catchments are hydrological delineations of sub-catchments (numbered by the South African system of T35 A–E); and key nodes refer to focal areas for the Tsitsa Project's engaged research and restoration work. Map by N.H. Huchzermeyer.

2.2. Integration and Monitoring Challenges in the Tsitsa Project

Like other complex SES projects, integration and monitoring are critical challenges in the Tsitsa Project [41]. The integration of data and mental models across transdisciplinary actors is central in the Tsitsa Project vision "to support sustainable livelihoods for local people through integrated landscape management that strives for resilient social-ecological systems and which fosters equity in access to ecosystem services" [49]. The project places strong emphasis on the importance of learning to promote collaboration amongst the different stakeholders involved and to enhance an adaptive approach within the project activities. In 2017, Tsitsa Project leadership engaged with experts who had experience in designing a complexity-sensitive MEL system for a catchment-based programme implemented by

the Association for Water and Rural Development (AWARD) in South Africa's Limpopo-Olifants Basin [20]. The experience from implementing and refining AWARD's system informed the participatory monitoring, evaluation, reflection and learning (PMERL) system for the Tsitsa Project [4,47,50–54]. The team that developed the Tsitsa Project's monitoring approach emphasize that in order for PMERL to lead to learning, the project must also integrate across diverse data sources and forms of knowledge [47]. The Tsitsa Project monitoring system should thus reflect the project's principles, which include: SES thinking; transdisciplinarity; a collaborative, reflexive and adaptive orientation; participation; and a strong scientific evidence base [47], encompassing issues that traditional M&E processes do not typically capture well. Emphasis needs to be placed on ongoing learning (i.e., formative evaluation) to develop appropriate feedback processes for strategic adaptive management and planning [47]. Project members have made ongoing efforts to find ways to incorporate and integrate these principles further.

The PSO process piloted in this case study is one way that project members have been collaborating to help realize this ambition. In the PSO process, experts underwent a learning process to help identify integration and monitoring challenges and gaps and to point to some insights on how these challenges could be addressed to enhance SES projects in this project and more broadly. PSO responds to the need for transdisciplinary teams to collaborate with a focus on learning in applied contexts such as in the Tsitsa Project. The PSO process is intentionally iterative and can include many rounds of feedback to adapting project objectives and implementation.

2.3. Methods

The research process was undertaken in four main phases, beginning with a scoping phase and followed by three phases of analysis and modelling (Figure 2).

The initial scoping phase was undertaken with various members of the Tsitsa Project research team and achieved an understanding of the key issues from various perspectives [30]. Data were generated from three sources: key informant interviews (data sources coded hereafter as 'I'), internal project documentation (particularly PMERL quarterly and annual reports; coded as 'D') and two workshop sessions (coded as 'W1'& 'W2'—reports from the workshops are available from the Tsitsa Project management at info.tsitsaproject@ru.ac.za upon request). Interview participants (n = 19) were selected based on their skills and position in the Tsitsa Project [55], and consisted of the heads of the various communities of practice in the project and representatives of the project management team. Collectively these stakeholders form the transdisciplinary research-praxis base of the Tsitsa Project.

During analysis and modelling phase 1, the interview and project documentation data were thematically analysed by the facilitating researcher as described by Braun and Clark [56,57] with codes emerging on the basis of the information collected from participants [58]. Data were used to create systems models [59,60] that paint a systemic picture of how the Tsitsa Project team sees the key issues playing out in the system. These systems models were presented, verified and discussed at a social learning workshop (W1, online), to which the interview participants and broader stakeholders identified during the interviews were invited. This workshop was attended by representatives from all the Tsitsa Project research-praxis communities of practice and various transdisciplinary stakeholder organisations including research institutions, implementers, NGOs and government funders (n = 29). Following W1, further verification and updates were gathered from project documents and reports compiled by the PMERL team. A review of SES literature on the themes that emerged from the process was done.

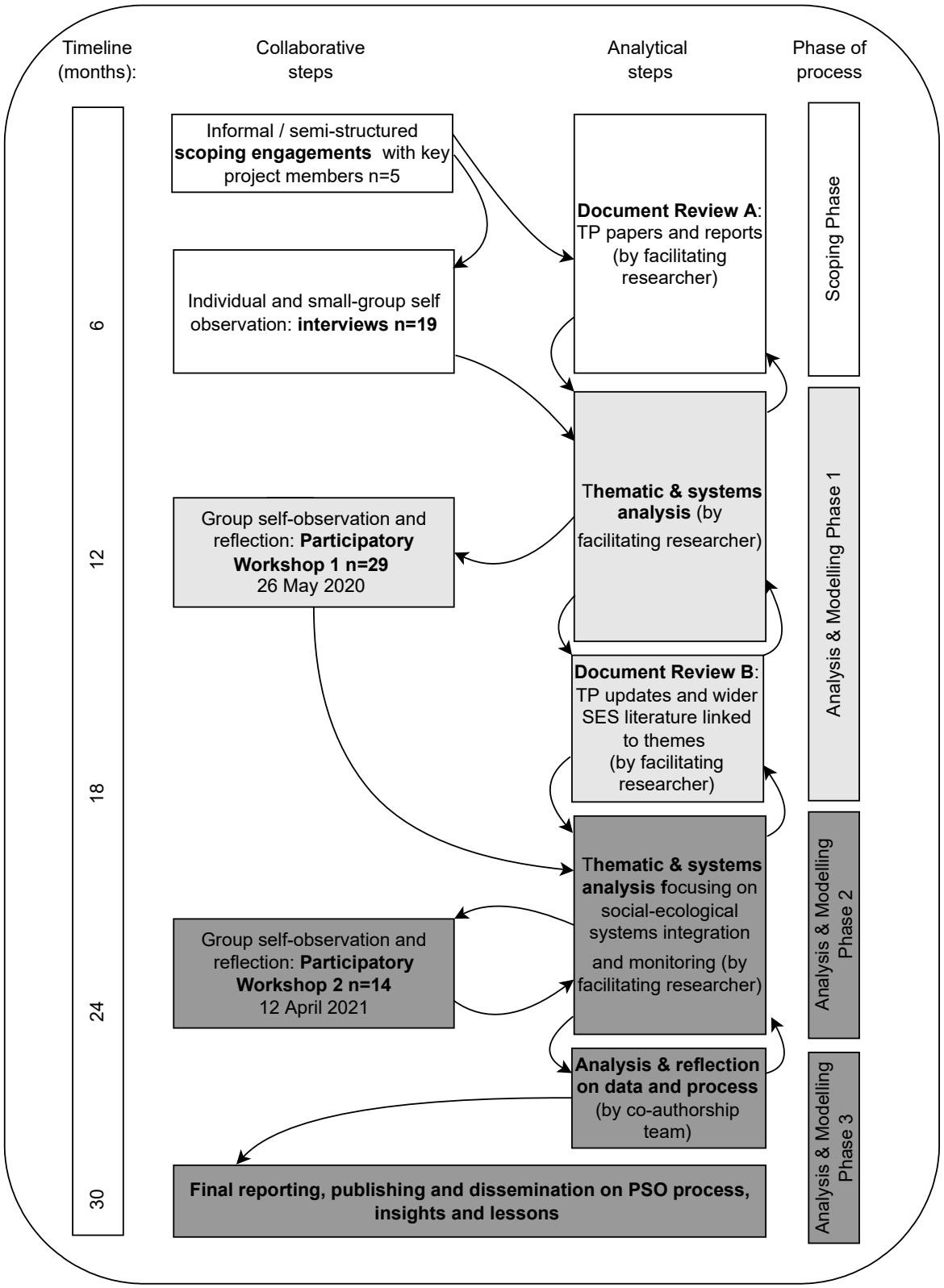


Figure 2. Research process that developed into a 'participatory self-observation process' as a social learning process to collaboratively better understand the Tsitsa Project. The process included iterative rounds of collaborative self-observation and reflection by participants. Rounds of analysis and modelling in phases 1 and 2 were done by the facilitating researcher, and analysis and modelling in phase 3 was done by the wider co-authorship team. Insights and lessons learnt were presented in project meetings with the national funder.

By 'analysis and modelling phase 2' of the process, SES integration and monitoring were identified as critical needs in the project, and in wider SES research. A second social learning workshop (n = 17) focussed on the integration and monitoring challenges. During this workshop, there were open ended discussions, and activity systems analysis [61,62] was used as a tool to co-create a model of SES monitoring in the Tsitsa Project. Contributions were positioned within the framework in real-time to stimulate discussion based on the concept of contradictions within and between people and the tools they used to achieve integrated monitoring [61]. Here, contradictions are defined as historically evolving tensions or underlying issues that can cause problems or block progress [63]. Identifying and addressing contradictions in the activity, can lead to improved functioning of the system.

The last phase of the process, analysis and modelling phase 3, started with the co-authors conducting collective analysis and reflection on the data and process, and drawing up insights and lessons for dissemination. These insights and lessons were presented in project meetings with the national funder (the DFFE) and at the National Green Skills Summit of 2021. Research was done on the specific aspects of integration and monitoring challenges identified in the PSO, and recommendations were made based on both the social learning process and wider literature.

The triangulation of approaches (direct questioning in interviews, systems modelling, polling, discussion and activity systems modelling) used at different stages of the research process enabled issues to be analyzed and addressed using a plurality of methodologies as per Roe's recommendation [64].

Research ethics clearance was obtained from the Wits University Ethics Committee (Clearance certificate: H19/09/13).

The PSO is novel in that it draws on and combines a number of broader inter-related principles and approaches, namely: social learning, PMERL, formative accompanying research, participant observation, participatory action research, and systems thinking (Table 1), which were selected based on stakeholder input, project documentation and the broader scientific literature. These different approaches were selected as a conceptual tool repository to help identify and address specific SES research and management challenges. Their underlying philosophies relate and contribute to the goals and principles of SES research in general, and to the Tsitsa Project case study in particular (see Table 1).

Table 1. The definitions and rationale behind the incorporation of various inter-related approaches as a conceptual tool repository in the participatory self-observation (PSO) process.

Approach	What Is It?	Why Is It in the Tsitsa Project Participatory Self-Observation (PSO) Process?
Social learning	A social learning process should: "(1) demonstrate that a change in understanding has taken place in the individuals involved; (2) demonstrate that this change goes beyond the individual and becomes situated within wider social units or communities of practice; and (3) occur through social interactions and processes between actors within a social network" ([65], p. 1)	A social learning approach was chosen because of the value it adds through the integration of different actors in reflexive, iterative research-praxis. Social learning was also incorporated into PSO because it is widely considered to improve the success of transdisciplinary efforts [66–68].
Participatory monitoring, evaulation, reflection and learning (PMERL)	A complexity-sensitive monitoring, evaluation and learning system developed for the Tsitsa Project, building on work done by the Association for Water and Rural Development [20] to explicitly include participation and reflection. PMERL processes in the Tsitsa Project are generally applied by a dedicated internal team.	The PSO process described in this paper fits within a series of PMERL social learning processes that have different scales and scopes and intensities (see 'formative accompanying research' below for more).

Table 1. *Cont.*

Approach	What Is It?	Why Is It in the Tsitsa Project Participatory Self-Observation (PSO) Process?
Formative accompanying research	A participatory research based on the assumption that having researchers on the inside of a process offers a deep vantage point to experience the inner workings, while explanations about the mechanisms of such collaborations benefit from the distance afforded by moving further away [69].	In the PSO process insights were gathered from people with different insider-outsider vantage points. The first author (the facilitating researcher) entered from a different research institution and moved along an insider-outsider continuum of roles as the process developed, thus adopting dynamic positionality in relation to the team. The gathering of insights was supported by insider perspectives from the core Tsitsa project team. PSO can therefore look from afar and up-close, which differentiates it from other PMERL activities. This 'zooming-in-and-out' is also often described as a key aspect of systems thinking [70] (see 'Systems thinking and modelling' below for more).
Participant observation	A method stemming from ethnography which can be defined as "the up-close involvement of the researcher in some form of participative role, in the natural, "everyday" setting to be studied" ([71], p. 6).	For this process, a group of researchers were collaborating to better understand the Tsitsa Project in which they were key members, thus forming a 'participatory self-observation process'.
Participatory action research	An interventionist approach to enquiry that involves researchers and participants working together to understand a problematic situation and change it for the better [72].	The PSO process took place within a larger research-praxis project that focuses on social change that promotes democracy and challenges inequality; is context specific, and involves iterative cycles of research, action and reflection.
Systems thinking and modelling	A suite of approaches and tools that transcend disciplinary boundaries by taking a systemic view of sustainability issues, which has led to "fundamental discoveries and sustainability actions that are not possible by using conventional disciplinary, reductionist, and compartmentalized approaches" ([73], p. 963).	Systems thinking was used to analyze data from various stages of the methodology, out of which emergent properties arose, which guided the focus and helped to distill insights from the PSO process. A systems approach has been associated with higher rates of integration in social-ecological systems research [11]. Systems models were drawn up at various stages of the PSO process.
Activity Systems Analysis	Activity systems analysis is a framework looking at the collaborative relations and contradictions within and between people and the tools they use in relation to a given object (or goal) in a system [61,62].	Activity systems analysis was used to co-create models analyzing the system through the notion of contradictions, which can stimulate learning by exploring the barriers to meeting particular stated SES goals. It was used in PSO as an integrating framework wherein inputs were positioned in relation to each other and discussed in real-time.

3. Results and Interpretation

The PSO process is well-suited to an integrated section for results and interpretation that positions insights from the case study in relation to wider literature. Thematic analysis of the interview data led to the identification of fourteen themes spanning multi-scale social, biophysical, institutional and integrative dimensions that the research-praxis team considered to be determinants of success of the Tsitsa Project. This is indicative of the breadth of considerations in a project with complex SES underpinning. Identifying all fourteen themes and selecting to focus on integration and monitoring was a part of the learning process. We begin this section by reviewing existing data and approaches to monitoring in the Tsitsa River Catchment, which prompted calls to further develop approaches integration and integrated monitoring. We then focus, firstly, on the challenges of SES integration, and secondly, on the challenges of SES monitoring. This is followed by a discussion section outlining overarching insights from the PSO process and its outcomes, as well as recommendations to take this research further.

3.1. Existing Data and Approaches for Integration and Monitoring in the Tsitsa River Catchment

A summary is presented here that synthesises the data and monitoring activities in the Tsitsa Project, compiled from interviews and document reviews during the scoping phase of the PSO process (Figure 2) and updated as the process developed. Fourteen themes emerged, which were thematically categorized into biophysical (or ecological), social, social-ecological, institutional, social-institutional or integrative domains (Figure 3).

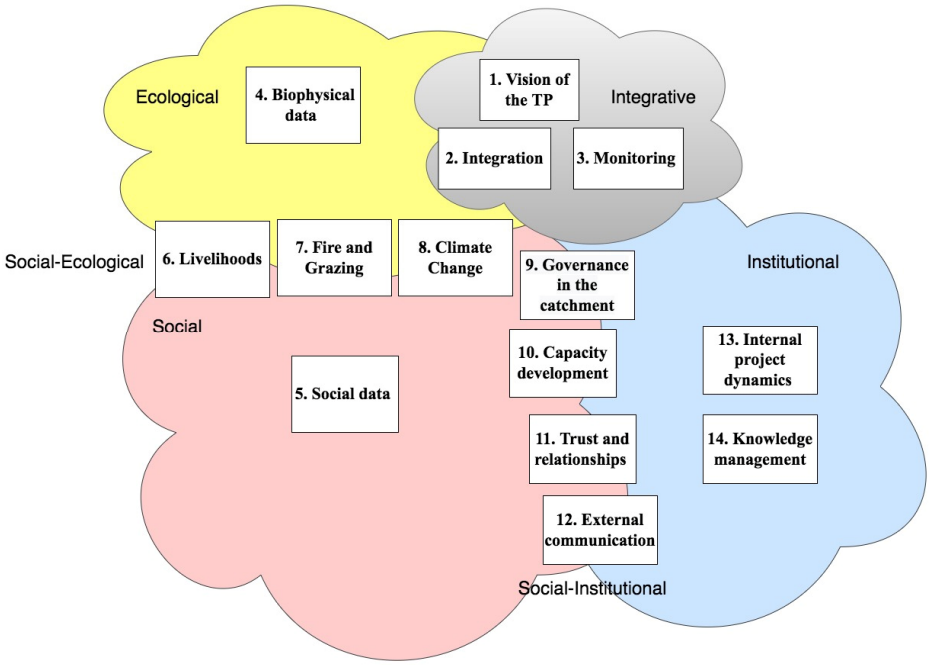


Figure 3. Key issue constellation that shows the fourteen themed key issues gathered from engagement with participants of the Tsitsa Project between 2019 and 2021. The key issues have been categorized as integrative (1, 2, 3), biophysical or ecological (4), social (5), social-ecological (6, 7, 8), social-institutional (9, 10, 11, 12) or institutional (13, 14) domains.

Biophysical data collection (Figure 3, theme 4) in the Tsitsa River Catchment was considered by PSO participants to be more developed than social data collection, with biophysical monitoring data having been collected on rainfall (patterns and intensity), gully erosion (almost 5 % of the catchment is gully), sediment yield, fire dynamics, hydrology (hydrological trends, water quality, health of the aquatic ecology, suspended sediment concentrations, and discharge), vegetation cover (species composition and biomass from transects representing extremities across the catchment), alien vegetation cover, and land cover classified by condition (woody vegetation, cultivated lands, grasslands) (I & D—[38,74]). Biophysical monitoring of a number of these variables has begun (I & D—[38]). Some of the biophysical data, for instance, data on suspended sediment, gully erosion and hillslope seep wetland vegetation, have been published [36,75,76].

From a social data (Figure 3, theme 5) perspective, a stakeholder analysis has been conducted [77] and socio-economic and demographic census data [42] have been collected using quantitative research instruments which are scalable to different purposes (W1). It was reported that the project needs social data at larger scales on how people use and value ecological infrastructure (I), but social data on peoples' values, power dynamics, or cultural identity, are often collected qualitatively and are highly context dependent and difficult to scale up (W1). Social data monitoring was planned via a social data survey that was developed to be conducted by community members, employed by the project, and which has been piloted but has yet to be fully rolled out (W2). Studies covering various topics in the social and institutional realms of SES have been published, including a learning process to help the team navigate praxis in a complex SES, a number of comparative case studies, and a study on building participatory governance in a rural restoration context (Figure 3, theme 9) ([3,4,78,79]).

There are published studies focusing on certain aspects of social-ecological interactions [43,44,80], but project members expressed a need for more integration across the biophysical (or ecological) and social spheres (I). Three themes namely, livelihoods, grazing and fire, and climate change were identified in the PSO process as being explicitly social-ecological in nature (Figure 3, themes 6–8). Data collected on livelihood initiatives (Figure 3, theme 6) focus on the production of vetiver grass plugs as a potential sustainable livelihood

avenue [40]. Other data collected on social-ecological interactions in the catchment includes connecting social national census data and ecological land cover data to better understand the effects of changes in population density on the landscape [42], and data from participatory mapping processes (to understand community priority areas and perspectives of natural resource problems) [34] (I & D). These data feed into integrated restoration plans (W2). The Tsitsa Project has been working at multiple scales, including through nodal structures (Figure 1). Each node comprises of several villages, for which integrated management plans were produced (W2 & D—[81]). The nodal plans place a heavy focus on the biophysical activities ([81] Section 4), but these are planned with reference to the non-biophysical activities (Appendix C of [81]), demonstrating the requirement for integrated social-ecological planning and monitoring. The project's PMERL and systems praxis teams have facilitated synthetic processes aimed at building a more integrated understanding of social-ecological dynamics (I).

This synthesis of data collection and monitoring revealed that although data covering a variety of topics has been collected, the project had a bias towards biophysical monitoring and approaches, and participants called for more emphasis to be placed on approaches to increase social-ecological integration and integrated monitoring (Figure 3, themes 2–3), which are the focus of the remainder of this paper.

3.2. Social-Ecological Systems Integration Challenge

Integration was a prominent theme that arose as both an area where the project has made progress and as an area where there are major challenges and gaps. Feedback from the process was summarized into narrative threads representing the ongoing progress that the project has made to improve integration as well as gaps that project members want prioritized (Table 2). Participants from the research-praxis team who had actively engaged in the Tsitsa Project for a number of years found that integration in such a large-scale broad SES project is complex with many aspects (including integration between: people, disciplines, knowledge types, institutions, datasets, scales, activities and their impacts on the ground), which can happen at many levels (W2). As the PSO process developed, collective critical reflection on the factors inhibiting and enabling complex SES integration in the Tsitsa Project led to three key, novel insights below, that could be relevant to other SES NRM projects.

3.2.1. A People-Based Process Is Appropriate and Necessary for Transdisciplinary SES Integration

PSO participants reported learning that there is a need (i) to be critical and ask "integration for what? and integration for who?" (I & W2); (ii) to recognize that "integration needs are dynamic and context-dependent: not all things need to be integrated all the time or to the same extent" (W2); (iii) to consider that although data collection is not usually done in an integrated way, data may still be able to be analysed in an integrative way (W2); and (iv) to conduct collective planning and activity updates to enable the data collected to be more compatible for integration (W2). People-based processes can help address these integration needs. The outcomes of people-based processes depend on the power dynamics and relational agents within a project; which determine which mandates are prioritized.

Analysis on the tools and approaches that the Tsitsa Project is using to achieve integration showed general 'Workshops and Meetings' (n = 14) to be the most frequently mentioned by interviewees, followed by 'PMERL' activities to encourage collective reflection (n = 4), 'Systems praxis' activities in which experts facilitate systems thinking and the use of system dynamics tools (n = 4), and 'GIS and Google Earth mapping' (n = 2) (I). With the exception of 'GIS and Google Earth mapping', these approaches are all participatory people-based processes. Even the GIS mapping, which is conventionally a more tool-based approach, had a participatory element as it was used for participatory GIS mapping in the catchment

The PSO piloted in this study is, itself, a people-based social learning process which has contributed towards cognitive integration by supporting team members to use different tools and methods (i.e., triangulation of methods, [64]) to surface and discuss different

transdisciplinary perspectives. The PSO enabled cross-boundary relations amongst the transdisciplinary team, where tacit knowledge became explicit and learning and knowledge production occurred across boundaries to form what Stange and others' [82] term as 'boundary spaces'. During the PSO, the team identified integration gaps and priorities in the project, and have done some actual integration; for instance, the need for a synthesis of drivers or degradation in the system, as identified through interviews, was subsequently done [44]. The evidence suggests that people-based processes are appropriate and necessary to determine what linkages are needed to characterize the system and meet project mandates in transdisciplinary contexts. Similar perceptions of people-based processes as effective avenues for information sharing have been documented in other NRM contexts [83]. It is important for these processes to include a variety of perspectives [5]. The sub-teams involved in people-based processes should be adaptively constituted as conditions change, new learning occurs, and the project matures [84].

3.2.2. Integration Is Enhanced by Having Transdisciplinary Teams Doing Applied Work

The team structure of people-based processes should include relevant stakeholders to enable delivery of results necessary for solving specific problems. PSO participants highlighted that the Tsitsa Project communities of practice which addressed themed problem areas had not been as useful in bringing transdisciplinary actors together as originally intended, and were therefore not helpful in enabling integration (W2). Given the ineffectiveness of the themed communities of practice to enhance SES integration, the deeper question that subsequently arose is 'how should teams in an SES project be structured to enhance integration?' The need for applied work as a catalyst for meaningful integration was strongly emphasized (W2). Participants found that working through teams that were 'task-focussed', rather than via the communities of practice (which were often de-facto 'discipline-focused'), was a good way to integrate and to achieve implementation on the ground (W2). The recommendation that emerged here is that people-based approaches (Section 3.2.1) in large SES projects should focus on applied (rather than conceptual) problems to enhance integration. The nodal plans described in Section 3.1 are an example where PSO participants felt applied work enhanced social-ecological integration (W2).

The link between integrated SES research and applied work is inferred in Guerrero and others' [11] finding that studies that provide recommendations for practice scored higher for the overall integration of social and ecological components than those that did not. This could be because studies with an applied aspect require integrated approaches. This applied approach also responds to the need to 'link science to practice', i.e., to bring 'praxis' to life (W2). Examples of such applied work that has improved integration include running an enhanced integrated planning process (I & W2); adaptive planning workshops (I); and an implementation workshop (W2). As part of the enhanced integrated planning process (which ran concurrently with the PSO process), project members posited 'The Tsitsa Project Approach' to work on integrated SES NRM problems. In the Tsitsa Project Approach work is structured in transdisciplinary clusters which would enable a shift away from the existing community of practice structure, with the aim of increasing integration (D & W2). This speaks to how team structure affects integration and was a lesson that emerged out of reflection on the different modes in which the project has been working and how these different ways of working affected their outcomes. Organising teams on the basis of applied tasks that include relevant transdisciplinary actors also addresses the need for further integration with communities and other stakeholders working on the ground, which was identified in W2. The Tsitsa Project found that organising project teams based on applied praxis tasks thus results in disciplinary, interdisciplinary and transdisciplinary sub-teams featuring in the project and integrating as needed, as recommended by Morton and others [84].

3.2.3. Transdisciplinary Teams Must Value Non-Biophysical Research

An advantage of transdisciplinarity is that it brings different world-views, approaches and values into dialogue [85]. Teams working on transdisciplinary SES processes need to

pay attention to values and to the relations of power within which they operate [86]. The values and relational dynamics of people working on an SES problem can influence the areas of emphasis during all stages of praxis, which in turn can lead to more or less sustainable SESs. SES teams need to value time spent on non-biophysical work (W2). Although one of the Tsitsa Project's guiding principles is to encourage polycentric and participatory governance approaches for sustainable management of the catchment [4], participants in the PSO process felt that the project still needed 'to draw on and integrate data from different places with regard to governance in the catchment' (I) and 'to stop disregarding social drivers' (I). A discussion emphasizing the need for 'the team to value time spent on non-biophysical work' held during workshop 2 revealed the ongoing perception that there were team members who still did not value the social aspects as much as the biophysical aspects of the project (W2). This could be a legacy bias from the original formulation of the project which focussed on the biophysical processes (D & W2), regardless of the project's evolution to the focus on the integrated SES approach reflected in project publications [4,34].

Values can be deeply embedded and difficult to change but one of the benefits of value-sensitive transdisciplinary approach [86] is the surfacing of values so that they can be acknowledged and addressed out in the open. When transdisciplinary teams use processes like the PSO to surface the contradictions in how different aspects of an SES problem are valued or not valued, a space opens for negotiation, discussion and trade-offs. There is a danger in larger complex projects where both biophysical and social issues have important dimensions that values may contribute the one overshadowing the other. Project governance and leadership should be value-sensitive and ensure equity and practicality.

Table 2. Data reported on 'Integration' during various phases of the participatory self-observation process in the Tsitsa Project. The data were categorized into achievements, placed in the "We have . . . " column, and gaps placed in the "We need . . . " column.

Data Source & Date:	We Have . . .	We Need . . .
Unprompted narrative threads on integration from interviews (I) July 2019–April 2020	1. Started the integrated planning process (n = 1). 2. Integration of research into praxis (n = 1). 3. Used meetings and workshops (e.g., science-management meeting & community of practice coordinator meetings) (n = 14), participatory monitoring evaluation, reflection and learning activities (PMERL reflections, workshops and teas) (n = 4) and the systems praxis community of practice (n = 4) as platforms for the integration of data. 4. Geographic information systems (GIS) and a Google Earth database (n = 2). 5. Catchment based events that improve integration with residents (needs to happen more) (n = 1). 6. Stakeholder analysis and sharing of reports as enablers of integration (n = 3). 7. A Tsitsa Project data portal and google drive folder (n = 1). 8. Adaptive planning workshop with government implementors and an objectives hierarchy for praxis (n = 1). 9. Started taking the role of governance, specifically empowering the people to participate in governance processes, more seriously (n = 1).	1. A data management system and integration (across the biophysical and social spheres) (n = 5). 2. To do more interpreting and synthesizing things, e.g., a synthesis of drivers of degradation (n = 2). 3. To "interleave" reporting requirements of Tsitsa Project and other bodies especially the Department of Forestry, Fisheries and the Environment (DFFE) (n = 1). 4. To integrate more with the catchment residents (by having more events such as integrated and adaptive planning workshops at village level and municipal level) (n = 1). 5. To be critical and ask "integration for what?" and "integration for who?" (n = 1). 6. Data accessibility (n = 1). 7. To integrate social and biophysical (n = 1). 8. To integrate between activities and their impacts/outcomes on the ground (n = 1). 9. To connect activities with desired outcomes along a value chain (n = 1). 10. Case studies to show the impact/value-add of integration (n = 1). 11. Integration of data using systems dynamics (n = 1). 12. Data driven project deliverables (n = 1). 13. Community of practice research protocols to be developed together to increase integration of data (n = 1). 14. To draw and integrate data from different places with regard to governance (n = 1). 15. To stop disregarding social drivers "governance was disregarded for a long time, but a change has started to take place" (n = 1).

Table 2. *Cont.*

Data Source & Date:	We Have . . .	We Need . . .
Narrative threads on integration from Workshop 1 (W1) May 2020 Updates on integration from PMERL Project Documentation (D) March 2020–December 2020 Updates on integration from Workshop 2 (W2) April 2021	10. A catchment coordinator who is a key enabler of integration. 11. Worked together more (because we do not have enough funding). 12. Quarter1 (Q1) Reflection report 2020, which made an important start to including quantitative indicator data. 13. Started explicitly using vision and principles (e.g., collaboration and integration) as a filter to analyse progress in reflection reports (from Q1 2020). 14. Inclusion of LIMA reporting into the PMERL process added an important source of field-based information (Q1 2020) (LIMA is an NGO that implements other parts of the Tsitsa Project). 15. Reflect and reconnect event (Aug 2020) included social-ecological system (SES) framing, SES outcomes, and reflection against the principle of SES and resilience thinking. (Q2 2020). 16. Developed & submitted Enhanced Integrated Plans for three nodes in the Tsitsa catchment to DFFE. This is a powerful way of integrating across the research and practice aspects of the project (Q2 2020). 17. The survey (livelihoods, grazing, social indicators, climate change indicators) to be administered by the CLOs and Citizen Monitors in 2021 (Q3 2020). 18. Tsitsa Approach document (Q3 2020) (the Tsitsa approach is structured under work clusters that may shift the existing communities of practice structure to increase integration). 19. Internal data management taking shape (improvements in storing and retrieving of data). 20. Student research actively working to produce an integrated account of bio-physical and social data related to ecological infrastructure. 21. Gone through the process of working on the DFFE bid which was a huge contributor to integration (n = 2). 22. The participatory mapping process as an example where we are integrating scientific and local knowledge. 23. Started to plan in a more integrated way, thinking beyond/across communities of practice—through the, Enhanced Integrated Planning, Tsitsa Approach and the DFFE funding bid, positing working through an approach structured under work clusters that shift the existing communities of practice structure—and hopefully increase integration. 24. Village-level integrated planning workshops 25. Recognized that the TP's integration needs are dynamic and context-dependent: "not all things need to be integrated all the time or to the same extent". 26. Held an implementation workshop focussing on biophysical data integration and integration between actors.	16. To focus our joint intellectual effort in an integrated way on the questions of scale. 17. The team to value time spent on non-biophysical work. 18. To keep working at integration of scientific and local knowledge forms. 19. Integration with people in catchment through feedback, PMERL and learning processes. 20. Boundary spanners in the catchment to be active integration agents (between governance institutions, implementing agents and communities). 21. To work through teams that are task-focussed (e.g., in nodes) rather than via communities of practice to achieve implementation on the ground. 22. To link science to practice more.

3.3. Social-Ecological Systems Monitoring Challenge

A major aspect of the integration challenge in SES projects is the requirement for integrated monitoring. There was enough data on integrated monitoring from the PSO to warrant its own section. Monitoring to track social-ecological outcomes in the Tsitsa Project is at an early stage [47]. There is a mismatch between what is written in the project documentation and what is conducted on a day-to-day basis (I), which is a common phenomenon [87]. As the PSO process developed, collective critical reflection on the factors

inhibiting and enabling integrated monitoring (Table 3) led to the following insights that could be relevant to other SES NRM projects, discussed in five sub-sections below.

3.3.1. SES Monitoring for Learning Requires Dedicated Efforts Integrating Qualitative and Quantitative Data

A key integration need that was identified is 'the need to integrate social and biophysical data' (I). 'Hard' biophysical and 'soft' reflection-based monitoring in the Tsitsa Project were running in parallel but were initially analyzed separately [74,88]. Interview feedback at the beginning of the PSO process confirmed that the initial focus by PMERL was on "synthesizing 'soft' (qualitative) data based on experiences without taking other data into account" and highlighted the need for 'hard' data to be integrated into PMERL monitoring (I). Through the efforts of PMERL the quantitative and qualitative data have started to be brought together in synthetic reflection reports. Some key developments are that (a) the PMERL reflection reports have started incorporating biophysical monitoring data from 2019 and 2020, related to indicators selected collaboratively in the project (D); and (b) that reflection reports now review progress against project objectives, which is important to ensure that tracking is relevant (I). The integration of reflections and indicator data needs to be developed further, but there is evidence that this is starting to permeate through the project, for example, the 2020 Meta-Reflection Report included some key biophysical baseline data findings (D—[47]). Sharing progress, processes and approaches on integrating qualitative and quantitative data for SES monitoring is important because SES approaches to monitoring and evaluation remain scarce [12].

3.3.2. SES Projects Produce an Overload of Data which Require Effective Data Management

Data overload is a common problem in large projects, and it is exacerbated when dealing with an SES project where there are large amounts of quantitative data which can be statistically analysed and qualitative data which are less easy to analyse and aggregate. It is important to put in place well-resourced data management practices at the start of big projects (W2). It is, however, also important for SES projects to account for emergent outcomes, which requires looking beyond the initial key questions (W2 & [89]). Collecting and analyzing good quality narrative data (such as reflective reports) on a regular basis can assist in pointing towards emergent areas that could require more attention. Even in a seemingly data-constrained context, a large SES project like the Tsitsa Project produces huge amounts of data (W2). Over the course of the PSO process the Tsitsa Project made some progress to guide data collection by selecting social and biophysical indicators through a collaborative process with researchers and communities (I & W1), and has developed and piloted surveys to collect social, livelihoods and livestock data for monitoring (D & W2). It is however still unclear whether all this data is critical to address specific key questions of the project. This speaks to an approach of 'collecting data first, and thinking of the questions it will answer later' which results in monitoring programmes not collecting the 'right' data to answer the questions fully [27]. Also contributing to large databases is a tendency to want to monitor everything that can be monitored [27]. Another problem raised in the Tsitsa Project is the lack of time or human resources to do the analysis and sense-making next steps related to monitoring, despite this being 'the most critical' (W2).

The Tsitsa Project's data overload problem speaks to generalized characterizations of data overload firstly as a 'workload bottleneck' where the project has collected too much to analyze in the time available, and secondly as a problem in finding the significance in data when it is not known what data from the large body of data will be informative [90]. Woods and others [90] propose solving workload bottlenecks by using automation and other technologies which can better organize the data. However, given the complexity and context-dependency of SES research, relying on technology is not enough and there is a need within the Tsitsa Project and other SES multi-stakeholder landscape initiatives to develop techniques to cope with data overload. People-based sense-making processes (see Section 3.2.1) could play a critical role to select relevant data for monitoring. The PSO

process has helped to spotlight the issue of data overload and highlight that people with the specific skills for data management and the ability to synthesise across components are critical for the success of a SES project.

3.3.3. The Scale of SES Monitoring Remains a Challenge

Bounding and scale are issues that need to be carefully considered when taking an SES approach [23,91]. Scale is a common challenge for both SES integration and SES monitoring but it emerged more strongly from the PSO in relation to monitoring (W1). In complex SESs there are often mismatches between ecological, social and institutional scales of monitoring [91]. Mismatched scales may inhibit appropriate monitoring frameworks because the kind and amount of information that they acquire may be inadequate to build an integrated understanding of key SES processes and feedbacks [91]. It is important for the team to include people skilled in this area to be involved with the project design from implementation to conclusion. Since the Tsitsa Project is a catchment-wide project, participants emphasised it needs a broad (i.e., catchment scale) observation system with the ability to: (i) track large-scale systemic changes, (ii) track processes that operate at catchment scales, and (iii) synthesize and report insights at the catchment scale (W1). However, localized observations have demonstrated that there is social, biophysical and institutional heterogeneity in the catchment, which is important to inform management and monitoring (W1). Another advantage of localized observation is the opportunity it provides to engage and empower resource users more directly, be linked more directly to on-the-ground management and practices, and therefore be more praxis-oriented and supportive of localised sustainability practices (W1). The team found working at the nodal scale (see nodal plans in Section 3.1) to be a good entry point for integrated social-ecological planning and integrated monitoring (W2). A number of participants (n = 6) suggested a multi-scale observation system to account for the scale of the project and include local-scale observations where both scales 'talk to each other' (W1). Suggestions include: "an embedded observation system that collects data on a broad level and conducts analysis on different levels", and "zoom in and out options so users get used to considering scale implications" (W1).

3.3.4. Learning Should Be a Key Process and Outcome of SES Monitoring

The interview data surfaced a contradiction between the Tsitsa Project's vision of what monitoring should be, and the monitoring activities that were occurring. Whereas the project views monitoring as a tool not only for accountability but also for learning and institutional behaviour change [29], interviewees reported that early data collection was driven by meeting funder reporting requirements, a long-standing issue in M&E [92]. Key members of the project reported not initially understanding what would be required of a project of this nature and size in terms of institutional learning (I), but as the project developed they reported finding value in the concepts of strategic adaptive management and reflective learning [20,29,30,47]. The theme of learning as an important process within, and outcome of, monitoring was carried through the PSO process and the team stressed the need for a monitoring system to enable learning and feedback on multiple levels, (e.g., by asking questions to improve the monitoring system itself) (W2—Activity System Modelling). The team also expressed the need to understand how well they are monitoring against the desired outcomes by instituting quality control checks (W2). The team felt that a tension between the rules of traditional M&E (as expected from many funders) and an openness to emergence could inhibit learning-focussed monitoring and should be explored further (W2).

3.3.5. Working Relationships Are Critical Enablers to Data Flow

Although data management has been an on-going challenge in the project, the team suggested that the lack of a database may not be the major factor limiting integrated monitoring. Instead, the evidence suggests social and institutional relationships are the

limiting factors (W2—Activity System Modelling). The Tsitsa Project team has dedicated a lot of time to developing relationships both internally and externally at different levels, but were unsure whether the working relationships were sufficiently well-developed to meet the objective of integrated monitoring to track social, ecological and social-ecological change and impacts in the Tsitsa River Catchment. Strong working relationships could be the critical lever "to operationalize the data flow and sense-making so that we can guide the whole project" (I). Strong working relationships are also helpful in deciding the type and amount of data needed in an SES context (W2). Working relationships can uncover and address contradictory mental models, world views and expectations between the funders and research-praxis team, which has serious consequences given that projects of this nature are dependent on and accountable to their funders. The tension between funder expectations and project goals which has been an obstacle to integrated monitoring in the Tsitsa Project (see Section 3.3.4). It is important for these actors to connect about expectations. The team were of the viewpoint that the project may have 'enough data' but the common intent and solid working relationships, which enable data and knowledge flow, are not always sufficiently well-developed (W2).

Table 3. Data reported on 'Monitoring' during various phases of the participatory self-observation process in the Tsitsa Project. The data were categorized into achievements, placed in the "We have . . . " column, and gaps placed in the "We need . . . " column.

Data Source & Date:	We Have . . .	We Need . . .
Unprompted narrative threads on monitoring from interviews (I) July 2019—April 2020	1. Done some assessment and adaptive management of work that was implemented (n = 1). 2. Started embedding (mostly biophysical) monitoring in the catchment (n = 1). 3. Grassroots/community input (n = 5) enabled by building trust and relationships. 4. Appointed and budgeted for community liaison officers and citizen monitors (n = 2). 5. Sent money to the catchment through the citizen technicians which is a government priority (n = 1) 6. Selected (social and biophysical) indicators (n = 1). 7. Social Indicators have been developed using capabilities approach (n = 2).	1. A reflective monitoring system to build high level understanding of how well we are meeting our objectives (n = 3). 2. A (high resolution reflective) monitoring system... (on paper this is there but in practice is not there)...with a catchment coordinator and community liaison officers. 3. To operationalize the data flow and sense-making so that we can guide the whole project. 4. Reports to be critiqued, distilled for learnings, and disseminated (n = 1). 5. To develop PMERL indicators and the protocols (n = 1). 6. Tangible case-studies of sustainable livelihood practices/small action research learning projects on the ground where we can learn from our interventions (n = 2). 7. To start using social indicators (n = 1). 8. Reflections to take hard data into account (based on peoples' experiences). 9. Data on the physical and social trends on the ground (n = 1) 10. To improve community voice and use social information to direct NRM efforts (human activities & responses to interventions are important for their sustainability) (n = 2). 11. Buy-in from communities-starting but more to go (n = 2) 12. Community liaison officers as key agents of change-to deepen participatory governance potential (n = 1). 13. To understand values: how people use and value ecosystem services (how people relate to their environment) (n = 1). 14. 'Softer context' to inform ethical implementation over long term (n = 1).

Table 3. *Cont.*

Data Source & Date:	We Have . . .	We Need . . .
Updates from Workshop 1 (W1) 26 May 2020	8. Finalized the selection of social and biophysical indicators chosen through a collaborative process with researchers and communities. 9. Climate change indicators proposed (Q1 2020) 10. Reflection reports now review of progress against objectives, NB for tracking (Q1 2020)	15. To develop surveys to gather social and social-ecological data related to the project indicators. 16. To consider issues around the scale (nodal vs. catchment) of our monitoring system: a multi-scale observation system 17. To focus our joint intellectual effort in an integrated way on the questions of scale.
Updates on monitoring from PMERL Project Documentation (D) March 2020–December 2020	11. First Tsitsa Project reflection reports presenting biophysical monitoring indicator data from 2019 and 2020 (Q1 2020 & Q3 2020) 12. Developed Surveys (Livestock, Social and Livelihoods) for the CLOs and other monitors to collect social, livelihoods and livestock data for monitoring.	18. To find ways of more effectively operationalising participatory evaluation and citizen monitoring (Q3 2020).
General updates on Monitoring from Workshop 2 (W2) 12 April 2021	13. Integrated two SDG indicators for water and sanitation into the survey. 14. Conducted basic interview and participant observation training with monitors through the Monitor Capacity Development short course. 15. CLOs with ever increasing capacity to implement social surveys. 16. Piloted and refined surveys. 17. Survey pilot results. 18. Guidelines to participatory monitoring of climate change adaptation. 19. Women's Capability Index study that provided social data, with a gender focus.	19. To find out what catchment residents want to monitor and how (n = 3) 20. To link our indicators, targets and monitoring practices to broader sets of indicators, such as the SDG indicators and Aichi targets 21. Innovative approaches to monitor social aspects without creating fatigue and being extractive. 22. To conceptualise innovative ways to offer benefits to participants of the monitoring process. 23. Follow-up training to build on the basic training to sufficiently equip monitors to carry out surveys.
Data from Activity Systems Modelling Exercise in Workshop 2 (W2) 12 April 2021		24. Time and manpower to filter through the monumental data that the project is producing and to do the next steps, related to monitoring, which is the most critical. 25. Solid working relationships and common intent to enable information flow for integrated monitoring. 26. Monitoring to be actively designed to enable learning and feedback 27. To understand and address tensions around scale.

4. Synthetic Discussion and Recommendations

In this paper, the PSO process was used to facilitate transdisciplinary observation, reflection and learning on the challenges around SES integration and monitoring in the NRM realm. We start this synthetic discussion by reflecting on the value-add of the PSO process. In reflecting on learnings that emerged from the learning process itself, the authors found that incorporating a plurality of approaches into the PSO's conceptual framing and engaging the team using various methods (including systems analysis and activity system modelling, Table 1) to elicit data [18] enabled the process to address different aspects of the integration and monitoring challenges. Earlier steps (interviews, systems modelling and W1) elicited 'what' needs to be done in terms of monitoring and 'why'. Later steps (discussion and activity systems analysis in W2) further developed the 'what' and 'why', but also looked at 'who' and 'how' by exploring the relations (including contradictions) among and between people and the tools they use to achieve integrated monitoring in the Tsitsa Project. This corresponds with the finding that studies that apply a greater number of tools and approaches achieve a higher level of integration [11]. This might be because the application of multiple tools and approaches can support a more holistic understanding of different social and ecological aspects, as well as their interactions.

During PSO we asked questions around how to integrate the social and ecological domains, both in terms of the types of data they are using and the types of questions

they are addressing. PSO could support integrated SES monitoring through ongoing collaborative observation and reflection to build a collective understanding of the links between (a) management actions and their social and ecological outcomes; (b) the pathways underpinning these outcomes; and (c) the non-linear relationships that result in these outcomes [11]. The PSO process prompted reflection to support adaptive multi-loop learning [93,94] around whether (and how) the project is producing the required SES outcomes, whether the outcomes themselves are appropriate, and the mandates and values underlying the desired outcomes (see Sections 3.2.3, 3.3.4 and 3.3.5).

Although considerable research attention has already been paid to learning about collaborative interdisciplinary research and to advancing it, there is relatively little research on the lived experiences of those working most closely on interdisciplinary collaboration [69]. PSO makes a contribution in this regard. Although PSO follows similar steps as existing SES frameworks [7,9,95], it goes beyond them by emphasizing that the process of transdisciplinary social learning, including the identification of knowledge gaps (and knowledge known/progress), be done collaboratively with researchers and participants, drawing on their lived experiences. In the PSO, co-authors were placed in the position of both participant and researcher/analyst and therefore played multiple roles (combining those of researcher-as-observer, researcher-as-participant and researcher-as-facilitator). These multiple roles were played out both within the research process and the wider NRM project within which the particular research process was embedded. This provided the opportunity for reflexivity from multiple perspectives with insights gathered via observing and participating in other project meetings (see formative accompanying research, participant observation and participatory action research, Table 1).

In addition to the three areas that emerged as focal points for improving the challenges of SES integration (reported in Section 3.2) and the five areas that emerged as major challenges for SES monitoring (reported in Section 3.3), some recommendations on possible ways to take the findings of this research forward are captured and discussed in the following three sub-sections, with an emphasis on the applicability of these recommendations to equivalent transdisciplinary SES projects.

4.1. People-Based Approaches That Focus on Applied Work Should Be Used to Advance Both SES Integration and SES Monitoring

PSO is applicable in contexts where stakeholders closely involved in a complex SES project are willing to collaborate to better understand their project, with the intention of using their learning to improve praxis. The Tsitsa Project is a large complex SES project aimed at improving social-ecological outcomes in a rural catchment with eroded governance systems, a history of disempowered resource users, high rates of poverty, and degradation of natural resources [4,44]. While the collection of relevant biophysical, social and social-ecological data are important to understand and manage SES projects, the PSO participants emphasized the need for more approaches to increase social-ecological integration and integrated monitoring of these data (Section 3.1). In a transdisciplinary SES project such as the Tsitsa Project it is not possible to achieve what is needed without all the role-players collaborating to locate and evaluate their activities in relation to the agreed broader project targets, strategies and plans [41]. This places participatory people-based processes (Section 3.2.1) such as the PSO at the center of SES integration and monitoring. The PSO process provided the team with a space and framework to do collaborative positioning of the data that had been collected and was being monitored, and led to social learning and reflection, resulting in emergent insights around SES integration and monitoring challenges. A manifestation of adaptive integration in the Tsitsa Project has been the emergence of applied praxis tasks, as being major catalysts of meaningful collaboration (Section 3.2.2). By focussing on areas of applied work, people based-processes can identify emerging needs and opportunities in complex projects, which could then feed back into adaptive processes. Applied praxis tasks necessitate the formation of ad hoc transdisciplinary working groups in which working relationships (Section 3.3.5) focussed on addressing integrated problems

are built. Thus people-based approaches that focus on applied work represent emergent adaptive architecture that builds purposeful integrative capacity.

4.2. Identifying Essential Data Needs Has the Potential to Address Issues of Data Overload (as Well as Other Integration and Monitoring Challenges)

As noted in the introduction and Section 3, the complexity of SESs mean that systems monitoring can easily suffer from 'data overload' issues, which was indeed raised as a significant challenge in the Tsitsa Project (Section 3.3.2). We propose an approach called Essential Variables (EV) that has been used to filter a limited set of critical data for systematic observation [96–99]. EVs help extract meaning from a limited set of data that is critical to build an understanding of (and characterise change in) a system of interest. Determining the set of EVs is an endeavour that aims to capture the key dimensions of a system of interest in the most efficient way possible [82]. EVs were first posited for coordinating the monitoring of global climate in the 1990s [96] and have subsequently been applied in other areas including oceans [97] and biodiversity [98]. The EV approach has also been proposed for interdisciplinary systems monitoring of countries' progress towards achieving the Sustainable Development goals [99]. The SES integration and monitoring challenges identified in this paper (particularly data overload, the need for participatory people based approaches, the importance of applied praxis tasks, and the need for integration of qualitative and quantitative data) could be addressed through the development and application of the EV approach tailored for SES; an area that has received little attention, with some notable exceptions [99–102]. While the primary purpose of an EV approach would be to address the data overload problem (Section 3.3.2), it could additionally be tailored to follow the other recommendations that emerged from the PSO process. The selection of SES EVs should be done via a participatory transdisciplinary sense-making process (Section 3.2.1.), incorporate and integrate qualitative and quantitative data (Section 3.3.1), and draw from lessons learnt (Section 3.3.4) through applied praxis where possible (Section 3.2.2). Since the EV approach significantly reduces the number of variables to be monitored, it may be easier to align scales (Section 3.3.3). The development of EVs for SESs should also take into consideration the values and goals of those working in a particular system of interest. For instance, the Tsitsa Project team expressed the desire for the monitoring system to consider what catchment residents want to monitor and how to do so (W2). This 'what' and 'how' from residents should be considered because even if it is apparently in conflict with what is most efficient or cost-effective, it could be important to improve long-term engagement and sustainability. Unlocking input from stakeholders like these is dependent on having good working relationships (Section 3.3.5).

4.3. Combining Quantitative Observation and Monitoring with Participatory People-Based Processes Would Enhance SES Monitoring

Monitoring to enable a high-level understanding of the progress and trajectory of a project like the Tsitsa Project is important. Observation and monitoring systems are often, however, primarily biophysical and quantitatively focussed, tool-based, and overseen by M&E specialists who are often external consultants not embedded in the project [92,103]. These systems are not equipped to do some of the sense-making and learning steps necessary to shed light on complex causal processes in SESs [103]. The PSO process developed in this study produced mostly qualitative data, was participatory (with a combination of insider and outsider perspectives), process-based, took an explicit SES approach, and reflected on lessons learnt and how to work these lessons into adaptive praxis and planning; all of which are challenges identified when attempting to couple traditional observation systems with the complexity of SESs. These features make PSO a good component or complement to make sense and meaning of data in an SES observation system. The participatory nature of the process, where those closely involved in the project were observing and evaluating their own progress, resulted in critical outcomes being more acceptable and trusted as evidenced by the team's high uptake, buy-in, ownership and commitment to the process, which was observed by the co-authors. The PSO process yielded many insights to

enhance integration and monitoring in SESs (see Sections 3.2 and 3.3), which could contribute to filling sense-making and learning gaps in more traditional M&E and which could prove to be crucial to a project's success and sustainability. Combining tools-based forms of monitoring with people-based processes may be a way to improve SES monitoring. We propose the incorporation of such "participatory self-observation processes" as important for learning and sense-making within a wider SES observation system that includes more traditional and often quantitative M&E structures (including indicators, and targets and models) to be used in conjunction to complement one another.

The PSO, illustrated with a case study on SES challenges, promotes collaborative observation and reflection for the purpose of learning based on the diverse experiences of transdisciplinary participants, which informs adaptive actions and helps move transdisciplinary learning into real-world applications. The broader lessons on SES integration and monitoring learnt from this process are not restricted to this SES context, but can be applied by teams navigating transdisciplinary integration and monitoring and curate landscapes towards sustainability across a range of geographic locations and levels of poverty.

Author Contributions: This research article has several authors; their individual contributions are specified below: Conceptualization, A.I., J.K.C.-H., M.S. and K.C.; Methodology, A.I.; investigation, data curation, and validation, A.I.; formal analysis, A.I.; writing—original draft preparation, A.I.; writing—review and editing, M.S., J.K.C.-H., K.C.; supervision, M.S., J.K.C.-H. and K.C.; & funding acquisition, M.S. All authors have read and agreed to the published version of the manuscript.

Funding: Funding for this study, (PhD scholarship and research costs) has been provided to Prof. Mary Scholes through her SARChI Research Chair in Global Change and Applied Systems Analysis (funded by the Department of Science and Innovation (DSI) and the National Research Foundation (NRF) of South Africa), NRF funding number: 101057. The research and implementation of the broader Tsitsa Project has been funded by the Department of Forestry, Fisheries and the Environment (DFFE), Chief Directorate: Natural Resource Management Programmes (NRM), Directorate: Operational Support and Planning. The contents of this paper do not necessarily reflect the views and the policies of DFFE, Chief Directorate: NRM, nor does the mention of trade names or commercial products constitute endorsement or recommendation for use.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Wits University Ethics Committee (Clearance certificate: H19/09/13, date of approval 13 September 2019).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data collected by the authors of this study are available on request from the corresponding author. The data are not publicly available due to the need to comply with the ethics clearance certificate obtained, from the University of the Witwatersrand, for this study. Restrictions may apply to the availability of third-party data. Data obtained through Tsitsa Project reports and documentation are available upon request from info.tsitsaproject@ru.ac.za with the permission of the project manager.

Acknowledgments: The Tsitsa Project Participatory Monitoring, Evaluation, Reflection and Learning (PMERL) Team; specifically Jessica Cockburn, Karen Kotschy and Wandile Mvulane; for authorship of key project documents for analysis and for analytical input on a previous version of this paper. The Department of Forestry, Fisheries and the Environment (DFFE), for being an active research participant and partner to the Tsitsa Project. Funding for this research was provided by the DSI/NRF SARChI Research Chair in Global Change and Applied Systems Analysis, held by Mary Scholes.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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5.2 Postscript

This paper provides a characterisation of some key integration and monitoring challenges in SES research, and provides recommendations to overcome them. The social learning process incorporated various inter-related monitoring and learning approaches to help identify and address specific SES research and management challenges. The underlying philosophies of the selected approaches relate and contribute to the goals and principles of SES research in general, and to the Tsitsa Project case study in particular. I recommend the incorporation of context-appropriate approaches when applying a similar approach in other contexts. The main findings of the paper include three focal points for improving the challenges of SES integration and five major challenges in SES monitoring. Having a process of iterative collaborative group self-observation and reflection, interspersed with thematic and systemic analysis of outputs from the collaborative process, led to the development of three overall recommendations to further develop integrated monitoring and management of SES. The recommendations from this paper, specifically around identifying essential data needs through an essential variable approach and combining quantitative monitoring with participatory people-based processes, form the basis of a relational SES approach to EVs which is presented in more detail in the subsequent chapter.

CHAPTER 6 – A SOCIAL-ECOLOGICAL SYSTEM ESSENTIAL VARIABLE APPROACH, TO DETERMINE SUSTAINABILITY AT A CATCHMENT SCALE

6.1 Preface

This chapter seeks to develop an essential social-ecological system variable (ESEV) approach to prioritise the data inputs needed to monitor sustainability in SES landscapes. In the process of decision-making toward sustainable development, we still face significant methodological and theoretical barriers. Integrated monitoring for assessing sustainability outcomes is among the key challenges in SES research. In this paper, ESEVs are introduced as a novel approach that incorporates many of the recommendations to improve integration and monitoring in SES which were highlighted in the previous chapter. The ESEVs and associated indicators are derived from a transdisciplinary people-based process involving systems thinking, relationality and social learning. The approach was piloted to select ESEVs to monitor progress towards improved SES sustainability of the Tsitsa River Catchment of South Africa, but the approach and methodology are applicable to various SES landscapes. The development and application of ESEVs contributes towards recent efforts to adapt and apply the EV concept to more integrated and interdisciplinary systems monitoring. The paper was submitted to the journal *Environmental Development* for consideration in a special issue on systems analysis for addressing environmental challenges in an African context, titled IIASA and systems analysis in Africa. The manuscript (ENVDEV-D-24-00161) is under peer review. The unpublished manuscript is presented below.

A Relational Social-ecological Systems Approach to Determine Essential Variables for Monitoring Sustainability at a Catchment Level.

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Abstract

This publication introduces Essential Social-Ecological System Variables (ESEVs), an approach aimed at addressing integration and monitoring challenges in Social-Ecological System (SES) projects at the catchment scale. ESEVs are defined as 'the minimum set of critical social-ecological variables to capture key features, processes, and interactions driving SES dynamics over time and space.' Notably, ESEVs differ from other essential variable approaches as they are based on the relational connection between the 'Social' and 'Ecological' aspects of SESs and are derived from a transdisciplinary process involving systems analysis and social learning. The ESESV approach was rooted in systems thinking to identify variables for monitoring progress towards improved SES sustainability within the Tsitsa River Catchment in South Africa. ESEVs were identified through a process involving interviews, workshops, and surveys with experts from a transdisciplinary SES project in the catchment. The criteria for prioritizing ESEVs and their associated indicators were determined based on 'essentiality scores,' and the degree of consensus among participants. The resulting ESEVs for the Tsitsa River Catchment included 'soil erosion related to human actions on the land,' 'participation in natural resource governance,' 'grazing and rangeland sustainability,' and 'land cover and condition.' Additionally, participants proposed 'access to water,' 'local natural resource governance system,' and 'human well-being in the landscape' as potential ESEVs. Monitoring ESEVs could be achieved through a mix of data sources, with reduced emphasis on biophysical earth observations. Applying the ESEV approach at the catchment scale ensured its contextual relevance and practicality. The study provides valuable insights for monitoring SES sustainability, offering an effective approach and process applicable to various SES landscapes.

Keywords: essential variables, systems thinking, relationality, integrated landscape monitoring, transdisciplinary practices, social learning.

1. Introduction

The importance of adopting an integrated social-ecological systems (SES) approach to tackle sustainability challenges is increasingly recognized (Fischer et al., 2015; Guerrero et al., 2018; Kliskey et al., 2021), as evidenced by a threefold increase in SES research publications from 2010 to 2015 recognition (Guerrero et al., 2018). Yet there are aspects of SES research, such as integrated monitoring, that require further development (Gurney et al., 2019; Itzkin et al., 2022; Schlüter et al., 2021).

SESs, characterized as complex adaptive systems, exhibit system behavior driven by dynamic relational and contextual processes (Preiser et al., 2018). Practical applications of integrated social-ecological monitoring of SESs in real-world scenarios remain limited (Gurney et al., 2019; Selomane et al., 2019), hindered by conceptual disparities, terminological variations, and disciplinary compartmentalization. Additionally, the complexity and involvement of multiple disciplines in SES predispose monitoring to 'data overload' issues, which are typical of many monitoring programmes (Lehmann et al., 2020a).

Addressing SES monitoring challenges necessitates novel monitoring methods and frameworks that consider the features of complex SESs (Rosenberg and Kotschy, 2020). This study proposes an integrated social-ecological monitoring approach, the essential social-ecological system variable (ESEV) approach, which draws on systems analysis (Hordijk 2021), and relationality (Haider et al., 2021; West et al., 2020). The term system analysis, in this article, denotes a transdisciplinary problem-solving process (Hordijk, 2021) that incorporates the principles of systems thinking (Forrester, 1992; Liu et al., 2015, 2007). Systems thinking (Forrester, 1992) transcends disciplinary boundaries, viewing interconnected system elements as driving complex outcomes (Arnold and Wade, 2015). While systems thinking underscores social-ecological interconnections theoretically, 'social' and 'ecological' entities typically maintain analytical segregation, perpetuating a human-nature divide (Liu et al., 2007; West et al., 2020). By merging systems thinking principles, with a relational perspective, this study aims to bridge the human-nature divide and emphasize dynamic social-ecological relationships as drivers of system patterns and behaviors (Garcia et al., 2020; Reyers et al., 2022; West et al., 2020).

Furthermore, the adoption of an Essential Variables (EV) approach tailored for SESs can address integration and monitoring challenges, including data overload and the need for participatory approaches (Itzkin et al. 2022). The development of EVs for integrated SES monitoring had received little attention until recently, with some notable work emerging, including Integrated EVs for Sustainability, a general reference list of SES variables, Essential Dryland Variables, and Essential Ecosystem Variables (Balvanera et al., 2022; Lehmann et al., 2020a; Pacheco-Romero et al., 2020; Wu et al., 2021). This study contributes by developing integrative SES EVs grounded in systems thinking and relationality, applied in a rural catchment case study.

1.1 Essential Variable Concept and Applications

In this paper EVs were explored as a monitoring approach for SES projects at a catchment scale. EVs have been defined as the minimum set of critical variables needed to capture the key dimensions of a system of interest in the most efficient and cost-effective way possible

(Reyers et al., 2017). EVs should be represented by indicators (Proença et al., 2017). For each EV more than one related indicator is adopted (Wu et al., 2021).
Early applications of the EV concept include Essential Climate Variables (Bojinski et al., 2014), Essential Ocean Variables (Constable et al., 2016) and Essential Biodiversity Variables (Pereira et al., 2013). Earth Observation (EO) played a big role in earlier EVs, which had a biophysical focus. Biologically relevant variables have been documented in many EV frameworks, but social variables have been lacking and more difficult to incorporate (Reyers et al., 2017; Wu et al., 2021).

However, there has been a recent shift recognizing the need for more integrated EVs. This shift towards a more integrated SES approach can be seen in literature proposing EVs for the Sustainable Development Goals (Fukui et al., 2021; Kussul et al., 2020; Plag and Jules-Plag, 2020; Reyers et al., 2017). EVs for global change and EVs for global boundaries of a Safe Operating Space for Humanity have been recommended (Plag and Jules-Plag, 2020). There has also been recent work in development around Integrated EVs for Sustainability (Lehmann et al., 2020a), Essential Socio-Economic System Variables (Lehmann et al., 2020a), EVs for the food-water-energy nexus (Mccallum et al., 2020). Essential Drylands Variables (Wu et al., 2021), and Essential Ecosystem Variables (Balvanera et al., 2022).

1.2 The Effect of Different Conceptualizations of Social Ecological Systems on Integrated Monitoring and Essential Social-Ecological System Variables

There are different conceptualizations of SESs in the literature (Figure 1). Early EVs work focused largely on ecological variables as per conceptualization (i) (Bojinski et al., 2014; Hayes et al., 2015; Pereira et al., 2013), with more recent work acknowledging the interactions between the ecological and social system as per conceptualization (ii) (Lehmann et al., 2020a; Pacheco-Romero et al., 2020). This paper moves the selection of EVs towards conceptualization (iii) by focusing on data that is produced through the relations of the social and ecological.

The bases for conceptualization (iii) are that the ‘social’ and ‘ecological’ aspects of an SES cannot readily be separated, that ‘social’ and ‘ecological’ separations are artificial, and that you cannot construct the system as a sum of its ‘social’ and ‘ecological’ parts, as the SES whole is not equal to a sum of the parts. These are central insights in the SES literature and in systems thinking and analysis more broadly (Meadows, 2009; Preiser et al., 2018). This conceptualization shifts from a perspective that focuses on the distinct parts of a system, to a relational perspective where the dynamic relations between system components are seen as the drivers of emergent patterns and behaviors (Garcia et al., 2020; Reyers et al., 2022; West et al., 2020). Complex adaptive systems are constituted relationally, and it has been argued that the focus of SES analysis should shift away from distinct, independent objects to the dynamic relationships between social and ecological objects (Reyers et al., 2022). The ESEV process identifies data focused on where the social and ecological interact. This conceptualization affects the EV selection criteria, and the resulting EVs (discussed further in the results and discussion section).

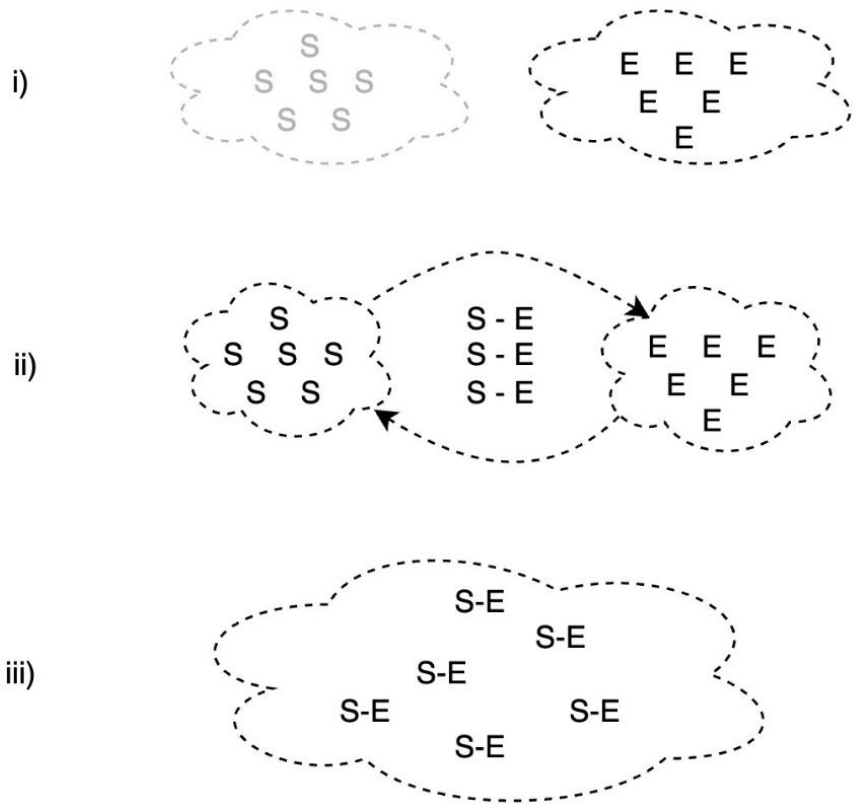


Figure 1. Representations of how the framing of social (S), ecological (E), and social-ecological (S-E) processes in research, described by Haider, Schlüter, Folke, & Reyers (Haider et al., 2021), manifest in Essential Variable (EV) approaches. In conceptualization (i), the 'E' and 'S' are seen as separate processes. In conceptualization (ii) the 'E' system and the 'S' system, are each measured separately, with several interactions between them which are also measured. In conceptualization (iii) the focus is on data that is produced through the 'S-E' relations.

1.3 Differentiating this study from other integrated Essential Variable work

This study sets itself apart from other integrated EV work by taking a relational perspective to monitor social-ecological relations for comprehensive characterization of social-ecological sustainability. While previous studies typically analyze social and ecological aspects separately before examining key interactions (Fukui et al., 2021; Lehmann et al., 2020a; Pacheco-Romero et al., 2020), this research fills a gap in cross-thematic EV identification by adopting a holistic approach (Lehmann et al., 2020b).

While this research was informed by a study that developed a general conceptual reference list of variables for monitoring SESs without a defined monitoring scale (Pacheco-Romero et al., 2020), as well as previous EV frameworks primarily applied at global, regional, or national levels (e.g., Kussul et al. 2020; Constable et al. 2016; Bojinski et al. 2014; Pereira et al. 2013), it is rooted in a case study at the catchment scale. Collaborating with a transdisciplinary team actively engaged in the catchment, this study addresses the need for context-sensitive monitoring, shaping the emerging contextual framing of variables. Possible reasons why an SES EV approach has not previously been applied at catchment scale include that (i) EVs work has largely been based on EO data which is available at national or global scales, (ii) Integrated EVs & the application of EVs with data that are not EO-based is a fairly new area of research, and (iii) there is lack of process for use in this kind of case study and at this scale meaning that a concerted effort into methodological development and innovation were needed to be done for implementation.

By addressing overarching issues of context-dependence and scale-dependence highlighted in prior research (Pacheco-Romero et al., 2020), this paper outlines steps to apply the ESEV approach in diverse contexts. The need for an integrated SES essential monitoring approach at catchment scale arose from a transdisciplinary social-learning process (Itzkin et al., 2022), echoing broader calls in SES research to innovate methods for assessing sustainability outcomes (Selomane et al., 2019). This approach offers broad applicability across various SES landscapes, aiding in overcoming methodological and theoretical barriers to SES monitoring to inform decision-making toward sustainable development.

2. Material and Methods

2.1 Case study Context

2.1.1 Tsitsa River Catchment and Tsitsa Project case study

The Tsitsa River Catchment (TRC) is located in the Eastern Cape province of South Africa (Figure 2). The catchment is characterized by steep topography and erodible soils, resulting in the formation of extensive gullies (le Roux and van der Waal, 2020). There are 2 types of rural landholdings, private and communal. Much of communal land was cleared and tilled for cultivation during Apartheid (Rowntree et al., 2018). The communal land (found in the eastern part of the catchment, shaded in yellow on Figure 2), is where most of the catchment's population reside, and coincides with more erodible soils (Van Der Waal et al., 2018). Residents rely, to an extent, on natural resources (Sigwela et al., 2017). Livestock holds cultural and financial value to residents (Van Der Waal et al., 2018). The catchment is a tributary of the Mzimvubu River, the last large, undammed river in South Africa. Proposals for a water resource development including 2 dams in the catchment have been put on hold because high sediment yields as a result of ecological and social issues would render a dam inoperable within 55 years (le Roux, 2018).

Between 2014 and 2023, the catchment was home to a social-ecological project, called the Tsitsa Project (TP), funded by the South African Department of Forestry, Fisheries and the Environment (DFFE). In the TP, interdisciplinary researchers, natural resource managers and residents collaborated, with the objective "to support sustainable livelihoods for local people through integrated landscape management that strives for resilient social-ecological systems, and which fosters equity in access to ecosystem services" (Van Der Waal et al., 2018) (p.18) in the upper TRC.

2.1.2 Integrated monitoring of the Tsitsa River Catchment (TRC)

The TP adopted an explicit SES approach, employing transdisciplinary research-praxis to enhance the catchment's landscape and sustainable livelihoods. Emphasizing integration across social and ecological domains, the project had a dedicated team focused on participatory monitoring, evaluation, reflection, and learning (PMERL). While PMERL facilitated the selection of biophysical and social indicators, calls from within the project prompted a move towards a more integrated understanding and streamlined monitoring system (Itzkin et al. 2022). This began with building an integrated understanding of SES drivers of degradation in the catchment (Itzkin et al. 2021), followed by exploring challenges around integration and integrated monitoring in SES research (Itzkin et al. 2022). The key focus of this paper is identifying ESEVs crucial for understanding and managing 'the system'. This question is context-specific, and depends on a project's management objectives or goals.

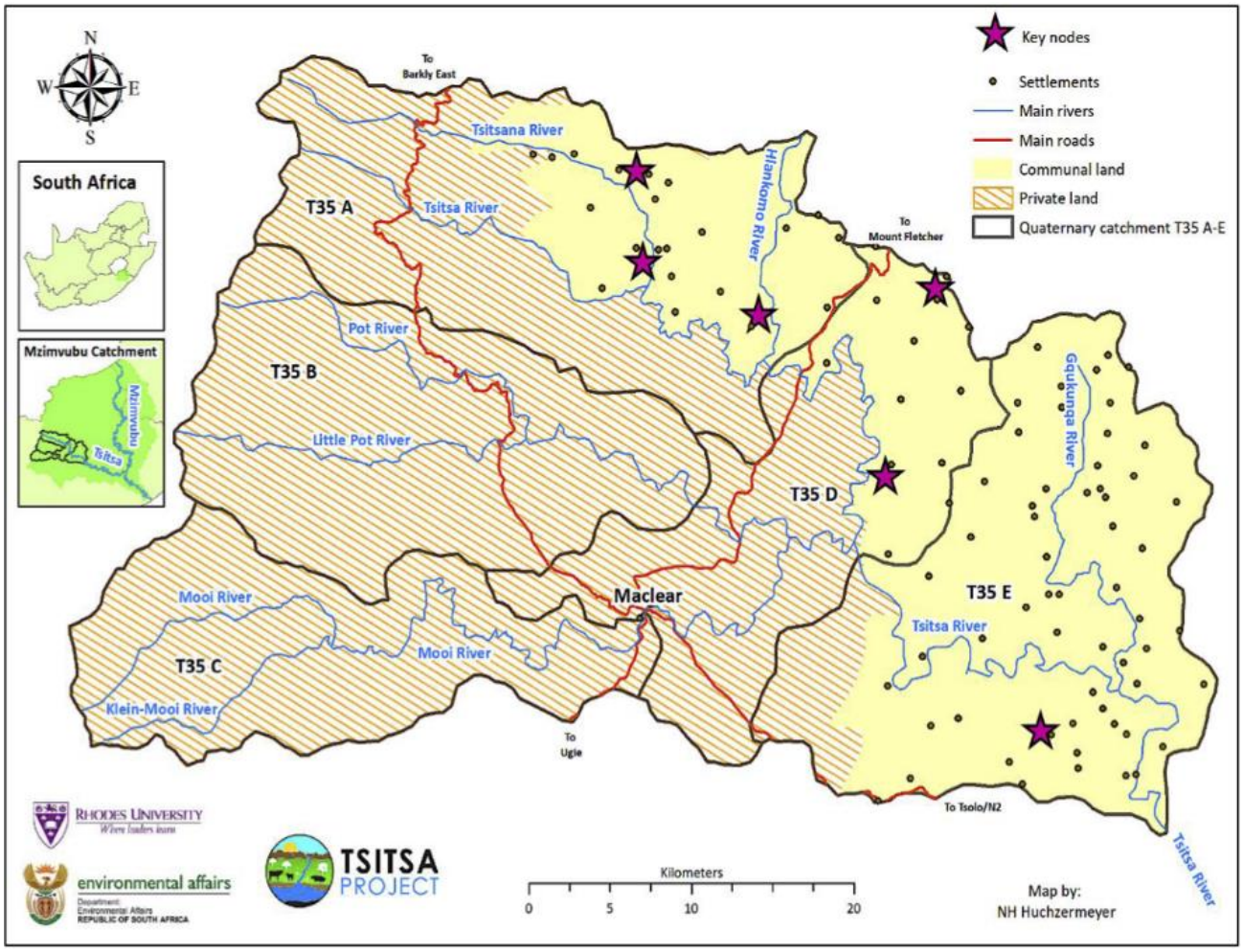


Figure 2. Map of the Tsitsa River Catchment by N.H. Huchzermeyer. The Tsitsa Project focused on the upper catchment, which coincides with the communal land where most of the catchment population resides and where soil erosion and land degradation are most severe.

2.2 Methods: A Systemic Transdisciplinary Social Learning Process

A transdisciplinary social learning approach was employed, involving representatives from all TP Communities of Practice, the internal decision-making team of the TP at Rhodes University, and stakeholders from diverse transdisciplinary organizations including research institutions, NGOs, government funders, and implementers. The data collection process comprised of iterative rounds of stakeholder engagement and analysis, divided into three phases, incorporating systems analysis as a transdisciplinary problem-solving process (Hordijk, 2021) that integrates the principles of systems thinking (Forrester, 1992; Liu et al., 2015, 2007).

2.2.1 Phase One: Developing Candidate Essential Social-Ecological System Variables and Indicators.

The research commenced with scoping interviews (n=19) conducted with various TP research-praxis team members (coded as 'I1'). The interview data underwent thematic analysis (Braun and Clarke, 2006; Clarke and Braun, 2014). This was followed by a review of internal project documentation (coded as 'D') and two workshop sessions (coded as 'W1'—n=29, & 'W2'—n=17), where systems modelling (Forrester, 1980; Meadows, 2009) and activity systems

modelling (Engeström, 2001, 1987; Ploettner et al., 2016) techniques were utilized to depict key issues in the system (Itzkin et al., 2021).
The data from phase one, along with indicators selected through expert-driven disciplinary processes within the project, underwent critical review considering the broader literature on EVs and integrated SESs, to generate a list of candidate ESEVs and indicators for the TRC.
Potential selection criteria to filter the candidate variables were established based on EV literature (Fukui et al., 2021; Reyers et al., 2017; Scholes and Biggs, 2005; Wu et al., 2021) and TP values and principles (particularly around community participation, which emerged strongly from phase one).

2.2.2 Phase Two: Gathering Input to Prioritize Criteria and Variables.

In phase two, a Google Form survey (coded as 'S') was developed, incorporating potential selection criteria, and candidate variables and indicators identified in phase one. The survey introduced ten potential selection criteria for variable prioritization and asked participants to score each criterion from 0 (non-essential) to 5 (most essential). Participants were also asked to score each candidate social-ecological variable and indicator and provide comments and suggestions.

2.2.3 Phase Three: Prioritization of Variables and Indicators.

In phase three, survey results (n=14) were used to conduct two "essentiality vs. consensus" analyses (based on the 'relevance vs. consensus' analysis conducted by Pacheco-Romero et al., 2020). The first analysis focused on the selection criteria for ESEVs for the TRC ('essentiality vs. consensus' a), while the second analysis addressed variables and indicators for monitoring the TRC ('essentiality vs. consensus' b).

'Essentiality' in this study refers to the importance participants assign to variables and indicators in relation to the ESEV selection criteria for the TRC and TP context. Consensus was estimated as the difference between the maximum standard deviation of the scores found throughout the (a) 10 potential selection criteria, and (b) 44 candidate variables and indicators, and the standard deviation of the score for each criterion, variable, or indicator (low differences indicate low consensus and high differences indicate high consensus).

Variables were ranked into five categories based on their percentile for essentiality and consensus: Priority levels 1 to 4 and a non-priority category. Priority level 1 (top priority) included variables with essentiality and consensus above the 90th percentile; level 2 included variables between the 75th and 90th percentiles; level 3 included variables with essentiality above the 75th percentile but consensus between the 50th and 75th percentiles and vice versa; and finally, level 4 included variables with essentiality and consensus between the 50th and 75th percentiles. The nonpriority category included variables with essentiality and consensus below the 50th percentile.

To assess potential biases and gaps in the list of variables, the additional suggestions and comments provided by researchers in the survey were analyzed. Comments and suggestions were themed, and recurrent themes (addressed five or more times by respondents) were identified as potential additional ESEVs. The results were discussed at a third participatory workshop (coded as ‘W3’, n=7).

Finally follow up expert interviews were conducted for themes where further input was required (coded as 'I2.1-I2.5', n=5).

Utilizing interviews, surveys, and participatory workshops, iteratively throughout the research process facilitated the analysis of issues using multiple methodologies, as per Roe's (1998) recommendation, and promoted new knowledge exchange from social learning (Reed et al., 2010).

3. Results

3.1 Proposed Essential Social-ecological System Variable Selection Criteria for Tsitsa River Catchment

The selection criteria for the development of EVs for SESs must take the values and goals of those working in a particular system into consideration. Participants proposed the most suitable selection criteria for ESEVs for their context. 'Captures System Essence' (Reyers et al., 2017) emerged as the highest priority selection criterion (level 2, Figure 3), followed by 'Relevance', 'Feasibility', 'Covers Key Social-Ecological Interactions' (inspired by (Haider et al., 2021; Schlüter et al., 2019a; Wu et al., 2021) and 'Resident Selected' (level 3, Figure 3). The TP has included catchment residents in the development and operationalization of its monitoring system, where possible. Participants expressed the desire for the monitoring system to consider what catchment residents want to monitor and how to do so (I1). While getting direct input on the selection of the ESEVs and indicators from residents was not possible in this process, resident input from project documents and community meetings was reviewed and taken into consideration. This resident input is important because even if it is apparently in conflict with what is most efficient or cost-effective, it could be important to improve long-term engagement and sustainability.

The selection criteria for the ESEVs are defined as follows:

1. Captures System Essence: represents the key features, processes and interactions driving SES dynamics over time and space (Reyers et al., 2017);
2. Relevance: indispensable/foundational for tracking system;
3. Feasibility: the state or degree of being easily or conveniently done within the context of the specific cultural, economic and social norms of the system of interest; and
4. Covering Key Social-Ecological Relations or Interactions: data that is co-produced by the social and ecological domains (inspired by (Haider et al., 2021; Schlüter et al., 2019a; Wu et al., 2021).

Drawing from the selection criteria above, the definition of ESEVs is: the minimum set of critical social-ecological variables to capture key features, processes and interactions driving SES dynamics over time and space.

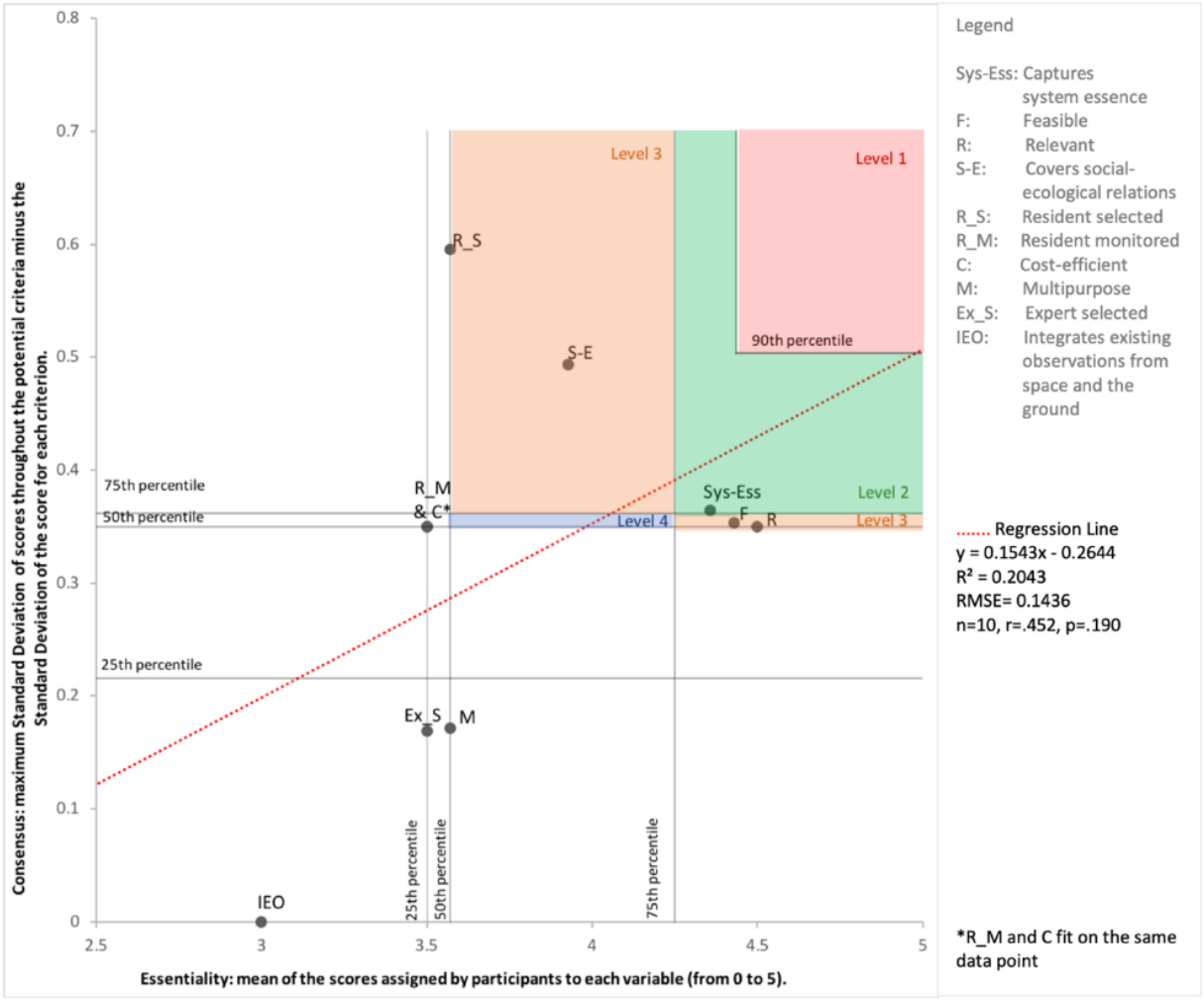


Figure 3. Selection Criteria for Essential Social-Ecological System Variables by priority in terms of essentiality (mean of the scores assigned by experts to each criterion), as well as the level of consensus (estimated as the difference between the maximum standard deviation of the scores for all potential criteria) around the essentiality assigned by the transdisciplinary Tsitsa Project research-praxis team (n=14).

3.2 Essential Social-ecological System Variables and Indicators for the Tsitsa River Catchment

Four social-ecological themes: 'sustainable livelihoods', 'natural resource governance', 'human impacts on the environment', and 'climate change adaptation' were identified. Within these themes, a list of eight candidate ESEVs and thirty-three potential indicators was developed. Analysis of the candidate ESEVs and indicators in the survey revealed a significant positive relationship ($n=41$, $r=0.811$, $p<.001$) between the average essentiality for characterizing and monitoring SESs obtained for each variable and the consensus observed across respondents (Figure 4). By applying the prioritization thresholds, four candidate ESEVs— 'soil erosion related to human actions on the land' (SE-EV), 'participatory natural resource governance' (P-EV), 'grazing and rangeland sustainability' (G-EV), and 'land cover and condition' (LC-EV)—and fifteen indicators were considered priority (Table 1). Priority variables 'soil erosion'(SE-EV), and 'participatory natural resource governance' (P-EV) were associated with priority indicators. Non-priority variables 'sustainable cropping' (C-EV) and 'sustainable forestry' (F-EV) were associated with non-priority indicators. 'Land cover and condition' (LC-EV), 'sustainable grazing and rangeland'(G-EV), 'access to natural resources' (NR-EV) and 'climate change adaptation (CC-EV)' comprised of a combination of priority

and non-priority variables and indicators. This may be related to the theoretical nature of the of the EV themes versus the practical nature of indicators. Other possible reasons for this are outlined within the relevant ESEVs sub-sections below.

Six of the sixteen priority indicators were duplicated to monitor more than one ESEV (as indicated with * in Table 1). The 'duplication' shows that a particular indicator is 'multi-purpose' which was a potential selection criterion (Figure 3) as it could be a desirable attribute for streamlined monitoring. Data on 'duplicated' indicators could be collected once, but analyzed differently for different themes, thus simplifying monitoring. This effectively reduces the number of priority indicators for monitoring.

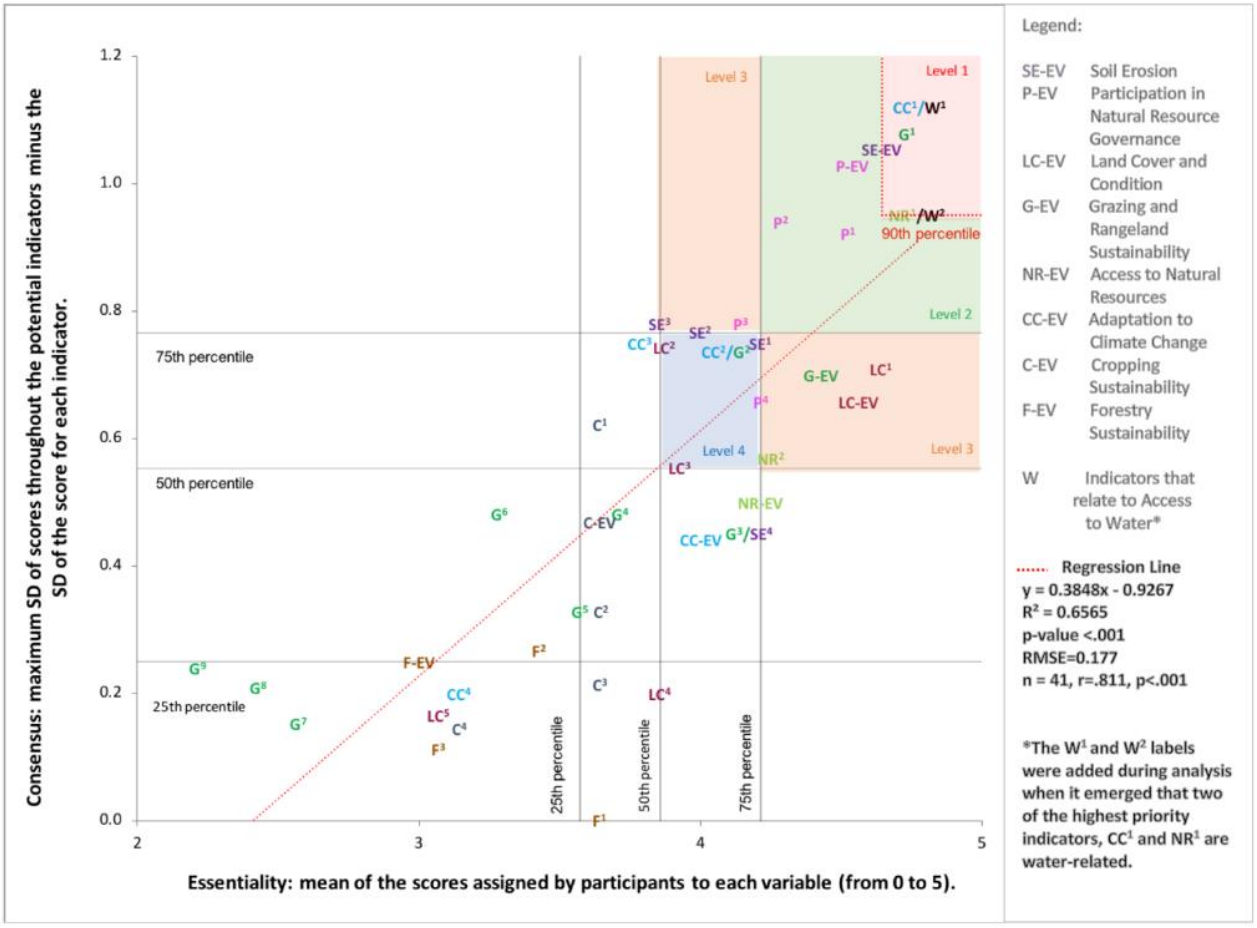


Figure 4. Essential Variable (EV) themes and associated indicators by priority in terms of essentiality (mean of the scores assigned by experts to each variable), as well as the level of consensus (estimated as the difference between the maximum standard deviation of the scores for all candidate variables and associated indicators) around that essentiality assigned by the transdisciplinary Tsitsa Project research-praxis team (n=14) (links with the indicators listed in Table 1 & Table 2).

The following sub-sections (3.2.1-3.2.8) present the combined analysis of the ESEV and indicator results from the 'essentiality vs. consensus' analysis of survey data (Figure 4), the additional suggestions and comments provided by participants during different stages of the research process, as well as how the study context determines priority. The presentation of the results in relation to the context highlights the importance of context to guide appropriate monitoring. The ESEVs are positioned in descending order from the higher to lower priority for the TRC. Variables considered non-priority for the TRC (3.2.5-3.2.8) have been included because they may hold priority status in different contexts and could serve as potential inputs when conducting the ESEV process elsewhere.

Table 1. List of prioritized social-ecological variables and associated indicators for the Tsitsa River Catchment. The list is structured into 6 social-ecological variables associated with priority indicators. Priority level 1 have relevance and consensus scores above the 90th percentile; level 2 includes variables with both values between the 75th and 90th percentile; level 3 contains variables where relevance was above the 75th percentile and consensus between the 50th and 75th percentiles and vice versa; and finally, level 4 includes those variables with relevance and consensus between the 50th and 75th percentiles. Potential additional indicators from the bias and gaps analysis appear in the last column, in italics.

Essential Social-Ecological Variable Theme	Essential Social Ecological Variable and **Priority Level.**	Associated Priority Indicators by level				*Potential additions with that emerged from gaps and bias analysis of participant input.*
		Priority 1	Priority 2	Priority 3	Priority 4	
Human Impacts on the Environment	Soil Erosion (related to human actions on the land) (SE-EV) **Priority 1**			SE[1]: Soil erosion by anthropogenic practices SE[2]: Mass stabilization and control of erosion rates SE[3]: Soil erosion as an ecosystem disservice		*SE[4]/G[3]: Percentage vegetation or ground cover** *SE[5]: Suspended sediment concentration*
	Land Cover and Condition (LC-EV) **Priority 3**			LC[1]/G[1]: Grassland condition*	LC[2]: Land cover change LC[3]: Woody invasive species cover	
Governance	Participatory Natural Resource Governance (P-EV) **Priority 2**		P[1]: Land user participation in natural resource governance structures	P[2]: Participation in sustainable land-use management practices P[3]: Land user satisfaction that their voices are represented in decision making and planning processes	P[4]: Women and youth participation in natural resource governance structures	*P[5]/CC[5]: Participatory governance, management or decision-making around climate change adaptation**
Sustainable Livelihoods	Sustainable Grazing and Rangelands (G-EV) **Priority 3**	G[1]/LC[1]: Rangeland condition*			G[2]/ CC[2]: Interventions to manage the grassland*	*G[3]/SE[4]: Percentage vegetation or ground cover** *G[10]: Willingness to practice sustainable grazing* *G[11]: Fire Regime*
	Priority indicators associated with Access to Natural Resources (NR-EV) **Non-Priority**	NR[1]/W[2]: Access to potable water*		NR[2]: Access to natural resources by sub-category (food types and sources, firewood, thatch, medicinal plants, sand for building)		
Climate Change Adaptation	Priority indicators associated Climate Change Adaptation (CC-EV) **Non-Priority**	CC[1]/W[1]: Interventions to store, capture and protect water*			CC[2]/G[2]: Interventions to manage the grassland*	*CC[5]/P[5]: Participatory governance, management or decision-making around climate change adaptation**

*Duplicated indicators identified as cross-cutting or multi-purpose, could monitor multiple Essential Social-ecological System Variables.

3.2.1 Soil Erosion, related to human actions on the land (Priority Level 1)

The Tsitsa catchment's duplex, dispersive soil structure makes it prone to soil erosion, which is exacerbated by various interconnected social and ecological factors (Itzkin et al., 2021; le Roux and van der Waal, 2020). The TP aims to mitigate soil erosion through integrated land use management, identifying it as a level 1 priority ESEV within the catchment. The three priority indicators (level 3): soil erosion by anthropogenic practices (SE^1), mass stabilization and control of erosion rates (SE^2), and soil erosion as an ecosystem disservice (SE^3), were based on the social-ecological literature (Pacheco-Romero et al., 2020; Shackleton et al., 2016) and could be measured across the catchment using earth observation.

However, challenges were noted in measuring SE^1 due to its complex nature, and SE^2 due to its temporal scale being out of sync with project timelines (S & I2.3). To address this, percentage vegetation cover (already being monitored in themes 3.2.3 and 3.2.4) and percentage bare soil were proposed as proxies for soil erosion (S, W3 & I2.2). Suspended sediment monitoring, already in place in the catchment (Bannatyne et al., 2022), was unanimously agreed upon as an essential indicator for assessing how much soil is leaving the system as the result of both natural and anthropogenic erosion, aligning with the TP's goal of reducing sediment through improved land management (W3). Remote sensing for land cover was also suggested as a potentially more efficient method for assessing erosion rates in the context of sustainable land management (I2.3).

3.2.2 Participation in Natural Resource Governance (Priority Level 2)

Participation in natural resource (NR) governance emerged as a priority ESEV (level 2), with all proposed indicators considered essential (S). This aligns with the TP Governance Community of Practice's emphasis that participatory governance development underpins the likelihood of biophysical restoration delivering ecological and societal benefits (Palmer et al., 2022). Overall 'land user participation' in NR governance structures (P^1, level 2) was highlighted as more significant than 'women and youth participation' (P^4, level 4). This could be because exclusion from structures is widespread in the catchment's rural community (I2.4). The participation indicators are suggestive of the relevance and potential effectiveness of governance processes in stimulating participation (I2.4).

Regarding 'land user satisfaction with their representation in decision-making and planning processes' (P^3, level 3), a household survey conducted in 2023 (n=178) revealed that most catchment residents do not desire increased representation. A range of factors could be behind this. It is possible that pushing people to participate in NR governance may be counter-cultural and could create unnecessary change resistance (I2.4). It is important to have an adaptive approach that takes consideration of feedback like the above, and to relate monitoring to the high-level goal (in this case social-ecological sustainability), rather than focusing on achieving some kind of imposed metrics.

To monitor participation in NR governance, a shift from annual household surveys to specific interventions, such as assessing participation and progress within grazing associations, was suggested (I2.4). This approach aims to analyze meaningful participation linked to relevant livelihood themes, moving beyond general participation to meaningful engagement in the context.

3.2.3 Grazing and Rangeland Sustainability (Priority Level 3)

The sustainability of grazing and rangelands are interconnected, with uncontrolled grazing and overgrazing identified as key drivers of degradation in the catchment (Itzkin et al., 2021). Positioned within the sustainable livelihoods layer, this ESEV highlights the importance of sustainable livestock and grazing practices for improving social-ecological sustainability.
Survey participants identified 'rangeland condition' (G1, level 1) as the sole essential indicator for monitoring rangeland and grazing sustainability in the catchment. A related priority indicator, 'interventions to manage the grassland' (CC2/G2, level 4), emerged from the climate change adaptation theme. All other 'grazing and rangeland' indicators were deemed non-priority (S), prompting consideration of the effectiveness of the chosen priority indicators for tracking grazing and rangeland sustainability.

Rangeland condition (G^1) in the catchment has been monitored along selected transects, facilitated by local eco-rangers (Huchzermeyer et al., 2021; Huchzermeyer, N; Schlegel, P; van der Waal, 2019), but faces challenges due to the need for skilled technicians proficient in species identification and the method's limitations in detecting changes over large areas. Simplified transect assessments focusing on basal cover of dominant life forms, along with catchment-scale vegetation cover monitoring using remote sensing, were proposed as alternative approaches for areas like the TRC (W3, I2.1).

Grazing associations support coordinated rangeland management, offering avenues for monitoring livestock management and density (Huchzermeyer et al., 2021). Additional indicators suggested (W3) include community willingness to implement grazing management practices, monitored through grazing association membership or household surveys, and fire regime monitored using remote sensing methods (Moderate Resolution Imaging Spectroradiometer (MODIS), Normalized Difference Vegetation Index (NDVI), Scar Maps, or the Advanced Fire Information System (AFIS)). Fire regime, though initially omitted from surveys, was deemed essential due to its link with rangeland condition and overgrazing, particularly in light of predicted climate change impacts (Snyman 2020, W3 & I2.1). Community reports of arson further underscore the social-ecological implications of fire management.

3.2.4 Land Cover and Condition (Priority Level 3)

Land cover and condition emerged as a level 3 priority ESEV. ‘Grassland condition’ (LC^1, level 3) was rated highest among potential indicators, which overlaps with the highest scoring indicator from the grazing and rangeland theme. Other essential indicators included ‘land cover change’ (LC^2, level 4), and ‘woody invasive species cover’ (LC^3, level 4). The TP focused its land cover and condition assessment on woody invasive species cover and erosion, establishing a digitized baseline for monitoring purposes (I2.2). While ‘land cover change’ (LC^2) is considered valuable for assessing landscape impacts, the TP has not specifically examined this aspect (I2.2, Biophysical Monitoring Report/s). Like many other countries, South Africa offers freely available land cover datasets updated every 2-5 years, providing broadscale insights into catchment-scale changes (https://egis.environment.gov.za/data_egis/data_download/current; most recent time interval 2020). Regarding ‘woody invasive species cover’ (LC^3), its ecological impact is negative, but its social-ecological implications are complex, necessitating social data on the value and utility (ecosystem services and disservices) of these species to communities.

3.2.5 Access to Natural Resources (Non-Priority)

The TP's overall objective includes 'fostering equity in access to ecosystem services' (Van Der Waal et al., 2018). Given the high levels of poverty and unemployment, as well as the rural nature of the catchment; there is a high reliance on natural resources, making 'access to natural resources' (NR-EV) a seemingly critical variable (S). It was therefore surprising that there was a lack of consensus around the overall importance of NR-EV as an ESEV. While both the proposed indicators were deemed essential (Table 1), 'access to potable water' (NR^1) was highlighted as more of a priority (level 1) than 'access to natural resources' (NR^2, level 3). The NR^2 indicator can be broken down into sub-categories (such as food types & sources, firewood, thatch, medicinal plants, water from the natural environment, and sand for building) depending on relevance. Participants also suggested considering monitoring the condition, management, and sustainable utilization of these natural resources (S). These data were proposed to be collected via annual household surveys.

Table 2. Variables and indicators considered non-priority for monitoring in the Tsitsa River Catchment in relation to the goals of the Tsitsa Project, but which may be higher priority in other contexts.

Theme	Social-ecological Variable theme	Non-Priority Indicators
Climate Change Adaptation	Climate Change Adaptation (CC-EV) (Non-Priority)	CC^3: Interventions to grow climate smart crops CC^4: Interventions to alleviate heat stress (for humans and livestock)
Sustainable Livelihoods	Non-priority indicators associated with 'Sustainable Grazing and Rangelands' (G-EV) (a priority 3 ESEV) *	G^3: Vegetation cover G^4: Livestock management G^5: Livestock density G^6: Income related to sustainable livestock livelihoods G^7: Sales rates of agricultural products G^8: Livestock theft G^9: Livestock ownership patterns
	Sustainable Cropping (C-EV) (Non-Priority)	C^1: Income from sustainable cropping livelihoods C^2: Ratio between crop land with sufficient ground coverage and total crop land C^3: Proportion of agricultural area under productive and sustainable agriculture C^4: Cropland production
	Sustainable Forestry (F-EV) (Non-Priority)	F^1: Progress towards sustainable forest management (methods of forestry) (non-priority) F^2: Forest area as a proportion of total land area (non-priority) F^3: Income from sustainable forestry products (non-priority)

* 'Sustainable Grazing and Rangelands' is an exception in this table in that it is a priority variable. It is, however, associated with several non-priority indicators.

3.2.6 Climate Change Adaptation (Non-priority)

Climate change adaptation initiatives recently started gaining traction in the catchment, with the TP conducting workshops for local government and developing climate change learning resources for monitors (Kotschy and Mvulane, 2020). The TP devised climate change adaptation indicators to monitor the outcomes of sustainable land management and livelihood interventions in the catchment (Rowntree, 2020). In the survey, climate change adaptation (CC-EV) was presented as a potential ESEV alongside indicators proposed by Rowntree (2020). While climate change adaptation emerged as a non-priority ESEV overall, two indicators stood out: 'interventions to store, capture, and produce water' (CC1), rated as the highest priority indicator (level 1), and 'interventions to manage the grassland' (CC2), rated as

another priority indicator (level 4). These indicators align with other themes, 'access to water' and 'grazing and rangeland sustainability'. Household surveys could be utilized to monitor these climate change adaptation indicators by counting the number of reported interventions implemented by households.

3.2.7 Cropping Sustainability (Non-priority)

Cropping sustainability (C-EV) and all the associated potential indicators (C^1, C^2, C^3 & C^4) were considered non-priority variables in the context (S). Monitoring cropping as an indicator of sustainable livelihoods related to project interventions in the TRC is tricky because cropping (including home gardens) in the communal areas is highly rain dependent (W3). Due to the past Apartheid policies vast areas in the catchment were contoured, but for various reasons are not suitable for cropping and remain largely unplanted. In the context of the TP, grazing on disused fields came up as a contributor of erosion due to a lack of grazing management (Itzkin et al., 2021). Interventions to address this could be monitored within the sustainable grazing and rangelands theme (3.2.3).

3.2.8 Sustainable Forestry (Non-priority)

Sustainable forestry (F-EV) and all proposed forestry indicators (F^1, F^2 & F^3) were considered non-priority for communal land in the catchment (S). Workshop participants indicated that forestry currently does not represent key features, processes, or interactions driving the social-ecological system dynamics of the catchment (W3). Most forestry land in the catchment is privately managed without strong connections to sustainable livelihoods, integrated landscape management, or equitable access to ecosystem services in communal lands. While some social and livelihood aspects related to woodlots were acknowledged, forestry was generally not seen as an ESEV (S & W3). It's worth noting that forestry's status as an ESEV could change, especially if initiatives such as the Forestry Master Plan to plant seven-hundred-thousand trees in the Eastern Cape were to materialize (DTIC 2020).

3.3 Additional potential Essential Social-ecological System Variables for the Tsitsa River Catchment that emerged during the research process

Three new potential ESEVs emerged during the survey process. The first is 'access to water', the second relates to the 'local NR governance system', and the third pertains to 'human well-being in the TRC' (Table 3). Although further engagement would be required to refine, finalize, and prioritize these ESEVs, they represent additional potential avenues for enhancing the understanding of the complex social-ecological dynamics within the TRC and beyond, which should be considered for future monitoring and research efforts.

Table 3. Additional Proposed Essential Social-Ecological System Variables (ESEVs) and Indicators to monitor the Tsitsa River Catchment in relation to the goals of the Tsitsa Project, based on topics brought up 5 or more times in the survey, which were discussed at the follow-up workshop & interviews.

Theme	**Additional Essential SES Variable (ESEV) Theme**	**Potential Indicators**
Water	*Access to Water (W-EV) (n=7)*	W^1: Interventions to store, capture and produce water (level 1, Figure 4) W^2: Access to potable water (including source & distance) (level 1, Figure 4) *W^3: Access to water from the environment* (including source & distance)
Governance	*Local Governance System (GS-EV) (n=5)*	*GS^1: Accessibility of local governance actors* *GS^2: Functional institutions enabling participatory NRM governance* *GS^3: Local governance capacity* *GS^4: Land user trust in governance processes – measures procedural trust,* [59], [60] *GS^5: Positive collaboration of land users with governance actors – measures rational trust* [60] *GS^6: Natural Resource Management Rules (in form and in use)*
Human Well-Being	*Human Well-being in the landscape (WB-EV) (n=5)*	*WB^1: A 'good life in the catchment'* *WB^2: Sense of place and identity* *WB^3: Ritual value from SES*

3.3.1 Access to Water (Proposed Addition 1)

Access to water was not initially included in the survey but emerged strongly as a potential addition during the gap analysis (Table 3). Two of the highest priority indicators identified in the survey, "interventions to capture, store, and protect water" (CC1/W1) and "access to potable water" (NR1/W2), are water-related (Figure 4). Furthermore, several suggestions were made in the survey (n=7) to include other water-related indicators (Table 3).
Access to safe drinking water is a top priority for catchment residents, the majority of whom collect drinking water directly from the environment, reflecting trends seen in other rural households in the Eastern Cape (Apraku et al., 2023). More than half of the household survey respondents (53.7%) reported experiencing significant periods without sufficient drinking water in the last month, highlighting water security concerns. Given the current climate change adaptation priorities in South Africa (Department of Environment Forestry and Fisheries. 2017), particularly in the highly vulnerable Eastern Cape region which is enormously vulnerable to changed rainfall patterns (Mahlalela et al., 2020), issues related to access to water and water-related climate change adaptation are crucial.

3.3.2 Local Natural Resource Management Governance System (Proposed Addition 2)

Several participants (n=5) in the survey proposed indicators related to the 'local Natural Resource Management (NRM) governance system', suggesting its relevance as an ESEV within the context. During the follow-up workshop (W3), participants strongly recommended its inclusion as an ESEV and discussed potential indicators (GS^1-GS^6, Table 3). The most emphasized aspect for monitoring the local NRM governance system focused on the accessibility of local governance actors to land users (GS^1). This aspect can be monitored through the presence of individuals facilitating connections between local land users and landscape governance (Fry et al., 2021) & (I2.4).

3.3.3 Human well-being in the landscape (Proposed Addition 3)

Human well-being is a multifaceted concept, encompassing objective and subjective dimensions (King et al., 2014), which makes its integration into a streamlined monitoring system challenging. Initially excluded from the survey due to its complexity and perceived social nature (rather than social-ecological), well-being was emphasized by survey participants (n=5) within the socio-ecological context. They highlighted dimensions of well-being relevant to the landscape, including landscape assets and livelihoods, sense of place, spiritual well-being associated with cultural sites and rituals, and identity (Table 3). Recognizing the significance of understanding human well-being for comprehending SES dynamics, they proposed framing it as 'human well-being in the TRC/landscape'. This corresponds with recent efforts to monitor well-being within a social-ecological context, acknowledging its ecological embeddedness (King et al., 2014; Sangha et al., 2015; Wali et al., 2017).

3.4 Addition of key ecological and social variables

Upon reflection, participants considered the SES variables derived from this process to be comprehensive and providing a broad overview to characterize the system in relation to the TP vision (W3). Alongside the ESEVs, a few ecological and social variables were identified as necessary for monitoring to characterize and contextualize the system. Ecologically, climate variability, particularly rainfall and hydrology, was deemed a crucial driver of SES dynamics over time in this catchment, given the high dependency of land conditions and livelihoods on climate (12). Thus, climate variability must be considered when assessing the suitability and efficacy of project interventions, especially with the increasing visibility of climate change impacts. Education, including technical education, and access to the knowledge economy were suggested as indicators of a thriving SES from a social perspective (S). This could broadly be monitored via capacity development initiatives, seen as integral to enhancing the agency of TRC residents in local governance processes (Palmer et al., 2022).

4. Discussion

The resulting list of ESEVs and associated indicators were designed as a preliminary framework, poised for continual refinement and augmentation in accordance with the iterative nature of adaptive learning processes. The conception of ESEVs was derived from a deliberate participatory selection process, guided by a relational perspective rooted in systems thinking principles, and considering spatial and temporal scales. This participatory approach ensured the contextual relevance and applicability of the chosen variables. By employing these selection criteria, a focused set of relational social-ecological variables has been distilled, serving as linchpins in understanding the fundamental drivers, processes, and interactions underpinning SES dynamics across time and space.

The proposed definition of ESEVs, encapsulating the "minimum set of critical social-ecological variables to capture key features, processes, and interactions driving SES dynamics over time and space," underscores a commitment to a holistic approach that embraces the complexity of SESs. This methodology, as informed by previous work (Haider et al., 2021; Reyers et al., 2017), sought to streamline the monitoring endeavor while simultaneously providing an encompassing and interconnected understanding of SES condition and function.

4.1 Strength of connectivity of the essential social-ecological system variables

This study used a relational conceptualization of SESs as being intrinsically connected to develop a set of variables for streamlined and integrated monitoring. The identification of cross-cutting indicators capable of assessing multiple EVs provided an early intimation of the strong connectivity of the ESEVs (Table 1). The systems model below visually illustrates the interconnectivity among various resulting ESEVs and indicators for the TRC (Figure 5). The model follows diagrammatic conventions of a causal loop diagram, with green '+' signs indicating relations where a change in the cause creates a change in the effect in the same direction, while red '–' signs show inverse relations. Reinforcing feedback loops, numbered R1-R4, enhance whatever direction of change are imposed on them to cause vicious or virtuous cycles (Meadows, 2009). Unboxed black text shows priority indicators through which changes in the ESEVs are proposed to be monitored. Figure 5 highlights causal relationships between priority indicators and ESEVs, demonstrating how monitoring these indicators allows tracking of ESEVs and SES dynamics.

Without intervention, many of the dynamics of the TRC reinforce the system in undesirable directions to form vicious cycles. To maintain brevity, only the main features that underscore the robustness of connectivity are discussed here. The four priority ESEVs identified for the TRC are strongly interconnected: a decrease in *participation in natural resource (NR) governance* including less *participation in sustainable land-use management practices* would result in less *sustainable grazing and rangelands*, and a decrease in (intact and natural) *land cover and condition*, which increases *soil erosion* (Figure 5).

Furthermore, the identification of several reinforcing loops (R1-R4) involving the priority ESEVs show how changes in these variables can exert a strong influence within broader feedback mechanisms that drive the SES dynamics of the TRC, making them well-suited for integrated monitoring. For example, as users attempt to extract maximum benefit from communal rangelands without effective governance, un*sustainable grazing and rangeland* practices persist, resulting in further deterioration in *land cover and condition* thereby perpetuating a vicious cycle (R1), thus driving the system in an undesirable direction. From a systemic perspective, the goal is to shift the feedback loops that have been reinforcing undesirable outcomes in the TRC, into virtuous cycles that produce desirable outcomes. This can be achieved primarily through changes in the direction of the ESEVs and can be tracked by monitoring the priority indicators. Shifting the direction of some of the reinforcing loops from vicious cycles to virtuous cycles would have a balancing effect, countering undesirable runaway effects on the system.

The three additional ESEVs that were identified through the bias and gaps analysis – *local natural resource governance system, access to water,* and *human well-being in the landscape* (Figure 5) – are nexus points that play key roles in driving the overall SES dynamics of interest. *Human well-being in the landscape* is clearly influenced by the other ESEVs and indicators: *access to water, access to natural resources, soil erosion related to human actions on the land, land cover and condition,* and *land user satisfaction of their voices represented*. While *human well-being in the landscape* does influence other variables, these connections are complex, and well-being did not emerge from this analysis as a major direct driver of other ESEVs in the TRC.

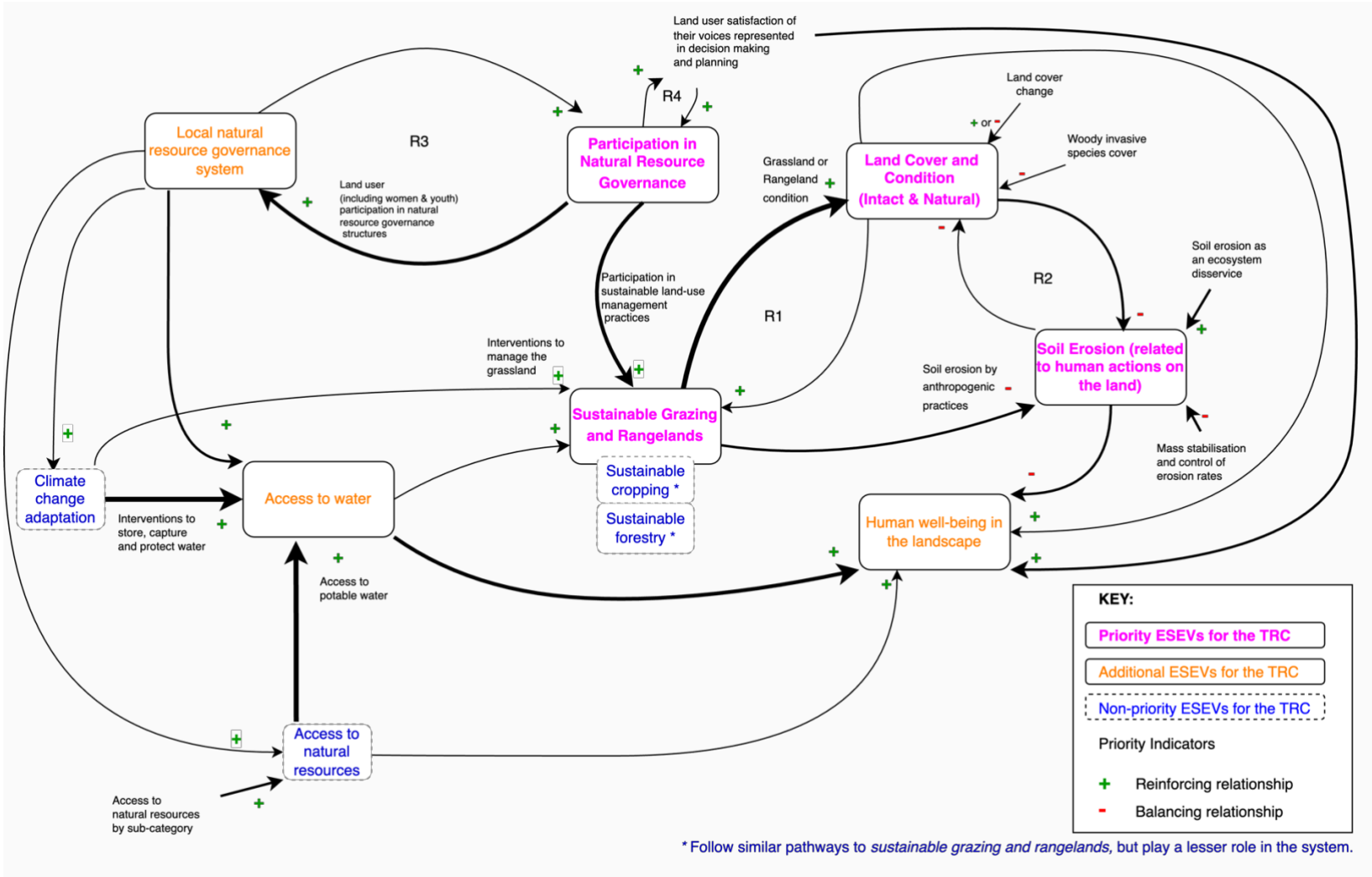


Figure 5. Systems diagram showing the relationships between priority Essential Social-ecological System Variables (ESEVs), non-priority ESEVs and additional ESEVs that emerged from a transdisciplinary social learning process in the Tsitsa River Catchment (TRC). The green '+' signs on the arrows show relations where a change in the cause creates a change in the effect in the same direction, and the red '−' signs on the arrows show inverse relations, where a change in the cause creates a change in the effect in the opposite direction. Arrow thickness is indicative of the strength/importance of certain connections in driving the social-ecological dynamics of the TRC system, with the weakest links being the thinnest lines and the strongest links being the thickest lines. The diagram numerically identifies reinforcing loops 'R1'- 'R4'.

Figure 5 thus illustrates the highly interconnected nature of the four priority ESEVs and associated indicators that emerged from this research, as well as the additional ESEVs later identified, versus the peripheral connections of the four non-priority ESEVs. The strong connectivity shows a close relationship between the sustainability of the landscape and the well-being of the communities.

4.2 Essential social-ecological system variables for sustainable livelihoods and restoration at catchment scale

Returning to the spatial part of the definition, the ESEVs proposed were applied at catchment scale, looking for changes that could be detected over the project period (annual to decadal scale). Monitoring at this scale, often utilized in integrated water resource management (Katusiime and Schütt, 2020; Savenije, 2002), focuses on the relations between land, water, and communities within the catchment. Results inform natural resource management decisions by local stakeholders and institutions. The fact that much of the EV work, including work on integrative EVs has been EO based (for example, Mccallum et al. 2020), may be a consequence of working at larger (regional or global) scales. Although EO remains as a data source, working at a catchment scale allowed for the incorporation of more varied sources of data to enable a more integrated social-ecological perspective. Employing a case study approach at this scale facilitated the identification of existing local institutions suitable for monitoring relevant, context-specific, social-ecological indicators. For instance, assessing participation and progress towards achieving the targets of grazing associations allows for the monitoring of relevant social-ecological relations in action (see 3.2.2). Monitoring through local institutions could also offer insights into the capacity of the local governance system (3.3.2) and inter-institutional relationships. Moreover, ESEV monitoring at the catchment scale could enable local institutions to utilize outcomes for adaptive natural resource management (Kingsford and Biggs, 2012).

Monitoring must align with indicator operational processes and long-term impacts, while also considering project objectives and timeframe. Monitoring is most pertinent for processes in which significant changes can be discerned primarily within the project's duration. Indicators in this study should be monitored at annual to decadal timeframes. Some indicators, such as mass and erosion rate regulation (3.2.1), were considered unsuitable due to mismatched timeframes.

The ESEV process could be tailored to address challenges in other river catchments. Although the ESEVs in this paper were developed for the TRC, many variables are applicable to other South African catchments with similar dynamics, such as Maqobeni, Tugela, and Olifants.

4.3 Areas of difficulty for social-ecological monitoring

Scale is a common area of difficulty for SES monitoring (Cumming et al., 2006; Maciejewski et al., 2015). The transdisciplinary team confronted challenges navigating the mismatches between the scales of ecological, social and institutional processes and monitoring (Itzkin et al., 2022). There was a mismatch between the scale of monitoring data using different methods. While EO collect broad scale data, observation methods such as transect walks and surveys collect more localized data which are not readily inferable to the catchment scale. While an ESEV approach does not explicitly address scale mismatches, by focusing on a significantly reduced set of data, it emphasizes key areas where the alignment of scale should be included in the approaches.

Difficulties in operationalizing certain ESEV s and indicators were identified. The ESEV, ‘soil erosion (related to human actions on the land)’ was highly prioritized, and while the associated indicators were also prioritized by the transdisciplinary team, upon further inspection with subject experts the indicators focusing on the anthropogenic contribution to erosion were found to be difficult to operationalize (see 3.2.1). Working across disciplines and in praxis brings varied perspectives but may lack the skills or knowledge to assess all selection criteria. Engaging subject experts is crucial for assessing feasibility. In the case of 'grazing and rangeland sustainability,' the overall ESEV was prioritized, but most related indicators were non-priority (see 3.2.3). This may be related to community reluctance to share sensitive data related to indicators such as G6 (income from sustainable livestock livelihoods), G7 (agricultural product sales rates), and G9 (livestock ownership patterns), making them difficult to operationalize.

4.4 Essential social-ecological system variables to make systems research simpler and more practical without losing the complexity

This study sought to simplify complex SES research outcomes without sacrificing their complexity. A participatory approach for ESEVs guided by both systems thinking and relational thinking, with a specific focus on practical application advances the realm of integrated SES monitoring. By adhering to the principles of requisite simplicity (Stirzaker et al., 2010), the proposed ESEV approach could assist in navigating complexities more effectively and efficiently, to find the simplest routes to understand the fundamental relational drivers of a system's dynamics.

5. Conclusion

This work has contributed to the understanding of social-ecological research in a rural catchment in southern Africa, where residents derive livelihoods from natural resources, and which is challenged by high levels of land degradation, a complex governance environment, and potential climate change impacts. By combining a transdisciplinary, participatory, systems approach, and a relational approach, a set of integrated Essential SES Variables was developed, which had not been done before. The ESEVs, including 'soil erosion related to human actions on the land,' 'participation in natural resource governance,' 'grazing and rangeland sustainability,' and 'land cover and condition,' hold the potential to inform integrated planning and management strategies at the catchment scale. In a world marked by complex development issues, the ESEVs pave the way for an integrative, adaptive, and contextually grounded approach to SES monitoring. This methodology is applicable to various SES landscapes.

The conceptual framing and methodology advanced in this study extend the realm of knowledge by offering a potent approach that underscores the importance of connectivity, context, and scale, contributing to simpler SES monitoring. The relational focus of this approach helps to overcome the dichotomies and dualisms in traditional SES monitoring frameworks, which reproduce separations between humans and nature. In conclusion, this study marks a significant step towards the advancement of SES monitoring by providing a rigorous framework of integrated ESEVs, reinforcing the importance of context, relational understanding, and adaptability in characterizing the dynamics of these complex systems.

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6.2 Postscript

This paper is a crucial addition to the thesis as it addresses the third objective of the study i.e., developing an essential social-ecological system variable approach to prioritise the types of data inputs needed to inform evidence-based management and policy to enhance sustainability in social-ecological systems landscapes in catchment studies. This research strives to cover an important gap in the domain of sustainable development by developing and piloting an innovative transdisciplinary method for assessing sustainability outcomes. In a world marked by complex development issues, this research paves the way for an integrative, adaptive, and contextually grounded approach to SES monitoring. The conceptual framing and methodology advanced in this study extend the knowledge by offering an approach that underscores the importance of connectivity, context and scale, contributing to simpler SES monitoring. The approach is applicable to various SES landscapes where it can help overcome methodological and theoretical barriers to SES monitoring to inform decision making toward sustainable development. The following chapter provides a synthesis of the entire study and presents the key findings, general conclusions, and recommendations.

CHAPTER 7 – DISCUSSION & CONCLUSION

The preceding chapter describes in detail the approach taken to select and prioritise Essential Social-ecological System Variables (ESEVs) and indicators. This approach allowed for the identification of critical social-ecological variables and indicators for monitoring the impacts of project interventions that would play crucial roles in larger feedback mechanisms influencing system functionality. This chapter begins by highlighting the high interconnectivity of the ESEVs and indicators that emerged from this process (7.1). This is followed with a discussion on how understanding social-ecological system (SES) drivers was a key step in identifying effective monitoring strategies (7.2), before exploring how ESEVs can fulfil a critical function to address data overload for efficient SES monitoring at catchment and local scales (7.3). The discussion then develops into a comparison of the ESEVs and indicators that emerged from this research with those proposed in the Essential Variable (EV) literature (7.4). The subsequent section discusses the value of novel approaches which combine multiple methods, including thinking and a transdisciplinary (TD) social learning-oriented methodology, to enhance SES monitoring (7.5). Finally, some of the methodological contributions made in this study are highlighted (7.6). Taken as a whole, this discussion underscores the contributions to knowledge that have been made in this study.

7.1 Interconnectivity of essential social-ecological system variables and indicators driving the dynamics of Tsitsa River Catchment

This research contributed to the process of identifying an array of integrated essential social-ecological variables (ESEVs) designed for monitoring SESs at the catchment scale. These variables were developed through a multifaceted approach that combined insights from scientific literature, local experts, and a participatory social learning process involving a deeply engaged transdisciplinary team, involved with a specific SES project in the Tsitsa River Catchment (TRC). The systems diagram (Fig. 5 in Chapter 6, p. 118) conceptually models the interconnectivity and influence of the various ESEVs and indicators for the TRC on one another. Its purpose is to illustrate how monitoring of the priority indicators could be used for integrated SES monitoring of system dynamics.

Chapter 6 contains a partial explanation of Figure 5, the dynamics of which are more comprehensively outlined below to further highlight the relationality between the priority indicators and the ESEVs, and how monitoring of the priority indicators allows the tracking of the ESEVs and SES dynamics.

The four priority ESEVs identified for the TRC – namely, *'soil erosion (related to human actions on the land)*' *'participation in NR governance*,' *'land cover change*,' and *'sustainable grazing and rangelands*' (in pink) – are highly connected, and their dynamics are considered to be key drivers of the TRC SES (represented by increased arrow thickness).

The main connections between priority variables are as follows: an increase in *participation in NR governance* including more *participation in sustainable land-use management practices* results in more *sustainable grazing and rangelands,* and an increase in *land cover and condition* (specifically intact, natural land cover types) which reduces *soil erosion*. Improved *land cover and condition* and reduced *soil erosion* increases *human well-being in the landscape*. An increase in *land cover and condition* also encourages and enables more *sustainable grazing and rangelands* in a reinforcing feedback loop (R1). The interplay between increased (intact, natural) *land cover* and reduced *soil erosion* forms a second reinforcing loop, to further increase (intact, natural) *land cover* (R2). The non-priority variables *sustainable cropping* and *sustainable forestry* (in blue) would influence the system by following similar pathways to *sustainable grazing and rangelands,* but the effects of these variables were determined to have less of an impact on the TRC, as indicated by their non-priority status.

As *Participation in NR governance* improves, there is more *land user (including women & youth) participation in natural resource governance structures,* which strengthens the *local NR governance system.* A strong and functional *local NR governance system* in turn enables *participation in NR governance* resulting in a reinforcing loop (R3). As the functionality of the *local NR governance system* increases, it is hypothesized that local governance rules in the TRC will increase equitable *access to natural resources* generally*,* and *access to water* in particular. An increase in *access to natural resources* and *access to water* increases *human well-being in the landscape*.

As *land user satisfaction of their voices represented in decision making and planning* increases, their *participation in NR governance* increases, which (if their experiences are

positive) increases their satisfaction of their voices being represented, to form another reinforcing loop (R4).

Human well-being in the landscape is the only ESEV that is not represented in the figure as being both a cause and an effect. *Human well-being in the landscape* is clearly influenced by the other ESEVs and indicators (*access to water, access to natural resources, soil erosion related to human actions on the land, land cover and condition,* and *land user satisfaction of their voices represented),* but is not shown to directly influence other ESEVs. While human well-being in the landscape does influence other variables, these connections are complex and did not emerge from this analysis as major direct drivers of the dynamics of other variables in the TRC.

Climate change adaptation was determined as a non-priority variable overall, but two associated priority indicators connect *climate change adaptation* to *access to water* and *grazing and rangeland sustainability.*

Figure 5 (Chapter 6) depicts the intricate interconnections among the four priority ESEVs and their associated indicators identified in this study, contrasting with the more peripheral connections observed among the four non-priority ESEVs. Additionally, the diagram underscores the importance of the three additional ESEVs identified through bias and gaps analysis by participants, highlighting their pivotal roles as nexus points influencing the overall dynamics of the SES under study. The robust connectivity depicted in the figure underscores the close relationship between landscape sustainability and community well-being.

7.2 Understanding how SES drivers contribute to more effective monitoring strategies.

Effective monitoring of SES requires a comprehensive understanding of the drivers that shape their trajectories. Building a participatory understanding of the drivers of SES dynamics proved to be an important early step in the development of ESEVs for efficient and integrated monitoring. The process of identifying drivers involved integrating transdisciplinary perspectives to identify key variables and feedback loops that influence the resilience and sustainability of these systems (chapter 4). This study has deepened the understanding of social-ecological research within a rural catchment in southern Africa, where residents derive

livelihoods from natural resources, and which is challenged by high levels of land degradation, a complex governance environment, and potential climate change impacts. This knowledge is crucial for designing monitoring strategies that can capture the key SES linkages relevant for sustainable land management.

The approach taken in this study acknowledges that although case studies of social-ecological problems like land degradation share some global, regional, or national 'core challenges' (Bodin et al. 2019), each complex SES is the result of a unique interplay of context-specific historical, social and ecological factors (Pulver et al. 2018), which can enable or inhibit systemic agency (Preiser 2019). Thus tapping into both broader knowledge on core challenges that occur repeatedly across many different contexts (via the broader scholarship) and building a context-specific understanding how those core challenges drive the SES dynamics in the specific case study (via the transdisciplinary perspectives from the TRC) were important steps in the selection of relevant monitoring variables. The systems application of the Drivers, Pressures, Stressors, Condition, Responses ($DPSCR_4$) process in chapter 4 highlighted the interconnected social-ecological nature of the problems facing the TRC, emphasising the need for an integrated social-ecological approach for monitoring these dynamics.

Building upon the systems models of the problem conceptualisation, to refine the selection of monitoring variables based on criteria aligned with the intrinsic connection between social and ecological aspects of SES (Reyers, Moore, Haider & Schlüter 2022; Garcia, Hertz & Schlüter 2020; West, Haider, Stålhammar & Woroniecki 2020), has played a crucial role in constructing a highly interrelated set of ESEVs (section 7.1). A relational approach sees SES as the result of the interplay of both the social and ecological elements, and the dynamic relationships among them (Preiser 2019). Since systems modelling captures both elements and causal relationships that connect them (Meadows 2009), it was found to be a suitable tool to build the relational SES understanding that is needed to guide integrated monitoring.

ESEVs have thus been designed to support efficient and integrated monitoring of fundamental interactions driving SES dynamics. The framework was developed to monitor the fundamental features, processes, and interactions influencing the trajectory of the TRC towards or away from the objectives of mitigating land degradation, enhancing livelihoods, and alleviating poverty. The approach can be tailored for integrated monitoring of other SES landscapes in relation to their specific context and goals.

7.3 A social-ecological system application of Essential Variables for integrated monitoring at a catchment scale.

The EV concept presents an opportunity to strengthen monitoring systems, by offering more efficient observations and capturing fundamental dimensions of the system (Lehmann, Masò, Nativi & Giuliani 2020). This study contributes to the recent evolution of EVs from predominantly environmental applications (Proença et al. 2017; Constable et al. 2016; Bojinski et al. 2014; Pereira et al. 2013), towards EVs that are more integrative of environmental and social dimensions (Kim et al. 2023; Balvanera et al. 2022; Pacheco-Romero, Alcaraz-Segura, Vallejos & Cabello 2020; Pacheco-Romero et al. 2022; Wu et al. 2021; Kussul et al. 2020; Lehmann, Masò, et al. 2020; Lehmann, Nativi, et al. 2020; Mccallum et al. 2020; Plag & Jules-Plag 2020; Zhao & Wu 2019; Reyers, Stafford-Smith, Erb, Scholes & Selomane 2017). A key factor differentiating this study from previous EV research in the above examples is scale. Much of the previous work done to operationalize integrated EVs for sustainability is based on European projects (such as ConnectinGEO: http://www.connectingeo.net and GEOEssential: http://www.geoessential.eu), using Earth Observation data, and is tailored for regional (primarily global north) or global applications (Lehmann, Masò, et al. 2020). The ESEV approach translates global scholarship on EVs into locally relevant praxis for the global south.

This study shows that just as EVs can play an important role building an efficient and critical knowledge base to monitor sustainability on global or regional scales, they can fulfil a critical function to address data overload in more localized monitoring. A local scale approach to EVs presents different opportunities to a global approach. One such opportunity is the potential of being able to incorporate transdisciplinary participation of those embedded within the problem context in the selection of EVs. This contributes towards addressing the difficulties associated with integrated monitoring, emphasising the requirement for participatory, people-centred methods, the importance of drawing on knowledge gained through applied praxis, and the necessity to blend qualitative and quantitative data, as highlighted by Itzkin, Clifford-Holmes, Scholes & Coetzer (2022, Chapter 5). Furthermore, working at the catchment scale facilitates the utilization of monitoring results by local stakeholders and institutions for informed natural resource management within the catchment area. While much of global and regional EVs, including integrative EVs, rely primarily on data from Earth Observation (EO), the ESEVs and indicators for the TRC supplement EO with other data sources. This approach recognises that while EO datasets such as those from Sentinel (15m) or Landsat (30m) provide relevant data at the local scale, there is considerable value in supplementing these datasets with

the nuanced local social-ecological data from field transects, surveys, and local institutions. In adopting a case study approach at the catchment scale, local institutions were identified as suitable for monitoring relevant social-ecological indicators. For example, assessing participation in sustainable land use practices such as grazing associations, is a means to monitor social-ecological relations in action. This research thus highlights the potential incorporation of diverse data sources, which in turn enables a more integrated social-ecological perspective, as a key advantage of taking an ESEV approach at a catchment scale.

7.4 Comparison of Essential Social-Ecological Variables from this Research with Similar Studies

The identified Essential Social-Ecological Variables (ESEVs) for the TRC shed light on the pivotal aspects of social-ecological dynamics within the TRC region. Monitoring soil erosion, land cover and condition, participatory natural resource governance, and sustainable grazing and rangelands emerged as crucial for understanding these dynamics. Notably, analogous variables are found in other integrative EV studies. For instance, the social-ecological implications of soil erosion resulting from the interplay of natural and anthropogenic factors are highlighted in various studies (Wu et al. 2021; Pacheco-Romero et al. 2020). Land cover is also recognised as a fundamental variable in monitoring SDGs (Fukui, Man & Phan 2021; Stehfest et al. 2019) and has been proposed as a key component in essential social-ecological monitoring (Fukui et al. 2021; Wu et al. 2021; Pacheco-Romero et al. 2020). While participation in natural resource governance was not found to be explicitly identified as an Essential Variable (EV), the broader category of governance is acknowledged as an essential, often overlooked, element in monitoring SESs (Pacheco-Romero et al. 2020). Variables related to monitoring sustainable grazing and rangelands also find resonance among the 'essential drylands variables' (Wu et al. 2021) and the general reference list proposed by Pacheco-Romero et al. (2020)for characterizing and monitoring social-ecological systems.

Similarly, additional ESEVs identified in this study share similarities with variables and indicators found in other EV literature. Notably, access to water (Pacheco-Romero et al. 2020), the local governance system (Fukui et al. 2021; Pacheco-Romero et al. 2020; Ostrom 1990, 2007), and human well-being in the landscape (Pacheco-Romero et al. 2020) align with broader environmental monitoring frameworks.

In contrast, the non-priority variable, access to natural resources, did not directly appear in other reviewed EV literature. However, its inclusion as a potential ESEV for the TRC

was justified by its emergence as a theme in the participatory research process and its connection to the project's goal of equity in access to ecosystem services, aligning with Balvanera et al.'s (2022) 'ecosystem service variables'. The other non-priority variables for the TRC, namely sustainable cropping and sustainable forestry, find parallel in essential SDG variables for monitoring land degradation (Zhao et al. 2023), SDG variables for green transformations (Fukui et al. 2021), EVs for the food, water, and energy nexus (Mccallum et al. 2020), and essential forest variables (Zhao & Wu 2019).

It is important to note that these ESEVs represent a tiny selection of variables from the broader EV literature. There are a multitude of potential EVs in the literature, designed for different purposes, most of which would either be unsuitable to meet the objectives of this research or would not meet the relational social-ecological criteria set by the ESEV framework. The method that was followed to identify ESEVs included identifying relevant themes that emerged from the transdisciplinary research process as key SES drivers within the TRC (as explained in sections 7.1 and 7.2) and cross referencing these themes against EV literature, increase comparability and rigour (since they would then have passed multiple critical filters). Filtering potential ESEVs against the ESEV selection criteria, developed in this study, enables the identification of a minimum set of critical social-ecological variables to capture key features, processes, and interactions driving SES dynamics over time and space. The intentional relational selection criteria is a notable difference from other EV studies. This process ensured that only variables that were both contextually relevant and theoretically appropriate (as per the relational social-ecological criteria) were chosen, thus effectively tackling the issue of data-overload typical in other SES monitoring programmes (Lehmann, Masò, et al. 2020).
The selection process also incorporated themes that emerged in the participatory research process.

A recommendation is to expand the application of the ESEV approach to additional SES case studies, to establish a "bottom-up" transdisciplinary set of potential ESEVs. This recommendation draws a parallel with the approach used to develop EVs for protected areas by engaging with practitioners from 27 internationally recognised Protected Areas (Hummel et al. 2022).

7.5 Novel approaches which combine multiple methods to conduct transdisciplinary social-ecological systems research

A comprehensive strategy is required to confront wicked SES problems, and a combination of systems thinking and a TD social learning oriented methodology proves effective in addressing these challenges. Complex adaptive systems thinking provides a bridge between the study of social and biophysical sciences, offering insights into the interlinked patterns that emerge (Preiser et al. 2021). Systems thinking, which explores the influence of components within a system and across systems, is particularly well-suited for tackling wicked problems (Burton 2017; Elsawah et al. 2017). Drawing on data about drivers of degradation within the target landscape, systems diagramming elucidated key interactions among context-specific drivers, revealing multiple processes simultaneously causing and exacerbating land degradation in the TRC.

The benefits of TD approaches to address wicked social-ecological system problems are outlined in section 2.5.4. Coupling an iterative and participatory TD approach with systems analysis is a powerful methodology for unravelling SES complexities. While systems thinking enables a nuanced understanding of intricate relationships within SES, an iterative TD methodology ensures continuous improvement of solutions through collaboration among diverse stakeholders. This agile and collaborative environment enhances efficiency and adaptability to changing stakeholder requirements. The participatory nature of the ESEV process, where knowledge is generated through social interactions at the local scale and draws on systems thinking and modelling, results in a new shared understanding of SES drivers and ESEVs, qualifying it as social learning (Reed et al. 2010). Together, systems thinking and a TD methodology guide us towards better solutions at each iteration, as they provide and integrate various perspectives on the dynamic challenges posed by wicked problems, such as integrated SES monitoring.

7.6 Methodological contributions of the methodologies employed in this study

Participatory and social learning approaches (sections 2.5.4, 2.5.5 & 2.5.6), have been used for decades, as has monitoring, evaluation and learning (MEL) (section 2.1.2). The transdisciplinary social learning process facilitated in this research could be seen as an application of the TP's MEL approach (section 3.3), where participatory learning and reflection was used to build a shared understanding of (i) the SES drivers in the study area, (ii) the broader problem context of integrated monitoring of complex SESs, and (iii) what approaches can

enhance integrated monitoring in support of research, planning, and management for sustainable social-ecological systems in the TRC and beyond. This iterative process resulted in the development of an essential variable approach to enhance integrated monitoring in support of research, planning, and management for sustainable SESs, and its application in the TRC. Keeping the process open to emergence proved valuable as it allowed for shared learnings around how to enhance SES integration and monitoring, gathered throughout the unfolding process (Chapter 5), to be integrated into the final product – the ESEVs (Chapter 6).

It is important for complex SES research and praxis to be experimental spaces that take an adaptive approach and that are open to emergence (Kingsford & Biggs 2012). The TP's nature as an experimental space where researchers, natural resource managers, and residents were able to collaborate towards a shared goal of improving social-ecological systems sustainability, provided a much-needed opening for transdisciplinary social learning to address challenges and foster sustainability. This is linked to the understanding of restoration programmes as taking place in and through complex SES, where the pathways to success need to be worked out *during and through* action-taking and reflection (Kotschy, Cockburn, Biggs & Rosenberg 2021).

7.7 Conclusion

In conclusion, this thesis advances integrated monitoring for assessing sustainability outcomes, which is a critical challenge in social-ecological systems (SES) research worldwide. This challenge is particularly pronounced in the context of developing world catchments, where nature and people are closely connected. To address this issue, the study introduces the essential social-ecological system variables (ESEV) approach, a novel integrated monitoring method developed through a transdisciplinary process combining various methods.

The overarching aim of developing and applying the ESEV approach in the Tsitsa River Catchment (TRC) was achieved through three research objectives. Objective one focused on employing a participatory systems analysis approach to identify and analyze the key factors driving land degradation within the TRC. This process established a solid foundation rooted in a participatory understanding of the contextual factors influencing the SES dynamics of the case study. Building upon this foundation, objective two involved the utilization of multiple methods and approaches in combination to develop and pilot a transdisciplinary social learning process to enhance integration and monitoring within SES landscapes. The insights gained from this iterative social learning process informed the development and framing of the ESEV

approach, which was the focus of objective three. The ESEV approach offers a relational understanding of SES sustainability, transcending the limitations of purely biophysical or social science perspectives. It also challenges conceptualizations of SESs that maintain a separation between social and biophysical processes. Valuable insights are offered not only regarding monitoring variables in the TRC case study, but also on the process of identifying ESEVs to simplify integrated monitoring in diverse SES landscapes. Overcoming methodological and theoretical barriers, ESEVs supply essential information on scientific processes within a relational SES framework. This study demonstrates the feasibility and value of the ESEV approach, particularly in settings facing integration and data-overload challenges, thereby effectively addressing a critical gap in SES monitoring.

In summary, this thesis pioneers a transdisciplinary mixed-methods approach for efficiently monitoring social-ecological sustainability outcomes. Through advancements in conceptualizations of integrative, and contextually grounded monitoring, it offers a fresh perspective for understanding the implications of development interventions. Through these innovations, this research marks a significant step towards the advancement of integrated monitoring in characterizing the dynamics of complex social-ecological systems.

CHAPTER 8 – REFERENCES

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Appendices

for

An essential variable approach for integrated social-ecological systems monitoring to determine sustainability in a South African catchment.

by
Adela Itzkin
(319735)

Thesis
Submitted in fulfilment of the requirements for the degree
Doctor of Philosophy
in
Animal, Plant and Environmental Sciences
in the Faculty of Science, University of the Witwatersrand, Johannesburg, South Africa

Supervisor: Professor Mary Scholes
Co-supervisors: Dr. Jai Kumar Clifford-Holmes and Dr. Kaera Coetzer

February 2024

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1. Ethics Clearance Certificate

UNIVERSITY OF THE WITWATERSRAND JOHANNESBURG

Research Office

HUMAN RESEARCH ETHICS COMMITTEE (NON-MEDICAL)
R14/49 Itzkin

CLEARANCE CERTIFICATE	**PROTOCOL NUMBER: H19/09/13**
PROJECT TITLE	A system approach promoting the interconnectivity of social and biophysical data within the Tsitsa Catchment to support integrated research, planning, and management
INVESTIGATOR(S)	Ms A Itzkin
SCHOOL/DEPARTMENT	Animal, Plant and Environmental Science/
DATE CONSIDERED	13 Seprember 2019
DECISION OF THE COMMITTEE	Approved
EXPIRY DATE	21 October 2022

DATE 22 October 2019 **CHAIRPERSON** pp (Professor J Knight)

cc: Supervisor : Professor M Scholes

DECLARATION OF INVESTIGATOR(S)

To be completed in duplicate and **ONE COPY** returned to the Secretary at Room 10004, 10th Floor, Senate House, University. Unreported changes to the application may invalidate the clearance given by the HREC (Non-Medical)

I/We fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee. **I agree to completion of a yearly progress report.**

Signature _____ Date _____/_____/_____

PLEASE QUOTE THE PROTOCOL NUMBER ON ALL ENQUIRIES

2. Participant Information Sheet (Interviews)

Project Title: A systems approach promoting the interconnectivity of social and biophysical data within the Tsitsa Catchment to support integrated research, planning, and management.

Good day. You are being invited to take part in a research study that will be conducted by me, Ms Adela Itzkin, a PhD researcher from the University of the Witwatersrand.

The study will be focussing on the interconnectivity of biophysical and social data in the Tsitsa Project (TP). The reason for the study is to pilot the use of an observation system that can provide adequate information to support integrated research, planning and management at the catchment scale.

I am conducting this research as part of my university studies, but the information I gather will be interesting and useful to government, local communities and researchers within the TP. The application value of the study is enhanced through input from as many researchers involved in the TP as possible. You have been identified as a potential participant because of your association with the TP research team.

The study involves an interview that could take between 30 minutes -1 hour. You will be asked a number of questions about your knowledge around existing data and the applications of these data in the TP. While the questions will ask you to provide certain information about your role and experiences in the TP, **no** names will be used in any results, documents or reports with which this study is concerned.

Your participation in this study is voluntary and you may choose to stop being a part of the study at any time. You may also refuse to answer any questions with which you are not comfortable.
If you have any concerns or complaints regarding the ethical procedures of this study, you are welcome to contact the University Human Research Ethics Committee (Non-Medical), telephone +27(0) 11 717 1408, email shaun.schoeman@wits.ac.za.

Many Thanks
Adela Itzkin
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Supervisor: Prof Mary Scholes
Office Number: 011 717 6407
Email: mary.scholes@wits.ac.za

3. Participant Consent Form (Interview)

Thank you for reading the information sheet about the interview. If you are happy to participate then please complete and sign the form below. Please initial the boxes below to confirm that you agree with each statement:

I was invited to participate in the research project conducted by Ms Adela Itzkin from the University of the Witwatersrand and I understand my role in the study.	☐
I understand that the reason for the study is to develop and pilot the use of an observation system that will integrate data and provide adequate information on scientific and social processes at the catchment scale, in order to support integrated research, planning and management.	☐
I understand that my participation in this project is voluntary.	☐
I am aware of the time required to answer the interview questions.	☐
I understand that the researcher will not identify me by name in any reports using information obtained from this interview, but that it is possible that my identity could be inferred from the information that I provide, and that therefore, anonymity cannot be guaranteed.	☐
I volunteer to participate in the research project.	☐

_____ _____

Participant's Signature Date

_____ _____

Researcher's Signature Date

4. Participant Consent Form (Interview-Audio Recording)

Thank you for reading the information sheet about the interview. I would like to audio record the interview. If you are happy to allow this then please complete and sign the form below. Please initial the boxes below to confirm that you agree with each statement:

I agree for this interview to be audio-recorded. I understand that the audio recording made of this interview will be used only for analysis and that extracts from the interview, from which I would not be identified by name but which could be linked to my position in the research team, may be used in any conference presentation, report or journal article developed as a result of the research. I understand that no other use will be made of the recording without my written permission, and that no one outside the researcher (Ms. Adela Itzkin) will be allowed access to the original recording.	☐
I agree that my data from the audio recording will be kept for future research purposes such as publications related to this study after the completion of the study.	☐

_____ _____

Participant's Signature Date

_____ _____

Researcher's Signature Date

5. Interview Instrument with Guiding Questions

1. What is/was your **role/position in the Tsitsa Project?**

2. You are familiar with the official key issues as stated in the Tsitsa documentation. **From the perspective of your CoP, what are the key issues that the Tsitsa project has addressed** that will meet the needs of the DEA and provide evidence for the research needed to inform policy?

3. **From the perspective of your CoP, what are the key issues that the Tsitsa project needs to address** that will meet the needs of the DEA and provide evidence for the research needed to inform policy?

4. **How do you define** what you are collecting as **data?** / What constitutes data collection?

5. **What data have you been involved with collecting?**
    - 5.1 Would you characterize the data as: social, biophysical or both?
    - 5.2 At what scale have these data been collected?
    - 5.3 At what frequency have these data been collected?
    - 5.4 How do these data relate to key issues in the project?
    - 5.5 Why were these data collected? (clarification if required: do the data build an evidence base for management or are they just being collected to build a better understanding of the catchment?)
    - 5.6 For what purpose have these data been used?
    - 5.7 Were there particular end-users in mind? If so, who are the end users of the data?
    - 5.8 Where are these data housed?
    - 5.9 Is the data publically available or is it limited to use within the CoP or specific group? My intended use for the data: Part of this project is to develop a social-ecological framework that can …. (Are the data available to be used as an input to a Social-Ecological Systems framework?
    - 5.10 Can I access the data as raw files or meta data sets? How?

6. **What other contexts do you perceive relevant data** (related to the above) **to be coming from?** (For example: researchers, consultants, managers, implementers?)

7. ***OPTIONAL:*** *What related data have you come into contact with or are you aware of?*
   - *7.1 Who has collected this data?*
   - *7.2 Would you characterize the data as: social, biophysical or both?*
   - *7.3 At what scale have these data been collected?*
   - *7.4 At what frequency have these data been collected?*
   - *7.5 How do these data relate to key issues in the project?*
   - *7.6 Why were these data collected? (clarification if required: do the data build an evidence base for management or are they just being collected to build a better understanding of the catchment?)*
   - *7.7 For what purpose have these data been used?*
   - *7.8 Were there particular end-users in mind? If so, who are the end users of the data?*
   - *7.9 Where are these data housed?*
   - *7.10 Is the data publically available or is it limited to use within the CoP or specific group?*

   My intended use for the data: Part of this project is to develop a social-ecological framework that can …. (Are the data available to be used as an input to a Social-Ecological Systems framework?

8. The Tsitsa Project speaks of integration and integrated management. For instance, when we think of management of livestock which has social dimensions, we need to think of it in terms of biophysical impacts that different management options would have as drivers of erosion and sedimentation of dam. **How would you describe the level of interconnectivity of data in the Tsitsa Project?**

9. To the best of your knowledge, **what approaches and tools have been used to try to achieve interconnectivity of data** in the Tsitsa Project?

6. Thematic Analysis of Interview Data

Thematic Analysis of Key Issues, Interconnectivity and Data Availability in the Tsitsa Project: Data Collection and Analysis Process Document

By Adela Itzkin
May 2020

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Abbreviations

CoP	Community of Practice
CLO	Community Liaison Officer
DEFF	Department of Environment, Forestry and Fisheries
PMERL	Participatory Monitoring, Evaluation, Reflection & Learning
KIA	Key issue addressed
KINA	Key issues that needs to be addressed
SES	Social-Ecological System
TP	Tsitsa Project

1. Introduction

Interviews were the approach used to collect data on key variables, interconnectivity and data availability in the Tsitsa Project (TP). The interviews occurred between July 2019 and January 2020. It is important to note that this report and the associated diagrams, represent only a partial snapshot at this moment in time. As The tables and diagrams from these interviews represent the knowledge and experiences of nineteen project members (from fourteen individual interviews and two group interviews) identified as key informants. Key informants are people, who as a result of their skills or position, have specialist knowledge that is more extensive, detailed or privileged than ordinary people, making them expert sources of information (Payne and Payne 2004).

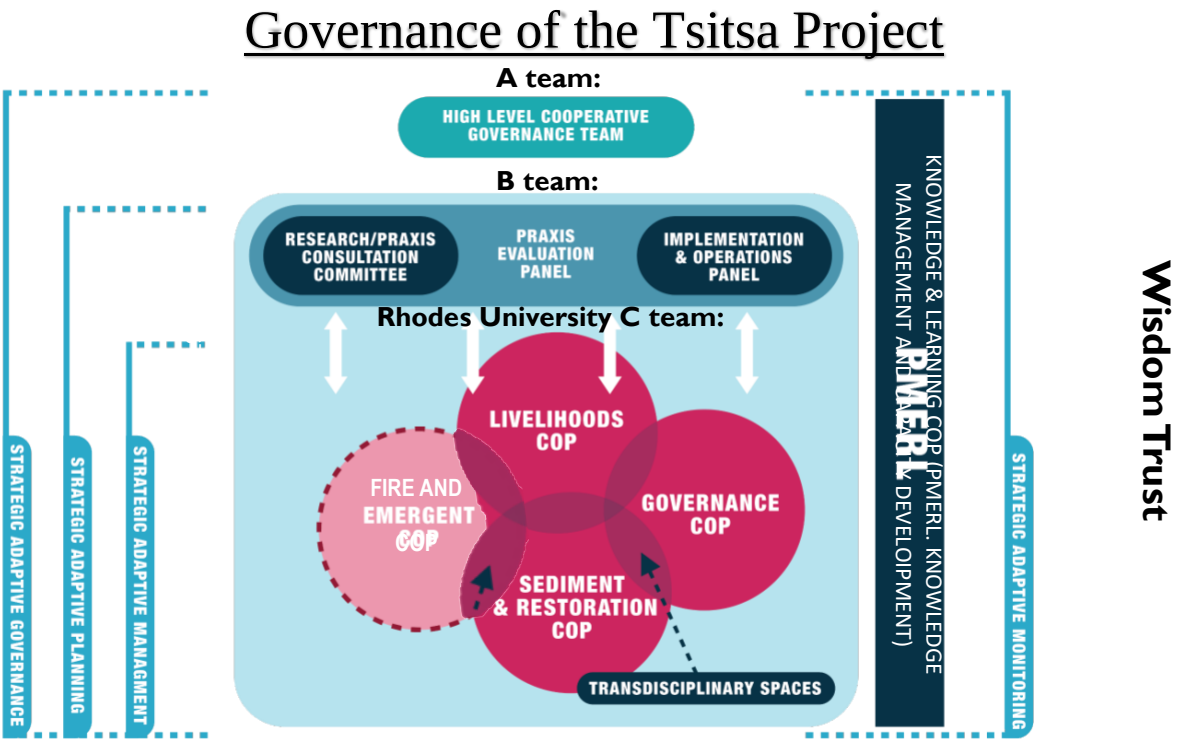


Figure 1. Institutional governance of the Tsitsa Project (TP) is broken down into several structures that operate on different levels. The 'A team' (also known as the Strategic Oversight Committee) is a high level cooperative government team comprised of members from different departments. The 'B team' is made up of provincial government members, implementers (who do restoration work on the ground), traditional leaders and the leaders of Rhodes University TP team who can influence decision making. The 'C team' is a TP Rhodes University internal decision making team. The Wisdom Trust is an advisory board made up of renowned experts in various disciplines. The research is approached through six themed Communities of Practice (CoPs) as follows: 'Sediment and Restoration', 'Governance', 'Livelihoods', 'Fire and Grazing', 'Knowledge and Learning', and 'Systems Praxis'(adapted from Botha et al. 2017, in consultation with Tsitsa Project Manager).

In the TP, research is done to inform integrated planning and management processes. Rhodes University leads the research component of TP, in partnership with multiple other universities, and is funded by the Department of Environment, Forestry and Fisheries (DEFF). The key informants for these interviews are experts considered to be most knowledgeable about the aspects of the TP under review, based on their roles and responsibilities in the TP. Project management and the coordinators of the various communities of practice (CoPs) based at Rhodes University were the first to be interviewed, and the list was extended upon review of the informants' recommendations. The list of nineteen key informants that follows and can be situated in Figure 1. I have not included names, but I will link responses to the informants' roles and responsibilities in the TP to qualify and contextualize when appropriate (as per my ethics application):

- Tsitsa Project Research Coordinator (member of B and C teams)
- Overall Project Coordinator (and former member of governance CoP) (member of B and C teams)
- Four members of the sediment and restoration CoP as follows:
    - The sediment and restoration CoP main coordinator,
    - The sediment and restoration CoP co-coordinator,
    - A key collaborator providing spatial soil erosion data, and
    - Research Assistant responsible for gather the biophysical data for baselines and monitoring.
- Four members of the participatory monitoring, evaluation, reflection and learning (PMERL) team of the Knowledge and Learning CoP:
    - PMERL Coordinator,
    - Knowledge and learning Coordinator,
    - Designer of PMERL Framework and Advisor,
    - New PMERL co-coordinator.
- Former knowledge management CoP coordinator.
- Capacity Development Coordinator (in the Knowledge and Learning CoP).
- Governance CoP coordinator.
- The Livelihoods CoP Coordinator.
- Livelihoods PhD project supervisor and Knowledge Management CoP Advisor.
- Catchment Coordinator .
- Two Grass and Fire CoP co-coordinators.
- Resource Economist and Wisdom Trust member.

The overall aim of these interviews was to critically review the current data availability in the Tsitsa Project and posit a hypothesis (co-created with the CoPs) of the key elements of the system and how they connect.
Research questions in this process are:

1. What are the key elements (variables?) of the system and how are they connected?
    - Which are first order effects, which are second order effects?
2. What is the level of interconnectivity of data in the project?
    - What approaches and tools have been used to try to achieve interconnectivity of data?
3. What data are available?

2. Methods

The interviews, which occurred between July 2019 and January 2020, were conducted, audio-recorded and transcribed by myself enabling me to familiarize myself with the data, before being thematically analysed to identify, analyse and report patterns (themes) within data as described by Braun and Clarke (2006, 2014).

What is thematic analysis?

"Thematic analysis (TA) is a method for identifying and interpreting patterns of meaning across qualitative data." (Clarke and Braun 2014 p. 6626).

Thematic analysis is appropriate because it provides a method for qualitative research that is not tied to a particular theoretical framework and is flexible to a range of research questions including about experiences or perspectives and influencing factors (Clarke and Braun 2014). Thematic analysis can be used with data generated through a researcher interacting with participants (the case in this analysis) or secondary sources of data (*ibid 2014)*.This thematic analysis is a realist account, which reports experiences, meanings and the reality of informants. I identified patterns/themes, that were data-driven and relevant to each of the research questions.

What is a theme?

"A theme captures something important about the data in relation to the research question, and represents some level of patterned response or meaning within the data set." (Braun and Clarke 2006 p. 82).

Why Coding?

Brent, Simelane and Clifford-Holmes (2017) categorise different types of databases in relation to so-called 'hard' sources of information (including physical laws and controlled and

uncontrolled experiments), and 'soft' sources of information (including the judgement of experts, and experiential/institutional system knowledge and personal intuition of participating stakeholders) (Figure 2). These interviews relied on expert judgement and stakeholder knowledge and are thus classified as soft data. According to Morse (2018 p. 808), soft data can be manipulated to increase hardness and rigor through coding.

A strategy for verification of soft qualitative data is to verify with participants through member checking. Member checking can also be used to continue with analysis, validate concepts and components, and complete data collection (Morse, 2018). The interview data has been (/will be) updated and verified through one on one sessions with selected informants and through a workshop that all informants were invited to, scheduled for 26 May 2020.

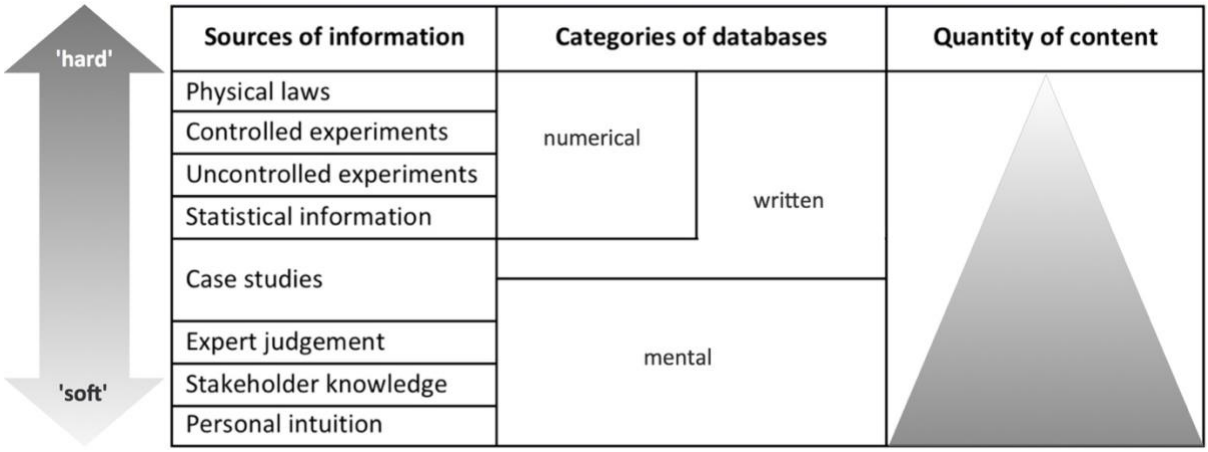


Figure 2. Continuum of information from so-called 'hard' sources through to so-called 'soft' sources. Conceptualised and designed by Jai Clifford-Holmes drawing from the work of Forrester (1980) and Ford (2009), and published in Brent, Simelane and Clifford-Holmes (2017).

Data Terminology:

The data corpus refers to all the data collected for this purpose, in this case the data corpus is comprised of the audio-recordings and transcriptions of all sixteen interviews. Data set refers to the data from the corpus that are being used for a particular analysis. Separate data sets were extracted from the corpus that focussed on portions of each interview relating to the three key questions (above). Data item refers to each individual piece of data collected, which together make up the data set. A data item in this instance would be an individual interview. Finally, data extract refers to an individual part of data, that has been identified within, and extracted from, a data item and positioned within a data set. There are many data extracts that make up each data set, which are arranged in themes, sometimes coded, and will feature in the final analysis.

3. Research Question 1: Key Issues/Variables in the TP System

In discussions about the key issues that the TP has addressed thirty issues were brought up, while fifty-one key issues that the TP needs to address were brought up. I have listed all the issues below because so as not to cluster too early and lose an important issue. The next step will be to aggregate the issues.

3.1 Key Issues Lists

The **key variables/issues** that participants felt the **TP has addressed** ('Key Issues Addressed' or KIA) are as follows, n = the number of interviews in which each variable was mentioned:

1. Grassroots/community input (n=5).
2. Co-construction, knowledge exchange and integration between CoPs (n=4)
3. Co-construction more broadly (n=2).
4. Baseline of biophysical and social dynamics (n=3).
5. Biophysical data-erosion and sedimentation (n=3).
6. Understanding issues around sedimentation processes (n=2).
7. Trust with communities and community leaders-citizen monitors (n=2)
8. Appointing and budgeting for community liaison officers (CLOs) (n=2).
9. Social Indicators developed using capabilities approach (n=2).
10. Trust has improved 'all-round' (n=1)
11. Relationship with implementers (on the ground) has been established (n=1).
12. Relationship with municipality and gov. depts. being established (n=1).
13. Buy-in from regions environmental affairs dept (n=1).
14. Catchment vision and the early output of an objectives framework (n=1).
15. Development of 'Capability Pathway' (n=1)
16. Applying the APP to cut barriers to participation (n=1).
17. Workshops (learning words & what is the TP) on stakeholder capacity to know and speak (n=1).
18. Integrated planning process started (n=1).
19. Integration of research into praxis (n=1).
20. Advanced our knowledge of the socio-ecological learning process (n=1).
21. Starting assessment and adaptive management of work (n=1).
22. spatial distribution of the source areas, (gullies) (n=1).
23. Establishing vetiver nurseries and employing people to monitor (n=1)
24. Development of the citizen science methodology (n=1)
25. Understanding the Stakeholder and Governance context (Stakeholder analyses) (n=1)
26. Process of selecting (social and biophysical) indicators is complete (n=1)
27. Embedding monitoring in the catchment (n=1)
28. PMERL collecting quarterly and BTO reports (n=1)
29. Sending money to the catchment through the citizen technicians (part of DEA's thing) (n=1)
30. Development of capacity development plan that embodies a principle of engaging in a social learning approach (n=1)
31. Set up project structure (n=1)

The **key variables/issues** that participants felt the **TP needs to address** ('Key Issues that Need to be Addressed' or KINA) are as follows, n = the number of interviews in which each variable was mentioned:

1. Data Management (/Knowledge Management) (both internal & external) and integration (n=5)
2. Using social information to direct NRM efforts (human activities & responses to interventions N.B. for sustainability) CLOs (as key agents of change-to deepen participatory governance potential) (Improve community voice) (n=3)
3. External communication about project (might find that communication and advocacy are more important than real data and hard-core proof, need a communications officer) (grassroots communication is difficult) (n=3)
4. Need a high resolution powerful reflective monitoring system (get the monitoring system running in terms of the indicators that the project has selected, and involving CLOs) to build that high level understanding of how well we are meeting our objectives (n=3)
5. Identifying areas where erosion is taking place that can be addressed / More research on how to minimize degradation and erosion on this landscape (n=2)
6. Tangible case-studies of sustainable livelihood practices/ small action research learning projects on the ground where we can learn from our interventions. (n=2)
7. Buy-in from communities (trying to get communities to feel part of what you are doing)-starting but more to go. (n=2)
8. Capacity development in catchment (area has been neglected for more than a hundred years there is a huge amount of work to be done at the grassroots for capacity building) and broadened to all TP actors (n=2) ? not included in Cap dev. Diagrams
9. Restoration for an agricultural context (research on how to increase the land productivity for forage, for livestock) (n=2)
10. Develop an indicator of erosion in the catchment (n=1)
11. Get grips on the sediment contribution from the source areas (n=1)
12. Measure sediment yield (Specifically the sediment yield contribution from gully erosion from different sized gullies.) (n=1)
13. Measure buffers, stores and sinks of hillside slopes (n=1)
14. More research on how to improve the water quality and maintain the ecological infrastructure that is still functioning. (n=1)
15. Extend the learning words and TP more deeply into the three nodes (n=1)
16. Gaps between Thesis work and what is needed for TP (missing glue) (n=1)
17. Budget for writing up or data analysis (n=1)
18. Reflections have not taken hard data into account (based on peoples' experiences). Do not have data on the physical and social trends on the ground. (n=1)
19. Two-way link between restoration work & opportunities for improved livelihoods from a sustainability POV (n=1)
20. A value-chain analysis for vetiver (n=1)
21. land use/land planning mapping, some done but not completed and in a small area (Dylan), needs to be scaled up. (n=1)

22. Values, how people use and value ecosystem services (how people relate to their environment). (n=1)
23. Interpreting and synthesizing things (n=1)
24. 'Softer context' to inform ethical implementation over long term (n=1)
25. Start using social indicators (n=1)
26. Grazing and fire CoP not up and running (rangeland management, livelihoods & livestock, complexity around that & how we deal with it not well addressed, assumptions around the theory around rangelands, is herding the best answer?) (n=1)
27. Need better institutional organization, structure, and guidance on the roles and responsibilities of each CoP coordinator and CoP (many of the people working on the Project do not have clear job descriptions). (n=1)
28. Key members of the project need to be very aware on what our project objectives are (At this point project objectives and where people fit in to those objectives to achieve the vision of the project are poorly understood by members). (n=1)
29. Engaging in a positive way with local municipalities (n=1)
30. Integrating everything with the catchment residents (eg: have more events and action on the ground at village level and municipal level in the catchment) (n=1)
31. Following the protocol of informing the catchment coordinator of planned activities. Buy-in from communities (trying to get communities to feel part of what you are doing)-starting but more to go. (n=1) (Adela thought: may be a lever for trust & capacity development?)
32. Protocols of how to engage effectively with each other (as the project grows it becomes more complicated and complex, which is why we are going to miss each other somewhere if we don't find these). (n=1)
33. Important for all TP members to have the same idea of how we work on the ground (we are from different fields, but we should all know what to expect and how to behave). (n=1)
34. Overall comprehensive governance network (catchment level governance is not operational. Each department does whatever they want, there is very little coordination and very little deep thinking about what is the best land use option so that is a big challenge). (n=1)
35. Continued unplanned grazing and fire management (biggest user of resources and benefits and it comes with its own challenges) (n=1)
36. Indicators and the protocols are being developed (n=1)
37. Social learning facilitation (CoP actors must be trained to facilitate for social learning) (n=1)
38. Funding (mismatch between the money required & the work that needs to be done) & (catalyzing agent for the grass and fire CoP and for our management plan is funding). (n=2)
39. PR person to 'package' and 'sell' the project (n=1)
40. Human capital (n=1)

41. Demonstrate the economic value of the restoration at the local level (n=1)
42. "Interleave" reporting requirements of TP and other bodies especially DEFF (n=1)
43. Grass and fire CoP want to get eco-rangers going (n=1)
44. Grass and fire CoP want to get grazing associations going (n=2)
45. Evaluate and talk about conservation agreements (n=1)
46. Drivers of degradation (difficult to change) (n=1)
47. Reducing the pressure on the landscape (by reducing grazing and fire) (n=1)
48. Extend capacity development beyond Rhodes (n=1)
49. Knowledge management capacity (e.g. a full-time dedicated person) (n=1)
50. Data on physical and social trends on the ground (n=1)

It is noteworthy that the number of needs (KINAs) listed by informants are far higher than what was listed as having been addressed (KIAs). This could talk to planning, governance, institution structure, lack of resources and ambitious expectations. Some of the issues that participants' feel need to be addressed could be linked to maturity of the project and the project could be on the path towards meeting those things.

3.2 Key Issues Table and Diagrams

The key issues were then categorized into the following high level categories/themes that relate to the overall Tsitsa Project goals and objectives (Table 1). Key issues that fit into more than one theme are italicized. Keeping in mind that a later objective of this project is to build an observation system for the Tsitsa Project and that the observation system must measure progress of the project in relation to the project's goals and objectives, the key issues that have been addressed and those that need to be addressed should be considered in relation to the overall vision of the TP. Table 1 therefore begins with participants' references to the overall project vision and objectives. Table 1 is intended to be accompanied by diagrams of the key issues in corresponding themes, drawn out using the free open source software diagrams.net (V1 of these diagrams can be accessed at https://drive.google.com/file/d/1GJ8x2y1mQuWYfUXw7k8rUbcmJaAtylwG/view?usp=sharing).

Table 1. Key issues in themes that relate to the Tsitsa Project goals and objectives.

Key Issue Theme	Data Extracts of Issues that have been Addressed	Data Extracts of Key Issue Gaps
Vision of the TP	• Catchment vision and the early output of an objectives framework (n=1).	• Drivers of degradation (difficult to change) (n=1). • Reducing the pressure on the landscape (by reducing grazing and fire) (n=1) . • *Two-way link between restoration work & opportunities for improved livelihoods from a sustainability POV (n=1) duplicated in 'Livelihoods'.*
Overall monitoring	• Starting assessment and adaptive management of work (n=1). • *Process of selecting (social and biophysical) indicators is complete (n=1) duplicated in 'Community monitoring'.* • Embedding monitoring in the catchment (n=1).	• PMERL, indicators and the protocols are being developed (n=1). • Tangible case-studies of sustainable livelihood practices/ small action research learning projects on the ground where we can learn from our interventions (n=2). • Need to start using social (and other?) indicators (n=1).

Key Issue Theme	Data Extracts of Issues that have been Addressed	Data Extracts of Key Issue Gaps
		• Reflections have not taken hard data into account (based on peoples' experiences). Do not have data on the physical and social trends on the ground (n=1). • Need a high resolution powerful reflective monitoring system to build high level understanding of how well we are meeting our objectives (n=3).
Community monitoring	• *Grassroots/community input (n=5) duplicated in 'Trust and relationships'.* • Appointing and budgeting for CLOs/citizen monitors (n=2). • Sending money to the catchment through the citizen technicians (part of DEA's thing) (n=1) • *Process of selecting (social and biophysical) indicators is complete (n=1) duplicated in 'Overall monitoring.'* • Social Indicators have been developed using capabilities approach (n=2).	• Using social information to direct NRM efforts (human activities & responses to interventions N.B. for sustainability) (improve community voice) (n=2). • *Buy-in from communities (trying to get communities to feel part of what you are doing)- starting but more to go (n=2) duplicated in 'Trust and relationships'.* • CLOs (as key agents of change-to deepen participatory governance potential) (n=1). • Values, how people use and value ecosystem services (how people relate to their environment) (n=1). • 'Softer context' to inform ethical implementation over long term (n=1). • *Integrating everything with the catchment residents (eg: have more events and action on the*

Key Issue Theme	Data Extracts of Issues that have been Addressed	Data Extracts of Key Issue Gaps
		ground at village level and municipal level in the catchment) (n=1) duplicated in 'Trust and relationships'.
Trust and relationships (community)	• Trust with communities and community leaders-citizen monitors (n=2) . • *Grassroots/community input (n=5) duplicated in 'Community monitoring'.*	• *Buy-in from communities (get communities to feel part of what you are doing) is starting but need more (n=2) duplicated in 'Community monitoring'.* • *Integrating everything with the catchment residents (eg: have more events and action on the ground at village level and municipal level in the catchment) (n=1) duplicated in 'Community monitoring'.* • Following the protocol of informing the catchment coordinator of planned activities. Buy-in from communities) starting but more to go (n=1) (Adela thought: may be a lever for community monitoring & cap dev?) • *Engaging in a positive way with local municipalities (n=1) duplicated in 'Trust and relationships (more generally)'.* • Important for all TP members to have the same idea of how we work on the ground (we are from different fields, but we should all know what to expect and how to behave) (n=1) (links with community monitoring & cap dev).

Key Issue Theme	Data Extracts of Issues that have been Addressed	Data Extracts of Key Issue Gaps
Trust and relationships (more generally)	• Trust has improved 'all-round' (n=1) • Relationship with Implementers has been established (n=1). • Relationship with municipality and gov. depts. being established (n=1). • Buy-in from regions environmental affairs dept (n=1). • Co-construction more broadly (n=2). • *Co-construction, knowledge exchange and integration between CoPs (n=4) also in internal project.*	• *Engaging in a positive way with local municipalities (n=1) duplicated in 'Trust and relationships (communities)'.* • *Protocols of how to engage effectively with each other (as the project grows it becomes more complicated and complex, which is why we are going to miss each other somewhere if we don't find these). (n=1) also in internal project.*
Capacity development	• Development of capacity development plan that embodies a principle of engaging in a social learning approach (n=1) • Development of 'Capability Pathway' (n=1) • Applying the APP to cut barriers to participation (n=1) (done by governance CoP). • Workshops (learning words & what is the TP) on stakeholder capacity to know and speak (n=1) (done by governance CoP).	• Capacity development in catchment (area has been neglected for more than a hundred years there is a huge amount of work to be done at the grassroots for capacity building) and broadened to all TP actors (n=2). • Extend the learning words and TP more deeply into the three nodes (n=1) (done by governance CoP) • Social learning facilitation (CoP actors must be trained to facilitate for social learning) (n=1). • Extending capacity development in the project beyond Rhodes (n=1).

Key Issue Theme	Data Extracts of Issues that have been Addressed	Data Extracts of Key Issue Gaps
Governance		• Overall comprehensive governance network (catchment level governance is not operational. Each department does whatever they want, there is very little coordination and very little deep thinking about what is the best land use option so that is a big challenge). (n=1).
Internal project dynamics	• *Co-construction, knowledge exchange and integration between CoPs (n=4) also in trust.* • Set up a project structure (n=1).	• Need better institutional organization, structure, and guidance on the roles and responsibilities of each CoP coordinator and CoP (many of the people working on the Project do not have clear job descriptions). (n=1). • Key members of the project need to be very aware on what our project objectives are (At this point project objectives and where people fit in to those objectives to achieve the vision of the project are poorly understood by members). (n=1). • *Protocols of how to engage effectively with each other (as the project grows it becomes more complicated and complex, which is why we are going to miss each other somewhere if we don't find these). (n=1) also in trust and relationships.* • Human capital (n=1). • *Funding (mismatch between the money required & the work that needs to be done) (catalyzing*

Key Issue Theme	Data Extracts of Issues that have been Addressed	Data Extracts of Key Issue Gaps
		agent for the grass and fire CoP and for our management plan is funding). (n=2). • Gaps between Thesis work and what is needed for TP (missing glue) (n=1) ?does this belong here?
Knowledge management	• PMERL collects quarterly and BTO reports (n=1).	• Data Management (/Knowledge Management) system (both internal & external) and integration (n=5). • Budget for writing up or data analysis (n=1). • Data on physical and social trends on the ground? • Knowledge management capacity (e.g.: a full time person).
External communication		• External communication about project (might find that communication and advocacy are more important than real data and hard-core proof, need a communications officer) (grassroots communication is difficult) (n=3). • PR person to 'package' and 'sell' the project (n=1).
Integration & integrated planning	• Integrated planning process started (n=1). • Integration of research into praxis (n=1).	• Interpreting and synthesizing things (n=1). • "Interleave" reporting requirements of TP and other bodies especially DEFF (n=1).
Baseline data	• Baseline of biophysical and social dynamics (n=3). • Understand Stakeholder and Governance context (Stakeholder analyses) (n=1) .	

Key Issue Theme	Data Extracts of Issues that have been Addressed	Data Extracts of Key Issue Gaps
*Sediment and restoration (and broader biophysical)	• Biophysical data-erosion and sedimentation (n=3). • Understanding issues around sedimentation processes (n=2). • Spatial distribution of the source areas, (gullies) (n=1). • Development of the citizen science methodology (n=1)	• Identifying areas where erosion is taking place that can be addressed / More research on how to minimize degradation and erosion on this landscape (n=2). • Develop an indicator of erosion in the catchment (n=1). • Get grips on the sediment contribution from the source areas (n=1). • Measure sediment yield (Specifically the sediment yield contribution from gully erosion from different sized gullies) (n=1). • Measure buffers, stores and sinks of hillside slopes (n=1) -not yet in diagrams. • More research on how to improve the water quality and maintain the ecological infrastructure that is still functioning (n=1).
Fire and grazing Note: the Grass and Fire CoP was not functional when I started conducting interviews in July 2019, but by the time I attended the science-management meeting November 2019, it		• Continued unplanned grazing and fire management (biggest user of resources and benefits and it comes with its own challenges) (n=1). • Grazing and fire CoP not up and running (rangeland management, livelihoods & livestock, complexity around that & how we deal with it not well addressed, assumptions around the theory

Key Issue Theme	Data Extracts of Issues that have been Addressed	Data Extracts of Key Issue Gaps
was up and running under with two coordinators, one of whom is from LIMA.		around rangelands, is herding the best answer?) (n=1). • Grass and fire CoP want to get eco-rangers going (n=1). • Grass and fire CoP want to get grazing associations going (n=2). • Evaluate and talk about conservation agreements (n=1). • *Funding (mismatch between the money required & the work that needs to be done) (catalyzing agent for the grass and fire CoP and for our management plan is funding). (n=2) duplicated in internal project.* • Restoration for an agricultural context (research on how to increase the land productivity for forage, for livestock) (n=2).
Livelihoods	• Establishing vetiver nurseries and employing people to monitor (n=1).	• A value-chain analysis for vetiver (n=1). • *Two-way link between restoration work & opportunities for improved livelihoods from a sustainability POV (n=1) duplicated in key issues.*
Social data and scaling		• land use/land planning mapping, some done but not completed and in a small area (Dylan), needs to be scaled up (n=1).
Economics		• Demonstrate the economic value of the restoration at the local level (n=1).

Key Issue Theme	Data Extracts of Issues that have been Addressed	Data Extracts of Key Issue Gaps
Other	• Advanced our knowledge of the socio-ecological learning process (n=1).	

*The project's initial biophysical focus, with the sedimentation and restoration team being the first funded (find ref in interviews) goes some way towards explaining why the project appears to be far ahead in terms of biophysical understanding.

3.3 Linkages of Key Issues to broader project documents:

Project Vision:

The key informants said the following about project vision and objectives (insert diagram and accompanying text):

Link it to :

The TP vision, described by Botha and others (2017: p.10) in the PMERL framework as a 'proto-vision-to be finalized with stakeholders' is:

"To support sustainable livelihoods for local people through integrated landscape management that strives for resilient social-ecological systems and which fosters equity in access to ecosystem services."

The vision appears in a number of other key project documents reviewed (Department of Environmental Affairs Ministerial Foreword in Fabricius *et al.* 2016: p.i, Biggs *et al.* 2019: p.8 & Huchzermeyer *et al.* 2019: p.9, Cockburn *et al.* 2020: p.9) and is sometimes described as the proto-vision and sometimes as the vision.

The vision has been guided by the seven foundational principles of the TP, and translated into six headline project objectives (Figure 3). An expanded objectives tree, compiled through a process of adaptive planning using a number of sources, is articulated in detail in "The Tsitsa Project Research Investment Strategy (vol 2)" (Bigg *et al.* 2019). The various CoPs are the vehicles of meeting those objectives and, ultimately, the project vision (Cockburn *et al.* 2020).

The PMERL framework describes five Change Domains within which the project should focus its efforts, namely: Access, Agency, Land Use Management, Governance, Livelihoods and Well-being (Botha *et al. 2017*).

According to a 2019 report on Biophysical Monitoring Methods in the Upper Tsitsa River Catchment this vision translates into the following broad **management objectives**:

"- Minimise land degradation and erosion risk.

- Maintain or/and increase land productivity.

- Maximise forage production for livestock.

- Improve water quality and quantity.

- Maintain or improve ecosystem services and ecological infrastructure."

(Huchzermeyer *et al.* 2019: p.9).

Vision:

To support sustainable livelihoods for local people through integrated landscape management that strives for resilient social-ecological systems and which fosters equity in access to ecosystem services.

Principles:

1. Social-ecological principles and resilience thinking
2. Transdisciplinarity
3. A collaborative, reflexive, and adaptive orientation
4. Expansive learning and capacity development
5. Polycentric governance
6. Towards equitable participation
7. Scientific-technical foundation and evidence base

Objectives:

1. Founding Principles
2. Ecological Infrastructure and Services - the biophysical
3. Livelihoods and well-being
4. Institutional actors and governance
5. Realising agency and collective action
6. Knowledge flow, communication and advocacy

Figure 3. Guiding concepts of the Tsitsa Project (Cockburn et al, 2020).

TP initially focussed on sediment mitigation and hence the Sediment & Restoration CoP has been the most active and productive thus far. However, it was soon realised that without taking into account "drivers of degradation" and without a systemic and strategic adaptive management approach (SAM), this COP's chances of success would be incredibly low. This realization and change of approach are echoed in the diagram above.

By 2016 the Livelihoods and Ecosystem Services and the Governance COPs were introduced and active and by the end of 2019 The Systems Praxis and Grass and Fire CoPs were active.

The 2020 Wisdom Trust Report outlines a practical suggestion that might be somewhat of conventional rehabilitation/restoration approach: This was to consider planting trees for livelihoods in highly degraded parts of the catchment which are too expensive to rehabilitate, given other needs (Biggs 2020).

PG Bison may already be doing this? Could the research body of the TP develop an evidence base for such an approach? This would also affected Agroforestry and could open other options for livelihoods.

inter-sector facilitators

The message here, that as a NRM Livelihoods focussed project the TP does not only need to be using a conventional rehabilitation toolkit, echoes what my diagram shows.

Monitoring

The project's progress in meeting its objectives then need to be monitored. (This is where monitoring comes in): Monitoring is used to evaluate the current state of ecological infrastructure as well as the effects of management on the condition of ecological infrastructure.

Overall monitoring: Add info/diagrams from my findings and compare it with:

"The following monitoring objectives have been preliminary chosen for the Tsitsa Project (Schlegel *et al* 2019):

- Compare baseline conditions of areas that are using different management approaches e.g. grazing and fire.
- Monitoring how different management systems affect the condition of ecological infrastructure over time.
- Monitoring changes in the landscape as a whole because of natural biophysical conditions (e.g. climate, pests, disasters etc.)"

-indicators

Botha *et al.* 2017:

Agreeable indicators are needed for biophysical, institutional and social measures and regular (weekly or quarterly) monitoring against these indicators, using mostly quantitative and in some cases qualitative data.:

- The biophysical indicators have been selected by NLEIP management based on the inputs of technical specialists (including a process led by the Institute for Natural Resources, INR).

Where are these indicators?

PMERL was envisioned to use qualitative and quantitative data, monitor against indicators, and collect more open-ended narratives (Botha *et al.* 2017). This 'mixed methods' approach is in itself not likely to lead to much learning, unless an attempt is made to integrate across the diverse data sources (*ibid* 2017).

Community monitoring: add info/diagrams from my findings

Trust and Relationships

Botha et al 2017: p 21: Engagement with local communities and other stakeholders is necessary to produce a joint vision based on the diverse values and contexts of the stakeholders. May only be effectively executed following an initial trust-building phase (see the stakeholder analysis by Sisitka et al., 2016). This is echoed in the interviews in which informants reported that the project has made progress establishing trust with communities and community leaders (n=2) and is now able to get grassroots community input (n=5).

Baseline Data

Grazing and Fire

Livelihoods

Botha *et al.* 2017 p 21: Livelihoods are at the core of the project. A livelihood in this context "comprises the capabilities, assets (including both material and social resources) and activities for a means of living" (Carney, 1998:2). One of the most widely used frameworks for understanding livelihoods is the SustainableLivelihoods Framework (SLF). The SLF describes and analyses five main assets, being human, physical, social and natural, in the context of vulnerability (such as climate change) and institutional processes which all together, if effectively constituted, can lead to optimal livelihood strategies (e.g. farming) and outcomes, including well-being.

Wisdom Trust: It is tricky to add the word "sustainable" as a qualifier of "livelihoods" as this introduces many different views. Possibly focusing instead on livelihood options is more pragmatic.

Communications and Advocacy

Appeared in Wisdom Trust Report (Biggs 2020)

Governance

TP "is a brave venture into polycentric governance. Its governance framework invokes the principle of deepening democracy and devolving power and decision-making to a network of

structures aimed at representing a mixture of community voice, emerging best /better practice, and strong collective governance" (Botha *et al* 2017).

Potential Key issues from Document Review that were not mentioned in my interviews:

Expanding livelihoods

Climate Change

Migration (in future)

3.4 Added Value of Key Issue Diagrams

The diagrams have added value by making connections explicit and enabling a systemic view of key issues in the project. Version one of the key issues diagrams can be accessed online using the free, open-source diagrams.net software https://drive.google.com/file/d/1GJ8x2y1mQuWYfUXw7k8rUbcmJaAtylwG/view?usp=sharing.

In the diagrams I extracted interview excerpts along with surrounding narrative thus explicitly positioning participant comments in context. This context made it clear that some comments belonged more closely in different themes than my initial sorting with more limited key variable lists. For instance, I initially did not link the themes for community input and trust and relationships as closely as they appear to be linked from the diagramming. I also found that community input, linked very closely with trust and relationships. In fact, findings suggest that trust and relationships are an important lever to community input. Another connection that emerged is the need for capacity development of residents/communities to be able to participate in governance processes.

The process of diagramming led to the identification of 4 issues which were initially missed upon evaluation of the text data set, being found to be systemically connected within their themes, These were added as key issues (KIA 31, KINA 48, 49 & 50).

The diagrams allowed things to be viewed differently, for instance, considering how alternative project entry points to restoration could lead to different outcomes ('Vision' tab).

3.5 Early analysis/ thoughts on Key Issues:

Some of the KIAs could enable the addressing of the KINA list with minor intervention. Some examples include the work done to build trust with communities is described as being a lever to the communities allowing and participating in monitoring; from sedimentation theme, that baseline work that is in place is a crucial precursor for next step which will be to fill the gaps; similarly for the municipal trust/relationship – establishing the 'relationship with municipality and gov. depts will eventually, with time meet the gap of engaging in a positive way with local municipalities. One of the ways that the KIAs list was therefore analyzed is through the lens of their value add as enablers to the KINA revealing that for some KINAS the pathways towards addressing the gaps are already established (so addressing them is a matter of *time* rather than a matter of *intent*).

Other items could be listed as KINAs as a result of a disconnect or breakdown in communication in the project as laid out in KINA: 'Key members of the project need to be very aware of what our project objectives are (At this point project objectives and where people fit in to those objectives to achieve the vision of the project are poorly understood by members) (n=1)' and concerns around 'missing each other'

Funding was listed as a limiting factor and KINA both in general terms and specifically in relation to the Grass and Fire CoP. The reality of limited funding means that the question of which KINA are a priority and can be realistically achieved? This is a question that could be further explored in the workshop.

The final list of key issues in the TP will be used to compile a list of variables that the TP research team believe are important. These will be passed through a range of filters for suitability as essential variables.

Other interviews/methods will be required to elicit potential essential variables from provincial and national DEFF (and possibly also from the communities).

4. Research Question 2: Integration

4.1 Perceived level of integration of data

To answer the key question "What is the level of interconnectivity of data in the project?' participants described how they perceive the level of integration of data in the Tsitsa Project. Their responses were coded as per Table 2. The table differentiates between responses that describe level of integration, and those that describe related factors which may enable or inhibit integration. Coding was guided by the data as seen in Table 3:

Table 2. Working definitions of coded responses to the level of integration of data.

Code no.	Code Wording	Describes	Code Description
1	Zero (Virtually)	level	Uses the words: zero, virtually zero, no or nothing.
2	CoPs are silos	factor	Refers to CoPs working separately or not sharing. This is an inhibitor to integration.
3	In principle	factor	Refers to integration being present in principle. This could be a potential enabler of integration, but emphasizes that integration is not happening enough in practice (hence it's negative position).
4	In people's heads	factor	Describes people with access to information or systems thinkers being able to integrate data in their heads (this implies a lack of recorded, measurable integration).
5	Poor	level	Uses the word poor to describe integration of data.
6	Intended	factor	The project has had a clear intention to be integrated from the beginning (but it is unclear whether this has translated into actual integration).
7	Data available	factor	Data is available for use within the project (this is an prerequisite/enabler of integration).
8	Not great	level	Uses a negative pronoun in conjunction with 'great'.
9	Some	level	Provides examples of integration of data in the project
10	More to be done	?	Includes comments: 'needs to be developed further', 'a lot still needs to done', 'we need to do more', 'there definitely needs to be integration between CoPs to come up with integrated management plan' or recommendations of specific steps TP must take.
11	Improving	(direction of) level	Uses the words such as 'moving forward', 'getting better' or 'getting there'.
12	Good	level	'Doing well' or a numerical score of 6/10 or above.

Table 3. Perceived level of integration of data.

Participant Position	Data extract	Coded for
Sediment CoP Coordinator	6 or 7/10 "Getting better"	12 Good 11 Improving
Sediment CoP Co-coordinator	General feeling that data is emerging and available for use within the project. Community participatory mapping was integrated	7 data available for integration 9 Some
Sediment CoP Collaborator	"A lot still needs to be done" Data portal/google drive with some data is a good start.	10 More needs to be done 9 Some?
Sediment CoP Research Assistant	Each CoP has been setting up their research protocols and gathering data but there hasn't been a lot of sharing between CoPs. Only used social data from interactive priority mapping. Now priority areas have been chosen for integrated management plan so there definitely needs to be integration so that's going to be the next step where the interconnectivity comes into play. In terms of my work I haven't had much interconnectivity, I haven't worked at all with the governance and only a little bit with the social side. I haven't had many people asking for data, only some students from IWR .	2 CoPs are silos 9 Some 10 more needs to be done
Governance CoP Coordinator	Interconnectivity of actual data is virtually zero. Interconnectivity of practice is better. Integrative: adaptive planning workshop with the DEA praxis group, implementers where we ran an objectives hierarchy development for their work, for the praxis. had value in the moment but it missed having value in the project because it wasn't written up and applied more widely	1 (virtually) Zero *Missed Opportunity
Livelihoods: Coordinator	Just observations, it is not synthesized and not researched thoroughly. From the restoration work you can see some good benefits already from a biophysical point of view but there's no connection to whether it has created better grazing lands,	?

Participant Position	Data extract	Coded for
	it is not being used like that. So that has not come through yet. In the same way as the nurseries growing vetiver, it hasn't been planted yet so we still don't know what benefits it could have from all perspectives.	
Livelihood CoP PhD Supervisor/Knowledge Management Advisor	Desire or intention to be integrated has been very clear from the beginning.	6 Intended
PMERL Coordinator, Knowledge and learning Coordinator & Designer of Framework	Nothing so far. At one level we have the stakeholder analysis, we try and share the reports but it is not really integration.	1. Zero (Virtually)
PMERL new member	No. Not in a system dynamics type of way, which I think is what we are hoping to do, I don't think it is that strong,. "quite strong in certain people's heads" and I certainly think that on the whole you will find that people generally are quite good systems thinkers because they choose to be in this kind of project, but not everybody of course. And it is not in a formal SD type of way, more of an implicit way, maybe they don't even realize this is how they are thinking. But then many people are also familiar with systems concepts and understandings.	1 (virtually) Zero 4 In some people's heads
Knowledge Management	Depends; people with access to data and who understand who the different role players are and what they are contributing, they have interconnectivity in terms of reporting structures. But in terms of other people using data and information within their own research and drawing from different places I think that interconnectivity is very poor, especially probably on the governance side.	5 poor 4 in some people's heads
Capacity Development Coordinator	From my perspective from what I have heard and experience I think the integration is quite poor. Not non-existent, just something that needs to be further developed.	5 poor 10 More needs to be done
Catchment Coordinator	I don't think it's that great, trying, but I don't think we are there yet. We still all	8 Not great 2 CoPs are silos

Participant Position	Data extract	Coded for
	have our own way of collecting data, our own way of making sense of the data cos we are still not working across the disciplines the data will be either very scientific or very social. I mean like I know people who do not like working with people but we are dealing with things involving people. **So you'd rather look at GIS instead of going to the people. Eish, it doesn't always give you the correct answer.**	
Research Coordinator	In principle integration is there, but in practice not good enough. Better than before we got here. Inside gov. one department does not speak to another at all. That's why we wanted a catchment coordinator so that we could have an impartial person to convene meetings without anyone feeling threatened. Integrated planning process is getting there. When we have traditional leaders who understand a causal loop diagram and can say if okay, if I allow sand mining here… that will cause so and so.. then I think we are at the integrated level. Participatory mapping was the first time people were asked, what do you want and where do you want it and how much? We need to make that regular business practice, having one survey is not enough.	3 In principle 11 Improving
Project Coordinator	Not great. Reason: death by deliver-ology, number of people working on the project, students, researchers, everybody is producing something often. Like on a monthly basis there is stuff coming out from between 5 and 10 people and all of the people involved are either, studying, working, working and studying. Now that I am where I am I can see more of the puzzle pieces but even when I was working with the governance CoP coordinator. it's been interesting watching because at first ppl were very much like this is our little box of tricks over here and you can keep	8 Not great 11 Improving 4 In people's heads

Participant Position	Data extract	Coded for
	your box over there and slowly as the relationships have gotten better they say ok, I'll have this this piece and you can take that piece, let's have a chat about it. So it's interesting to watch how that changes, and the people who are interested will do it, and the people who aren't won't.	
Resource Economist & Wisdom Trust member	My exposure is limited but I was struggling to see how you move from a very top-class academic research and convey that to a local level, For scientists and researchers, whether it is an anthropologist or an economist or a natural scientist, data is numbers that you can work with to write up something very explicit. I think the data for people on the grounds and that live in the system, they don't think in such terms with respect to data. Data is like 'where will tomorrow's bread come from?' and I am not sure if they've crossed that bridge yet. And if you don't speak the level of data that matters for a person at a very local level, then the data remains at a very high levels and is esoteric and disconnected from the people whose lives it is actually supposed to help. So yes, it has created a bit of money, so from an income perspective, but that is a very short-term focus - 'today's job and today's income' and is not really touching the longer -term sustainable livelihoods theme. I think we have to think in terms of what constitutes data, knowledge and information for the person who lives there, and how his life will be impacted on or by the restoration work, visa vie then how researchers are receiving it (the numbers that leads to papers vs. impacts on them in their lives).	10 More needs to be done
Grass and Fire CoP Co-coordinators	A: Doing well. The communities are consulted at all levels but we can definitely work on it a little more. I think at this time we do come up with the basis of the interventions which is then taken to the communities to figure out if they are happy with it or if there is anything that they would like to change, but moving forward we need to do more.	12 Good 10 More needs to be done 11 Improving

Participant Position	Data extract	Coded for
	B: I think we are slightly moving forward in this process towards integration.	

Some participants responses included more than one code, and prevalence was counted at the level of the data item.

Table 4. Composite responses in relation to integration of data.

Code	1	2	3	4	5	6	7	8	9	10	11	12
	Zero (Virtually)	CoPs are silos	In principle	In people's heads	Poor	Intended	Data available	Not great	Some	More to be done	Improving	Good
	n=3	n=2	n=1	n=3	n=2	n=1	n=1	n=2	n=3	n=5	n=4	n=2

Items from the data set focussed on the level of integration in the project were used to create a set of diagrams which can accessed through the be viewed using the free open source software draw.io, these diagrams can be accessed using the link:

https://drive.google.com/file/d/10KXFSmI86sJbp38j_jDtJZoZakZ_mqM6/view?usp=sharing

Level of data integration analysis:

The range of responses to this question is interesting; it covers a whole gamut suggesting that people are divided. If there was unanimity in responses that would be a more straightforward starting point. The

responses generally point to the fact that while there is some integration of data, there is definitely a lack and more needing to be done.
The most positive feedback was 'doing well' and 'six or seven out of ten' which was only used by two informants. None of the informants described integration of the data as being outstanding or excellent, so there was no such category assigned. This reinforces the impression that integration is an area in the project that requires more attention.
Thematic analysis reduces data to codes which making it easier to identify and communicate themes and trends, but this comes at the cost of some of the richness of the original data in context (insert examples). This points to the importance of referring back to the original data set during analysis. The diagrams that I drew out using draw.io can be a helpful to communicate statements simply as possible with relevant context.

The informants' were critical of the level of integration of data in the project with the most prevalent responses being that integration is currently poor or not great. and more needs to be done (n=5). Some informants were more positive, stating integration of data is improving (n=4), that there is a clear intention to integrate (n=2) and even that the level of integration of data is 'good' (n=2).
The fact that integration of data is described in three interviews as happening 'in some people's heads'
is interesting as it speaks to challenges that the project faces in terms of knowledge management and collaboration. This speaks to a number of the key issue gaps identified including # 27, 28, 32 in gaps

list. That statement could however be viewed positively as it implies that an overall vision exists so a coordinated vision could be enacted by the 'bigger picture' thinkers connecting the dots.

Q: are people talking about the same thing here? For instance, the Fire and grass CoP seemed to be talking specifically about integration with communities, rather than the integration of data more generally.
The response on level of integration from the resource economist's perspective brings up larger questions around making 'top-class academic research' relevant at a local level context, and about the possible disconnect between data collected by scientist for the purposes of publishing papers (where things are ideally explicit) and data that can impact the lives of people on the ground, especially in a longer term sustainable livelihoods context.

4.2. Tools and Approaches to integrate data

The tools and approaches reportedly used to integrate data were coded as per Table 5 (guided by the data). Items from the data set focussed on tools and approaches to integrate data in the project were used to create a set of diagrams which can accessed through the be viewed using the free open source software draw.io, these diagrams can be accessed using the link:

https://drive.google.com/file/d/1ibWPPLwYL6H4VmauvlVq4_8kRo15p8ZX/view?usp=sharing

Table 5. Coded data extracts on tools and approaches to integrate data.

Data Extracts on Tools and Approaches to integrate per data item (interview)	Coded for
- Integrated planning, google earth, RS inputs in google earth to communicate things easily. - Since the beginning we had a fairly integrated holistic approach. - link with the drivers, can't restore the catchment without understanding the drivers, so there is a very strong holistic approach. - Maps and workshops were people discuss conceptual ideas and how they see it are some of the best things.	1 Workshops and Meetings 3 Integrated planning (adaptive planning process?) 4 RS (GIS, Maps, Google Earth) x2 14 Integrated/wholistic approach?
- Systems praxis CoP - Potential to engage citizen monitors as TP champions, raising awareness in their communities, with the hope of stimulating citizen science.	2 Systems Praxis CoP, SD modelling 5 Citizen Monitors, and CLOs 9 Community Engagement
- Portal or google drive folder where data can be accessed is one. - Newsletter - Workshops at Rhodes or in the Tsitsa Catchment	1 Workshops and Meetings 6 Google Drive / Website 11 Newsletter
Annual science management meeting, previous years they had students presenting their data and their findings, and it just gave the other CoPs and idea of who is doing what and what's relevant to them. I think that's quite important for seeing what's out there and how you can interconnect.	1 Workshops and Meetings 1.1 Sci-Man meeting
So the tools I use are principles for how to build a transdisciplinary team and how to develop TD practice, SAM in particular, the application of the adaptive planning process. And then the literature and framing of TD research and the framing of complexity. So when my ontology shifted to a complexity based ontology, the way I work shifted dramatically, so the design of research projects, the suite of	12 SAM, 13 Conceptual framing (TD CSES) 14 Integrated/wholistic approach?

Data Extracts on Tools and Approaches to integrate per data item (interview)	Coded for
research projects you do is framed by complexity thinking. So what we do is framed by the nature of connectivity. So with students' work I would never just look at how seeps function, there had to be seeps functioning in relation to the ecosystem services and the people owning the livestock. A student is looking at which areas are productive has to be framed in terms of the history of the land use and how the people have shaped what that land looks like. So the conceptual framing shapes the data collection for me. So what I hope is that I practice intentional TD CSES practice.	
PMERL is trying to do this but I don't think we're there yet, and I don't know how we will do it.	10 PMERL activities
Sci-man meetings-integrative spaces. Not successful because there just is not enough time to have real discussions in that sort of fora. Project could have done better in terms of talking between the different CoPs. I know that things were put in place to help facilitate some of that. The hierarchical structure was set up to be integrative between those CoPs, but to be honest with you, I actually think that the kind of ways to integrate the data more specifically is to have projects that are more integrating and synthetic of the information that are already there. Need someone to go and actually think about how these data sets speak to each other and what are the implications of that for how this functions. So I think approaches like System Dynamics modelling of the broader catchment bringing together this different data and also scenarios, not only the quantitative scenarios but also scenario processes that are more qualitative in nature and that bring the more local communities, and the technical communities and the science communities to bring these bits of data together is really what is going to achieve that integration. I think it is hard to achieve integration on the go.	1 Workshops and Meetings 1.1 Sci-Man meeting 2 Systems Praxis CoP, SD modelling 15 Extended project teams/structures
Stakeholder Analysis (Lawrence Sisidka and Nina Rivers).	7 Stakeholder analysis
Dialogue at reflection meetings and talking about how things are connected. EG: Reflection tea, one of the indictors is something around security, crime, cattle theft, something like that seems like a bit an odd one but because it came out of a masters student's interactions with people in	10 PMERL activities

Data Extracts on Tools and Approaches to integrate per data item (interview)	Coded for
the catchment it stayed in there. It was the one they generally didn't support that much. But then we had a discussion about how people fears feed into other things and it's that kind of discussion that makes people say 'oh actually I see why that is there even though it is not an obvious one'.	
The Sediment CoP coordinator using GIS to spatially represent different data and information steams. They have used Stats SA through one of his students, they are taking a lot of student data and trying to integrate that spatially to inform the catchment management plan in terms of what needs to be done for implementation. Tools: google drive, the website	4 RS (GIS, Maps, Google Earth) 6 Google Drive / Website
- Science-management meeting (even though the presentations are not integrated, the platform as a whole and maybe the discussions afterwards, people are integrating what they are hearing). - Training courses that we are running in development are seeking to link biophysical and social. - Quantitative data collection processes, linking them in with their impacts on social processes, or social change or livelihood change. Livelihoods is a nice example where the data around sediment and erosion rate and rainfall and everything, then bringing in livelihood business around growing vetiver grass to then improve people's livelihoods towards social-ecological justice. - Reflection processes (PMERL). - The research colloquium. - CoP coordinator meetings. - Collaborative paper writing. - Systems modelling. - Workshops that LIMA is running, the grazing agreement processes (they are bringing spatial data and landscape composition work and looking at behaviour around grazing).	1 Workshops and Meetings 1.1 Sci-Man meeting 1.2 The research colloquium 1.3 CoP coordinator meetings. 1.4 Training Courses 1.5 Implementor / LIMA Workshops (grazing) =community engagement 9 Community Engagement 2 Systems Praxis CoP, SD modelling 8 Collaborative paper writing. 10 PMERL activities (Reflections, workshops, teas, meetings) 16 Linking quantitative data with impacts on social processes
- Talking and talking and talking, and screaming. - Science-management meetings (different stakeholders attending & different inputs) used to have the students presenting their	1 Workshops and Meetings

Data Extracts on Tools and Approaches to integrate per data item (interview)	Coded for
work and the people that have their own research present on what they have done or what they plan to do. That way you get input from other experts in the room, and from there things develop and you find space to collaborate and because we share the outcomes of things that we are doing with other people, other people can try use them or reference them. - Meetings (a lot). - It took a while to get all the big guns in one room kind of giving each other space for the other to talk. And I think that's (a result of) patience, talking, having Harry in the room. Harry does work, I mean he knows how to manage these situations because he has been through them so many times. He's like the pillar that holds things together. I think him understanding how things work and that they take time because it is different personalities, different fields, different egos.. so ya, I think that's where we tried.	1.1 Sci-Man meeting
- Strategic adaptive management from Harry - Science-management meeting - Science-management-society meetings. - Not institutionalized to the point where everything gets used at the right time and the right place (size and geography of the place). - Effort to do this in a multi and transdisciplinary way. But didn't start in 2014 by going to the community and asking, do you want a dam? Do you want restoration to happen? - Recently, systems thinking, bringing in a culture of using these kinds of principles and tools.	1 Workshops and Meetings 1.1 Sci-Man meeting 2 Systems Praxis CoP, SD modelling 12 SAM 13 Conceptual framing (TD CSES)
- Tsitsa google drive and the Tsitsa admin folder drive. - Website and some of the data is there, otherwise you just email me and ask for it. - CoP coordinator meetings, and for the most part that's just the researchers, and what we try to do, need to start doing from now on is discussing 'What have you just done? What are going to do?' so we can have a quick catchup around the table so people can find out who is bringing what back from the catchment and that sort of things. - Getting more complicated because now we've got LIMA as well. So now it's a whole other organization but with two people so we need to make sure they know what they need to know and that we are getting information back from then as well. - It's difficult. It would be easier if everything was open source, but it's not. It becomes layers of challenging stuff.	1 Workshops and Meetings 1.3 CoP coordinator meetings 6 Google Drive / Website
- Research colloquium, - Workshops	1 Workshops and Meetings

Data Extracts on Tools and Approaches to integrate per data item (interview)	Coded for
- Papers. And those are shared among the variety of different disciplines and focus areas, and that is highly commendable = big achievement, able to cross several bridges from a research perspective. - Some gaps in respect to the economics part but those are small potatoes within the bigger scheme of things. It is the downward to people that I am not always sure of. Even the link to policy and government, which is Michael Kawa and so on with the natural resources program, they are doing great work in trying to be connected to the policy sphere, even there they have crossed many bridges that other projects have not crossed, really going out of their way to link to the governance. Probably also because it has been funded by them so there is a vested interest and it makes the links shorter.	1.2 Research colloquium 8 Collaborative paper writing.
- On the ground our CLOs have become an integral part of that. People on the ground are embedded beneficiaries helping us communicate with communities. - In terms of TP institutionally, PMERL reflections. - I think the researchers are also thinking more about it in terms of the impact of the project on the ground as opposed to the impact of the research, becoming more of an implementation project so everyone is starting to come out of the boxes/silos and communicate with one another which is good. - Community engagement-getting more input now and taking that forward in whatever we recommend for the TP so that is one of the things we are doing. - Intra-project level: COP coordinator meetings are very useful to share and communicate between different CoPs. (One last year, now one every month). Just one more thing, In terms of communication outside the project, these different team (C,B, A, wisdom trust…) I think its hugely beneficial for getting the message out there and trying to integrate what we are doing as a project into the different spheres of national and possibly international policy and that kind of thing	1 Workshops and Meetings 1.3 CoP coordinator meetings 5 Citizen Monitors, and CLOs 9 Community Engagement 10 PMERL activities (Reflections, workshops, teas, meetings) 15 Extended project teams/structures 17. Implementation drive

Table 6. Tools and approaches to integrate data, counted on the level of data extract.

Code	Prevalence
1 Workshops and Meetings	n=14
2 Systems Praxis CoP, SD modelling	n=4
3 Integrated planning (adaptive planning process?)	n=1
4 RS (GIS, Maps)	n=3
5 Citizen Monitors, and CLOs	n=2
6 Google Drive / Website	n=3
7 Stakeholder analysis	n=1
8 Collaborative paper writing.	n=2
9 Community Engagement	n=3

10 PMERL activities (Reflections, workshops, teas)	n=4
11 Newsletter	n=1
12 SAM	n=2
13 Conceptual framing (TD CSES)	n=2
14 Integrated/wholistic approach?	n=2
15 Extended project teams/structures	n=2
16 Linking quantitative data with impacts on social processes*	n=1
17. Implementation drive	n=1

*For example, data on sediment/erosion rate and rainfall for growing vetiver grass to improve livelihoods (towards social-ecological justice).

The word cloud below emphasizes the relative number of mentions of the various tools and approaches used to integrate data in the TP known by the key informants (Figure 4). The most prevalently mentioned tools to integrate data in TP are 'Workshops and Meetings' which were mentioned a total of fourteen times (Table 6) in nine out of the sixteen interviews. 'Workshops and meetings' were then broken down into types, with the most prevalently mentioned type being the science-management meeting (n=5), followed by CoP coordinator meetings (n=3) (Table 7).

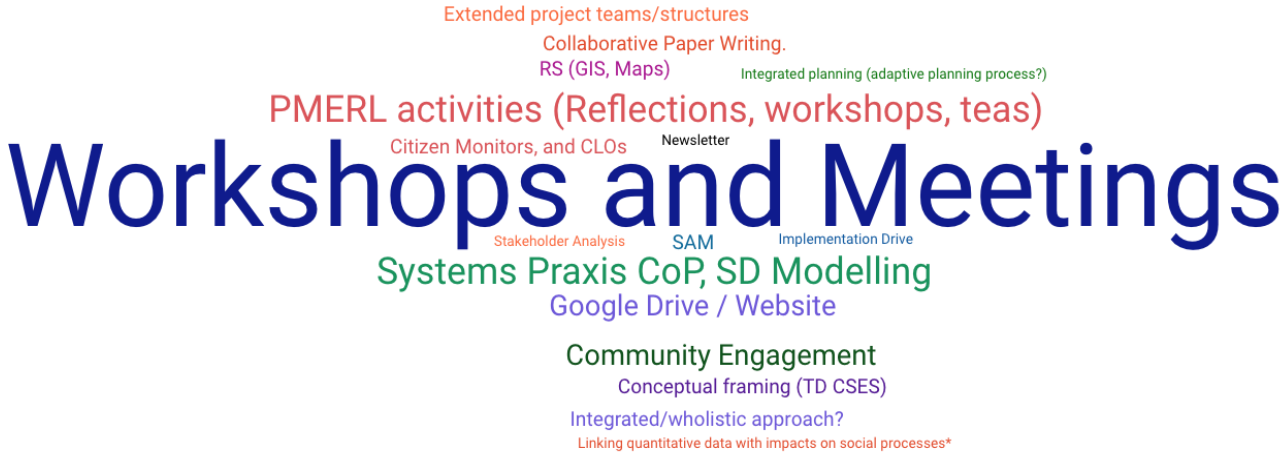


Figure 4. Word cloud of tools and approaches to integrate data in the TP described by key informants.

Table 7. Types of "1. Workshops and Meetings" counted on the level of data extract.

Types of '1. Workshops and Meetings' mentioned	Prevalence
1.1 Science-Management meeting	n=5
1.2 The research colloquium	n=2
1.3 CoP coordinator meetings	n=3
1.4 Training Courses	n=1
1.5 Implementor / LIMA Workshops	n=1
1.6 General	n=2

In 2019 the focus and format of the science-management meetings shifted. To be more inclusive, student presentations and highly scientific presentations were limited, to focus on

inclusion of a wider variety of stakeholders. It is interesting that two participants explicitly mentioned the science management meetings in their previous format as being integrative:

> 'Previous years they had students presenting their data and their findings, and it just gave the other CoPs and idea of who is doing what and what's relevant to them. I think that's quite important for seeing what's out there and how you can interconnect'

> 'Science-management meetings (different stakeholders attending & different inputs) used to have the students presenting their work and the people that have their own research present on what they have done or what they plan to do. That way you get input from other experts in the room, and from there things develop and you find space to collaborate and because we share the outcomes of things that we are doing with other people, other people can try use them or reference them.'

One participant described science-management meetings as 'integrative spaces' but stared that they are not successful because there 'is not enough time to have real discussions in that sort of fora'. Another informant commented that even though the presentations at the Science-management meeting are not integrated, maybe the in discussions afterwards, people are integrating what they are hearing.

This brings up an interesting question, can integration of data meaningfully happen in discussions and in peoples' heads?

In terms of the newly instated CoP Coordinator meetings, they had one meeting in 2019 and the project coordinator decided to have one every month. The participant described them as 'very useful to share and communicate between different CoPs'. Another participant described the CoP coordinator meetings as a space to have a quick catchup around the table on 'What have you just done? What are going to do?' so people can find out who is bringing what back from the catchment. The newly instated CoP coordinator meetings could help overcome barriers to integration, and break the silo behaviour of CoPs mentioned in section 4.1

After 'Workshops and Meetings' the next most prevalent tools and approaches to integrate data are activities led by the 'Systems Praxis CoP' who facilitate System Dynamics modelling and other (n=4), and PMERL activities (n=4).

In terms of the systems praxis CoP activities, the research manager spoke about the importance of developing a culture of using principles of systems thinking, this reference to culture speaks to project manager's comment in section 4.1 (about the level of integration) that

those who are interested in integration will do it and others won't. The capacity development coordinator believes that for integration of data to happen the project needs a dedicated person (or people) to think about "how these data sets speak to each other and what are the implications of that for how this functions… approaches like System Dynamics modelling of the broader catchment bringing together this different data and also scenarios, not only the quantitative scenarios but also scenario processes that are more qualitative in nature and that bring the more local communities, and the technical communities and the science communities to bring these bits of data together is really what is going to achieve that integration," and adds that "it is hard to achieve integration on the go."

The tools and approaches mentioned in this section do not all speak to integration of data. Some seem to be made in reference to integration more generally. For example, despite PMERL activities being described as a tool being used to achieve integration of data in four interviews because the PMERL team have not yet been collecting or working with data in their reflections. Participants' descriptions of how PMERL have been integrating data are:

- "Dialogue at reflection meetings and talking about how things are connected."
- "In terms of TP institutionally, PMERL reflections."
- "Reflection processes (PMERL)."
- "PMERL is trying to do this but I don't think we're there yet, and I don't know how we will do it."

It should also be noted that the integrated planning process (mentioned in Table 6) is coming to the fore (expand on gov's recent requirements) and will require CoPs and other structures of the project to engage and share more data.

A few people mentioned how the project's growth makes integration more challenging. (e.g. the project manager said that 'now it's getting a bit more complicated because now we've got LIMA' and there are 'more moving pieces to keep track of'. The catchment coordinator also pointed to the project growing and becoming more complicated and complex, and stressed the importance of protocols to engage effectively so people do not 'miss each other'.

How effective that has been in the governance structure itself I am not sure because of the internal problems that the NRM has had the last twenty months which is disconnected from TP but because of the internal problems in NRM, the effectiveness of the information that has been generated to actually impact policy and impact a variety of governance processes might have been diluted. What it just points to is that when you would like to have really good

connectedness of research in this way that it has been done as a social-ecological learning process then you have to have your systems in tact at the various ends so it doesn't help if you have this engine that works and produces all this fantastic beautiful work if there is an institutional failure on the recipient's side whether the recipient is the old gogo in the valley trying to make ends meet and then a break down communication between the headman or then the breakdown towards the DEA NRM, it doesn't matter. For those processes to be effective you have to have those institutional connectedness and have that intact.

A recent development (shared internally in April 2020) towards integrated planning and implementation is a Google Earth database for the Tsitsa River catchment developed by the Sediment and Restoration CoP. The database includes layers for boundaries, biophysical data, actors and important people, community input and integrated planning. This tool is accompanied by a database map outlining the different forms of data and their respective sources. The team plan to update the database as the project develops.

4.3 Linkages of Tools and approaches to Integrate with broader project documents

Science Management Meeting

Tools: The Science-Management Forum has the main goal of closing the "knowing-doing gap" by bringing managers and scientists together on a regular basis for two-way knowledge sharing and to engender and institutionalise trust within the TP (Botha et al. 2017).
Some informants pointed to the Science-Management meetings in their 'previous form' as being integrative spaces, but the project vision to expand the Science Management Forum to a Science-Management-Society Forum appears to be taking shape and the format of the meeting in 2019 was changed to focus less on high level scientific presentations and be more inclusive of a wide range of stakeholders including traditional leaders and the various monitors. (The change in the structure of Sci-man could be linked to Fig 6 of Botha et al. 2017: p. 24).

Botha p 44: The facilitation provided by Harry Biggs at the quarterly Science Management meetings is perhaps the best example of where the pertinent information is distilled and presented in the appropriate language to all the NLEIP attendees.

CoP Coordinators Meetings

Botha et al. 2017 P. 44: A significant amount of learning and cross-pollination happens at the COP level, but is not yet well documented. (Interesting this is still reported to be the case in my interviews).

5. Research Question 3: Data Availability

There is no up to date overall database of the work that has taken place in the project, but as of 2020 a new Knowledge Manager has been hired and a database is in development. A spatial database using the free Google Earth platform, developed by the Sediment and Restoration CoP, has also recently been released and is planned to be updated as the project develops. Having an accessible database is necessary to build a high level understanding of what the TP is doing in relation to its goals, and to identify gaps and opportunities for collaboration and interconnectivity. This is acknowledged by many members of the project with data management being mentioned as a 'key issue that needs to be addressed' in 5 interviews. Data was categorized as biophysical, social or biophysical and social as follows:

Biophysical Data

Theme	**Data Extract**
Hydrology & Water Quality	• Discharge down the river (water level), 20 minute from 2015. Used for sediment yield calculations (n=4) • Spot water quality readings in river, phosphate, nitrate, EC, temp, PH, SASS5. 2015 & 2019 (n=4) • Sediment concentrations (mg/l). 7 Stations, Daily/Sub-Daily in Flooding from 2015 (n=3) • **"The hydrology and sediment yield are the two key things we need to know from a biophysical point of view"** • Resuspended sediment upstream and downstream (n=1) • Turbidity, 7 sites (n=1), & visual Clarity data using a rough guide (n=1) • Daily photographs of river conditions, 7 sites (n=1)
Erosion & Sediment Yield	• Model of potential sediment yield of the Tsitsa catchment, not calibrated or validated (n=1) • Gully erosion location shape file, showing over 9000 gullies-almost 5% of the catchment is gully (n=1) • In Progress: Drone digital elevation/surface models to calculate the volume that the same 3gullies expanded every year =the sediment yield. Annual from Sept 2017 (n=1)
Climate	• Rainfall (mm) in catchment from 2015, historical data for surrounding area near Mtata (n=3)
Landcover mapping/ MODIS/ Vegetation	• Alien trees GIS database, verified in the field to some extent, 1:6000 Catchment scale, once-off 2018 planned to be repeated every 5 years (n=2) • Vector Maps of Natural forests, alien stands, cultivated fields and wetlands, once off (n=2)

	• MODIS, 4 sites high resolution trends-2000/2002 and 2019 (n=1) • Landcover mapping incorporating "Biophysical human-based physical information on where graveyards are, where springs are, land use, land cover" Once off Ntabalanga catchment (n=1) • Vegetation transect surveys with species composition and biomass of areas from highly degraded to good condition from the lower and middle catchment. Tried to target 5 extremities, 10-15 sites, once off 2019 (n=1) • Restoration comparative pictures of summer or dry and rainfall times. (n=1)
Grazing & Fire	• Collars on cows to track movement, quart scale in comparable catchment, once-off (n=1) • Fire dynamics: thesis, historical analysis catchment scale using remote sensing (n=1)

Biophysical & Social

Theme	**Data Extract**
Participatory NRM	• Natural resource participatory and priority mapping workshops (asked community what their problems were). Biophysical data of what the natural resource problems and priority areas are, but the discussion around those problems form really important narratives understanding the social side of why those are problems. They looked at which wetlands are used, important grazing lands and where the springs are that people collect water. 2017 (n=4) • participatory mapping: focus group mapped resources important to them (social and spatial) 5 villages T35E incomplete PhD (n=2) • household questionnaires about what kind of resources they were using and reliant on with data on land cover and land use, mostly to ground truth 5 villages T35E incomplete PhD (n=2) • Community Mapping their natural resource related issues was done at catchment level –1 meeting per traditional authority area. Busy now with village level (10 villages) (n=1) • In Progress: Prioritization of each gully in GIS using all biophysical and social data that is available, to be mapped showing which gullies that are most active, most connected and most important or problematic to the community members (n=1) • Wetland hillside seeps ecology, resilience and use in terms of ecosystem services T35E, PhD-Once off (n=1)
Social and Biophysical Context	• Stakeholder analysis: contextual spatial datasets about where the municipalities, villages and farms are & their demographics extracted from census data, vegetation data, national land cover maps and in consultation with chiefs. T35A-E Once off (n=2)

Landcover/ land use mapping/ MODIS	• Land and terrestrial systems (landcover & land use) including social data on cultivated land. Used National to give broad idea, then mapped all the woody vegetation across the catchment, all the cultivated lands, the grasslands at catchment scale & classified them according to their condition. Once to be repeated in 5 years (n=1) • In Progress: MODIS: forage availability related to the history of land-use, T35E (n=1)
Livelihoods/Vetiver	• raw data of vetiver plant growth-has not been analyzed, done through the citizen monitors. 3 nodes, 5 villages, 35 households (n=1) • Socio-economic data from 'greenpreneurs' HHs (annual earnings from vetiver, challenges, food insecurity) (n=1) • WRC Green Village report in two-headman zone in T35E (n=1)
Reflection, Monitoring and Evaluation	• Impacts of restoration on sedimentation and livelihoods-Data about land restoration is with government (but Project partners could unlock it Michael Braak, Christo Marais etc) (n=1) • Indicator Protocols being developed, will influence what the monitors do and what data they will collect (n=1)
Dam Economics	A systems Study (n=1) on: • Perceptions of land use changes and the value that those land use changes would have for people. • Cost of the restoration, different interventions, with different costs. • The value of the ecosystem goods and services generated by those restoration activities especially then the erosion control and the reduction of sediment and the benefit there-of. • The cost of the planned dam. • Comparing costs of the dam and its construction with restoration costs, and what would be forfeited if we don't do the restoration cost regardless of the opportunity costs (published w/Rozanne).

Social

Theme	**Data Extract**
Participatory NRM	• "Did you feel included and respected and did you learn something?" 1 node once off hons (n=1) • Benefits and Perceptions of Citizen Monitors, Interviews once per person, T35A-E (n=2) • Community photographs of what resources people thought were important, ranked by importance to the community and how often they were used. 1 Village T35E, Once Hons (n=1)
Relationship & Capacity Development	• Interviews conducted in developing a capacity development plan. Building understanding is the first step towards building agency to engage in the decision-making process that will result in improvement of the situation in livelihoods and natural resources. Core CoP members, once 2019 (n=1) • Workshops with catchment residents in Maclear and interviews with residents and gov officials in East London on integrated

	water resource management and catchment management forums or 'land and water forums'. (Cap Dev & relationship building) Once. (n=1) • Meetings and fieldwork building an understanding of the project, and building an understanding of the people that we were working with and relationship building. Looking for opportunities to work together (n=1) • Activity theory based reflection on the implementers T35E Sinaxo node. Once MSc, (n=1)
Grazing & Fire	• Grass and Fire Workshop to start conservation around rangeland and fire management (n=1) • In Progress: Questionnaire on livestock composition and use, Not yet done (n=1).
Census Data	• Census data disaggregating census clubs, once off MSc (n=2)
Reflection, monitoring and Evaluation	• Reflection meetings, reflection reports and meta-reflection reports. Syntheses of reflection teas. Quarterly and Annually (n=4) • Implementors collect info about production, performance, hectares, person days etc, but we don't have access to this, they have a separate monitoring and evaluation system which just goes off to head office (n=1) • Objectives hierarchy development for implementors praxis work. Not written up. Once (n=1)
Other	• Transdisciplinary 'movement as a form of knowledge making' PhD (n=1)

The TP is a research-praxis project and restoration work is happening concurrently with research and monitoring. The Tsitsa Project is currently doing restoration work in Quaternary Catchment T35 A-E which is also the current focus area for the biophysical monitoring (Huchzermeyer, Schlegel & van der Waal 2019).

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7. Workshop 1 Background Information

Workshop 1 Reading: Thematic Analysis of Key Issues, Interconnectivity and Data Availability in the Tsitsa Project

By Adela Itzkin (PhD student at Wits), Co-supervised by: Prof. Mary Scholes, Dr. Jai Clifford-Holmes
and Dr. Kaera Coetzer

The purpose of this document was to provide the broader Tsitsa Project (TP) team with summarized feedback, including systems models, developed from a round of key informant interviews undertaken as part of a PhD project to develop an observation system for the Tsitsa River Catchment. The interviews were conducted with nineteen key informants between July 2019 and January 2020.

This document is essentially the pre-reading provided to participants in preparation for Workshop 1. The contents of the document were discussed in more detail during a participatory workshop session (Workshop 1) on 26 May 2020. Systemic diagrams presented in this document provided entry points for discussion. Out of this session we were able to verify and discuss key findings from the interviews, and their implications for integrated monitoring.

The full document is available upon request.

8. Workshop 1 Report

Workshop Report: Enhanced Integrated Planning Workshop Session 1 Thematic Analysis of Key Issues, Interconnectivity and Data Availability in the Tsitsa Project (26/05/2020).

By Adela Itzkin (PhD student at Wits), email: adelaitzkin@gmail.com cell: 082 801 2420. Co-supervised by: Prof. Mary Scholes, Dr. Jai Clifford-Holmes and Dr. Kaera Coetzer

The purpose of the virtual feedback session held on 26 May 2020 was:

(a) to provide the broader Tsitsa Project (TP) team with summarized feedback on a round of key informant interviews to review the current data availability in the Tsitsa Project and posit a hypothesis (with input from the TP communities of practices) of the key elements of the system and how they connect, and

(b) to verify and discuss key findings from the interviews and their implications for the development of an observation system for the Tsitsa River Catchment to be undertaken as part of a PhD project.

This document reports back on the finding from workshop 1,, attended by twenty-nine participants, including fifteen of the nineteen key informants from the interviews, and there was representation from all the TP research-praxis communities of practice (CoPs). In addition to the fifteen key informants, there were representatives from various stakeholder organisations as follows: eight researchers and advisors affiliated with Rhodes University and the TP; three researchers from the University of the Witwatersrand; one participant from Gamtoos Irrigation Board (an implementer for the TP); one participant from The Department of Forestry, Fisheries and the Environment (DFFE, who fund the project); and one representative from LIMA (a local NGO).

The workshop, hosted on Zoom, was structured as a presentation with the step by step unfolding of systemic diagrams drawing from key informant descriptions of selected key issues in the Tsitsa Project.

The full document is available upon request.

9. Workshop 2 Background Information

Interdisciplinary social learning workshop about key issues in the Tsitsa River catchment (12/04/2021).

PhD research by: Adela Itzkin (student at Wits), email: adelaitzkin@gmail.com cell: 082 801 2420. Co-supervised by: Prof. Mary Scholes, Dr. Jai Clifford-Holmes and Dr. Kaera Coetzer

Purpose

There were multiple purposes for the virtual workshop that was held on 12 April 2021:

a) as a follow up to build on learnings that emerged from key informant interviews (between July 2019-Jan 2020) and the workshop (in May 2020) where we worked on building a shared social-ecological systems understanding of the key issues facing the Tsitsa River Catchment (from the perspective of the Tsitsa Project);
b) to apply a social learning approach towards knowledge integration and co-production by interdisciplinary researchers in the TP; and
c) to discuss linkages of some of the key issues in an integrated and meaningful monitoring system.

Background

Workshop 2 was intended to provide a space to allow participants to share updates on the 14 key issues they originally reported to me, and for us to collectively build on our shared understanding of the system by discussing some of these key issues in more depth. This involved looking at barriers and opportunities for further integration within and between (key issue) themes, and ways to support each other and enable integration. We also discussed linkages of some of the key issues to monitoring.

The full document is available upon request.

10. Participant Information Sheet (Survey)

Project Title: A systems approach promoting the interconnectivity of social and biophysical data within the Tsitsa Catchment to support integrated research, planning, and management.

Good day. You are being invited to take part in a research study that will be conducted by me, Ms Adela Itzkin, a PhD researcher from the University of the Witwatersrand, Johannesburg.

The study will be focussing on the interconnectivity of biophysical and social data in the Tsitsa Project (TP). The reason for the study is to pilot the use of an observation system that can provide adequate information to support integrated research, planning and management at the catchment scale.
I am conducting this research as part of my university studies, but the information I gather will be interesting and useful to government, local communities and researchers within the TP. The application value of the study is enhanced through input from as many researchers involved in the TP as possible.
You have been identified as a potential participant because of your association with the TP research team.

The study involves a survey that could take between 20 - 30 minutes. You will be asked a number of questions around social-ecological systems monitoring in the Tsitsa River Catchment . While the questions will ask you to provide certain information about your role and experiences in the TP, **no** names will be used in any results, documents or reports with which this study is concerned.

Your participation in this study is voluntary and you may choose to stop being a part of the study at any time. You may also refuse to answer any questions with which you are not comfortable.
The University of the Witwatersrand Human Research Ethics Committee (Non-Medical) has granted approval for this study (ethics clearance number: H19/09/13). If you have any concerns or complaints regarding the ethical procedures of this study, you are welcome to contact the University Human Research Ethics Committee (Non-Medical), telephone +27(0) 11 717 1408, email shaun.schoeman@wits.ac.za.

Many Thanks
Adela Itzkin
Cell Number: 082 801 2420
E-mail: adelaitzkin@gmail.com
Supervisor: Prof Mary Scholes
Office Number: 0828898670
Email: mary.scholes@wits.ac.za

I have read the information sheet and I volunteer to participate in this research project.

_____ _____

Participant Signature Date

11. Essential Variable Survey Background Information

Update on Essential Social-Ecological System Variable Selection for the Tsitsa River Catchment.

PhD research by: Adela Itzkin (student at Wits), email: adelaitzkin@gmail.com cell: 082 801 2420.
Co-supervised by: Prof. Mary Scholes (mary.scholes@wits.ac.za), Dr. Jai Clifford-Holmes (jai.clifford.holmes@gmail.com) and Dr. Kaera Coetzer (kaera.coetzer@up.ac.za).

Purpose

- The purpose of this document is to provide context for the accompanying essential social-ecological system variables (ESESVs) survey, in which I am asking for input in order to verify and critique findings.
- The results from the survey will be analyzed and will form the basis of a final participatory session at the Tsitsa Project Reflection and Learning Indaba in King Williams Town on the 7th and 8th of March 2023. During the session we will discuss, reflect on and critique the ESESVs that emerge from my research process in relation to the vision (and monitoring) of the broader Tsitsa Project.

PhD update

During the course of my PhD I ran a series of individual and group engagements, to gather input from researchers and other key stakeholders (including yourself) involved in the Tsitsa Project. During these engagements we discussed and reflected on 3 main questions. Those short on time can get the gist of the current focus and rationale for the survey from the key points in Question 0.

1. **What are the key elements of the system and how do they interact to cause and exacerbate land degradation in the catchment?**
   Participant input informed the development of an integrated social-ecological systems (SES) understanding of key drivers of degradation in the Tsitsa River Catchment. We demonstrated that it is the interplay between natural and human drivers, most notably, changes in land use and land cover (particularly the clearing and subsequent disuse of fields), and uncontrolled grazing, which exist in a socio-economic context characterized by poverty and poor governance, that cause the resulting widespread erosion and land degradation.

Resultant publication: Itzkin, A., Scholes, M. C., Clifford-Holmes, J. K., Rowntree, K., van der Waal, B., & Coetzer, K. (2021). A social-ecological systems understanding of drivers of degradation in the Tsitsa River Catchment to inform sustainable land management. *Sustainability (Switzerland)*, *13*(2), 1–28. https://doi.org/10.3390/su13020516

2. **What can we do to enhance social-ecological system integration and integrated monitoring in the Tsitsa River Catchment (TRC) and SES projects more broadly?**
   Integration and integrated monitoring emerged as pressing conceptual and methodological challenges, both in the TRC and in wider SES research. Recommendations to enhance integrated monitoring and management of SESs were explored.

Resultant publication: Itzkin, A., Clifford-Holmes, J. K., Scholes, M., & Coetzer, K. (2022). Approaches to Enhance Integration and Monitoring for Social-Ecological Systems. *Land 2022, Vol. 11, Page 1848*, *11*(10), 1848. https://doi.org/10.3390/land11101848

3. **Which SES variables are essential (ESEVs) to measure, to understand (and manage) the system?**
   - ✓ It is yet to be determined whether ongoing monitoring of the indicators selected within the project would provide us with an understanding of the key overarching social-ecological interactions driving the dynamics of interest. This work experiments with ESEVs as an alternative entry point to integrated monitoring. The biophysical, social and social-ecological indicators already selected through expert-driven disciplinary processes within the project are considered as potential inputs, as is the data gathered through my participatory transdisciplinary process, all of which will be filtered through the ESEV selection criteria.
   - ✓ An ESEV approach is being taken to compile and verify social-ecological variables based on participant consensus on their relevance in the context of the Tsitsa River Catchment (TRC). The Candidate ESEVs and associated indicators presented in Table 1 were compiled drawing from the indicators selected by the Tsitsa Project, data from my research process, and potentially relevant indicators from the essential variable literature. Your input in the survey will help to verify, critique and modify the list (Table 1 on the next page).

Way Forward

The next steps for this work are to:

- Collate and integrate the survey results from the EV survey with the other data already collected throughout my research process;
- Discuss, reflect on, and critique the ESEVs that emerge at the Tsitsa Project Reflection and Learning Indaba; and
- Posit an integrated observation system guided by the final ESESVs for the TRC.

Acknowledgements

- I would like to thank all the key informants and workshop attendees for their participation and input.
- Funding for this study, (PhD scholarship and research costs) has been provided to Prof. Mary Scholes through her SARChI Research Chair in Global Change and Applied Systems Analysis (funded by the Department of Science and Innovation (DSI) and the National Research Foundation (NRF) of South Africa).
- The research and implementation of the broader Tsitsa Project has been funded by the Department of Forestry, Fisheries and the Environment (DFFE), Chief Directorate: Natural Resource Management Programmes (NRM), Directorate: Operational Support and Planning. The contents of this work do not necessarily reflect the views and the policies of DFFE, Chief Directorate: NRM, nor does the mention of trade names or commercial products constitute endorsement or recommendation for use.

Table 1. First proposed list of essential social-ecological system variables (ESESV) for integrated monitoring of the Tsitsa River Catchment. To be refined based on input from surveys and final workshop.

Essential Variable Layer	**Candidate Essential Social-Ecological Systems Variables (ESESVs)**	**Potential Indicators associated with ESESV** These were compiled drawing from the indicators selected by the Tsitsa Project (in green), data from my research process, and potentially relevant indicators from Essential Variable literature.
Sustainable Livelihoods	1. Grazing Intensity 'Uncontrolled or over grazing' was identified as a key social-ecological driver of degradation in the catchment (Itzkin et al. 2021). This ESESV is positioned within the sustainable livelihoods layer because sustainable livestock and grazing practices may be key interventions to improve social-ecological sustainability.	1.1. Livestock density (by type), 1.2. Rangeland vegetation cover (%) 1.3. Livestock production (as an ecosystem service supply) 1.4. Livestock theft 1.5. Rangeland condition 1.6. Natural Resource income equivalent from Livestock 1.7. Livestock management – e.g. rotational grazing (Land-use management[1]) 1.8 Export/sale rates of agricultural products
	2. Cropping intensity Cropping activities in the catchment have declined. The impact of grazing on fields that were previously used for cultivation may be an important contributor to soil erosion.	2.1. Proportion of agricultural area under productive and sustainable agriculture 2.2. Natural resource income equivalent from cropping 2.3. Ratio between cropland which is 'sufficiently covered' and total amount of crop land[2] 2.4. Cropland production (as an ecosystem service supply)
	3. Forestry Intensity Definition to be determined in relation to context. Forestry did not emerge as a current driver on the communal areas, but it may be important to consider how livelihoods and the landscape will be affected by a Forestry Master Plan to plant seven-hundred-thousand trees in the Eastern Cape in the near future.	3.1. Forest area as a proportion of total land area 3.2. Progress towards sustainable forest management (Land-use management is 1 of the TP's 5 change domains[1]) 3.3. Natural resource income equivalent from forestry products
	4. Access to natural resources Access to natural resources is 1 of the Tsitsa Project's 5 change domains[1].	4.1. Access to natural resources (food types & sources, firewood, thatch, medicinal plants, etc.) 4.2. Access to potable water
Polycentric Natural Resource Governance	5. Participation in natural resource governance processes Links with key issue 'Governance in the catchment' (Figure 1). Governance is 1 of the Tsitsa Project's 5 change domains[1].	5.1. Land user participation in governance structures, 5.2. Women and youth participation in natural resource management governance structures, 5.3. Sense of inclusion - satisfaction with 'voice' 5.4. Participation in sustainable land-use management
Human actions on the land	6. Land cover and condition Land use practices, especially those related to grazing and cultivation were identified as potential leverage points (Itzkin et al. 2021). Indictors for land cover and condition were prioritized by the TP sediment and restoration community of practice.	6.1. Woody Invasive Species cover 6.2. Grassland condition 6.3. Landscape Function 6.4. Land cover change 6.5. Land use intensity[3]
	7. Soil Erosion (related to human actions on the land) Result of interacting natural and anthropogenic factors.	7.1. Soil erosion (by anthropogenic practices) 7.2. Soil erosion (as an abiotic-economic[4] ecosystem disservice) 7.3. Mass stabilization and control of erosion rates (as a regulation and maintenance ecosystem service)
Climate Change Adaptation	8. Climate change Adaptation Climate change adaptation is an SES variable that reflects the outcomes of a set of social-ecological relations.	8.1. Interventions to manage the grassland 8.2. Interventions to grow climate smart crops 8.3. Interventions to store, capture and produce water 8.4. Interventions to alleviate heat stress

1. The Tsitsa Project's change domains describe some areas that are important in the project, to help track progress. The 5 change domains are access to natural resources, agency, sustainable land-use management, governance and well-being.
2. 'Sufficient coverage' would need to be determined in relation to the context.
3. Land use intensity is a compound, additive variable in which different kinds of land uses contribute to an overall level, and as such may qualify as a candidate ESESV rather than simply an indicator. Can be discussed further at the upcoming workshop.
4. Ecosystem disservices can be classified according to their origin and primary dimension of human well- being affect

12. Google Form Survey Instrument

Essential Social-Ecological System Variables to monitor the Tsitsa River Catchment

Thank you for participating in this survey to collect a transdisciplinary array of opinions and knowledge about key variables to monitor social-ecological systems functioning of the Tsitsa River Catchment (TRC) in relation to the Tsitsa Project's vision "To support sustainable livelihoods for local people through integrated landscape management that strives for resilient social-ecological systems and which fosters equity in access to ecosystem services" (Biggs et al., 2018, p. 15).

This work combines a social-ecological systems (SES) approach and an essential variable (EV) approach. The SES approach is based on the conceptualization that you cannot construct a complex social-ecological system as a sum of its social and ecological parts. The EV approach is a filter to guide the selection of indicators to be monitored. The result is a focus on Essential Social-Ecological Systems Variables (ESESVs), considered critical to capture the social-ecological dynamics underpinning the trajectories of the TRC SES over time. There are usually a number of indicators associated with each EV. The biophysical, social and social-ecological indicators already selected through expert-driven disciplinary processes within the project are considered as potential inputs, as is the data gathered through my participatory transdisciplinary process.

Please read the accompanying background sheet for further background into my project, the basis for the variables included in this survey, and next steps of my research. Please feel free to reach out to me or my supervisors for more information or if you have any concerns about this survey (contact details on background document and information sheet).

* Indicates required question

Ethical Clearance*

I have ethical clearance to conduct this research through the Wits University Human Research Ethics Committee, and have emailed you a participant information sheet about the survey. If you are happy to participate, please tick the checkbox below.

Check all that apply.

☐ Yes

Personal Details

1. 1. Name (this is optional and will remain confidential):

_____

2. 2. Please briefly describe your role/position/involvement in the Tsitsa Project:

_____

3. 3. Tick if you want to be acknowledged in derived publications

Check all that apply.

☐ Yes, include my name in the acknowledgments

4. 4. Tick if you want to receive the results of this study

Check all that apply.

☐ Yes, send me the results of this study

Social Ecological Essential Variable Selection Criteria

EVs have historically been sectoral, with the main selection criteria being feasibility, relevance and cost-effectiveness. This
work contributes towards recent efforts applying EVs beyond
sectoral approaches as cross-thematic
and within complex social-ecological system domains. This requires a re-thinking of the section criteria. The selection criteria of EVs for SESs must take into consideration the values and goals of those working in a particular system of interest. Both traditional and novel selection criteria are listed below for you to prioritize in relation to the context in which you work/ed in the Tsitsa River Catchment.

6. Please rate which potential criteria you believe are most important to guide the selection of Social Ecological Essential Variables for the TRC. The scale goes from 1 "least essential" to 5 "most essential" to monitor, with 0 being "not essential".

Mark only one oval per row.

	0 (Not essential)	1	2	3	4	5 (M esse
Feasible (the state or degree of being easily or conveniently done)	◯	◯	◯	◯	◯	◯
Relevant (indispensable/foundational for tracking system)	◯	◯	◯	◯	◯	◯
Cost-Efficient	◯	◯	◯	◯	◯	◯
Captures 'System Essence' (represents the key features, processes and interactions driving SES dynamics over time and space).	◯	◯	◯	◯	◯	◯
Covers Social-Ecological Relations or Interactions (co-produced by the social and ecological)	◯	◯	◯	◯	◯	◯
Integrates existing observations from space and the ground	◯	◯	◯	◯	◯	◯
Expert-Selected	◯	◯	◯	◯	◯	◯
Resident-Selected	◯	◯	◯	◯	◯	◯
Resident-Monitored	◯	◯	◯	◯	◯	◯
Multi-purpose (at the nexus of many processes)	◯	◯	◯	◯	◯	◯

7. Please select the 3 - 5 criteria that you would consider most important to guide selection of essential SES variables in the TRC

Check all that apply.

- [ ] Feasible
- [ ] Relevant
- [ ] Cost-efficient
- [ ] Captures system essence
- [ ] Covers social-ecological relations or interactions
- [ ] Integrates existing observations from space and the ground
- [ ] Expert-selected
- [ ] Resident-selected
- [ ] Resident-monitored
- [ ] Multi-purpose

8. Is there a selection criteria that is missing from this list that you consider important to consider?

Essential Social-Ecological Systems Variable Layer: Sustainable Livelihoods

There are 4 categories for consideration under the sustainable livelihoods banner, namely: grazing, cropping, forestry and access to natural resources. Each ESESV will be accompanied by a number of potential indicators for monitoring. Please punctuate each candidate ESESV and its potential indicators according to what you consider to be their relevance as "essential" to measure in order to understand and manage the Tsitsa River Catchment (TRC) social-ecological system (in relation to the vision of the Tsitsa Project: ”To support sustainable livelihoods for local people through integrated landscape management that strives for resilient social-ecological systems and which fosters equity in access to ecosystem services”).

The scale goes from 1 "least essential" to 5 "most essential" to monitor, with 0 being "not essential". Please keep your selection criteria to determine 'essentiality' from section 2 in mind.

9. **Sustainable Livelihoods Candidate ESESV 1: Grazing**
How essential do you consider grazing and rangeland sustainability, as a candidate ESESV, in the TRC?

Mark only one oval.

	0	1	2	3	4	5	
0 (N	◯	◯	◯	◯	◯	◯	5 (Most essential)

10. In terms of monitoring grazing and rangeland sustainability, please indicate how essential you consider the following as potential indicators associated with grazing.

Mark only one oval per row.

	0 (Not esential)	1	2	3	4	5 (Most essential)
Potential indicator 1.1: Livestock density (by type)	◯	◯	◯	◯	◯	◯
Potential indicator 1.2: Rangeland vegetation cover (%)	◯	◯	◯	◯	◯	◯
Potential indicator 1.3: Livestock production (products generated by livestock)	◯	◯	◯	◯	◯	◯
Potential indicator 1.4: Livestock theft	◯	◯	◯	◯	◯	◯
Potential indicator 1.5: Rangeland condition	◯	◯	◯	◯	◯	◯
Potential indicator 1.6: Natural resource income equivalent from livestock (financial equivalent)	◯	◯	◯	◯	◯	◯

Potential indicator 1.7: Livestock Management						
Potential indicator 1.8: Export/sale rates of agricultural products						

11. Would you modify the candidate ESESV for grazing as 'grazing and rangeland sustainability"? If so, please specify?

    Similarly would you add/modify any monitoring indicators associated with grazing?

12. **Sustainable Livelihoods Candidate ESESV 2: Cropping**
    How essential do you consider cropping sustainability as a candidate ESESV, in the TRC?

    Mark only one oval.

	0	1	2	3	4	5	
0 (N							5 (Most essential)

13. In terms of monitoring cropping sustainability, please indicate how essential you consider the following as potential indicators associated with cropping.

Mark only one oval per row.

	0 (Not essential)	1	2	3	4	5 (Most essential)
Potential indicator 2.1: Proportion of agricultural area under productive, sustainable agriculture	⬭	⬭	⬭	⬭	⬭	⬭
Potential indicator 2.2: Natural Resource Income Equivalent (financial) from cropping	⬭	⬭	⬭	⬭	⬭	⬭
Potential indicator 2.3: Ratio between 'sufficiently covered' cropland and the total crop land	⬭	⬭	⬭	⬭	⬭	⬭
Potential indicator 2.4: Cropland production (products generated by cropping)	⬭	⬭	⬭	⬭	⬭	⬭

14. Would you modify the candidate ESESV for cropping as 'cropping sustainability'? If so, please specify?

    Similarly would you add/modify any monitoring indicators associated with cropping?

15. **Sustainable Livelihoods Candidate ESESV 3: Forestry**
    How essential do you consider forestry sustainability, as a candidate ESESV, in the TRC?

    Mark only one oval.

	0	1	2	3	4	5	
0 (N	◯	◯	◯	◯	◯	◯	5 (Most essential)

16. In terms of monitoring forestry sustainability, please indicate how essential you consider the following as potential indicators associated with forestry.

Mark only one oval per row.

	0 (Not essential)	1	2	3	4	5 (Most essential)
Potential indicator 3.1: Forest area as a proportion of total land area	◯	◯	◯	◯	◯	◯
Potential indicator 3.2: Progress towards sustainable forest management (methods of forestry)	◯	◯	◯	◯	◯	◯
Potential indicator 3.3: Natural resource income equivalent from forestry products (Financial equivalent)	◯	◯	◯	◯	◯	◯

17. Would you add to/modify the candidate ESESV for forestry as 'forestry sustainability'? If so, please specify?

    Similarly would you add/modify any monitoring indicators associated with forestry?

18. **Sustainable Livelihoods Candidate ESESV 4: Access to Natural Resources**
    How essential do you consider access to natural resources, as a candidate ESESV, in the TRC?

    Mark only one oval.

	0	1	2	3	4	5	
0 (N	◯	◯	◯	◯	◯	◯	5 (Most essential)

19. In terms of monitoring access to natural resources, please indicate how essential you consider the following as potential indicators.

Mark only one oval per row.

	0 (Not essential)	1	2	3	4	5 (Most essential)
Potential indicator 4.1: Access to natural resources (food types & sources, firewood, thatch, medicinal plants, sand for building, etc.)	⬭	⬭	⬭	⬭	⬭	⬭
Potential indicator 4.2: Access to potable water	⬭	⬭	⬭	⬭	⬭	⬭

20. Would you modify the candidate ESESV for 'access to natural resources'? If so, please specify?

Similarly would you add/modify any monitoring indicators associated with access to natural resources?

21. Would you add any of other candidate ESESVs for 'sustainable livelihoods'? If so, please specify?

Essential Social-Ecological Systems Variable Layer: Natural Resource Governance

Each ESESV will be accompanied by a number of potential indicators for monitoring. Please punctuate each candidate ESESV and its potential indicators according to what you consider to be their relevance as "essential" to measure in order to understand and manage the Tsitsa River Catchment social-ecological system (in relation to the vision of the Tsitsa Project "To support sustainable livelihoods for local people through integrated landscape management that strives for resilient social-ecological systems and which fosters equity in access to ecosystem services").

The scale goes from 1 "least essential" to 5 "most essential" to monitor, with 0 being "not essential". Please keep your selection criteria to determine 'essentiality' from section 2 in mind.

22. **Polycentric Natural Resource Governance Candidate ESESV 5: Participation in natural resource governance**
How essential do you consider participation in natural resource governance, as a candidate ESESV, in the TRC?

Mark only one oval.

	0	1	2	3	4	5	
0 (N	◯	◯	◯	◯	◯	◯	5 (Most essential)

23. In terms of monitoring participation in natural resource governance, please indicate how essential you consider the following as potential indicators.

Mark only one oval per row.

	0 (Not essential)	1	2	3	4	5 (Most essential)
Potential indicator 5.1: Land user participation in NRM governance structures	⬭	⬭	⬭	⬭	⬭	⬭
Potential indicator 5.2: Women and youth participation in NRM governance structures	⬭	⬭	⬭	⬭	⬭	⬭
Potential indicator 5.3: Sense of inclusion- percentage of land users satisfied their voices are represented in decision making and planning processes of the catchment	⬭	⬭	⬭	⬭	⬭	⬭
Potential indicator 5.4: Participation in sustainable land-use management	⬭	⬭	⬭	⬭	⬭	⬭

24. Would you modify the candidate ESESV 'participation in natural resource governance', or add another candidate ESESV associated with polycentric natural resource governance? If so, please specify?

    Similarly would you add/modify any monitoring indicators associated with polycentric natural resource governance?

Essential Social-Ecological Systems Variable Layer: Human impacts on the land

There are 2 categories for consideration under the 'human actions on the land' layer, namely: land cover & condition, and soil erosion (related to human actions on the land) . Each candidate ESESV will be accompanied by a number of potential indicators for monitoring. Please punctuate each candidate ESESV and its potential indicators according to what you consider to be their relevance as "essential" to measure in order to understand and manage the Tsitsa River Catchment social-ecological system (in relation to the vision of the Tsitsa Project ”To support sustainable livelihoods for local people through integrated landscape management that strives for resilient social-ecological systems and which fosters equity in access to ecosystem services”).

The scale goes from 1 "least essential" to 5 "most essential" to monitor, with 0 being "not essential". Please keep your selection criteria to determine 'essentiality' from section 2 in mind.

25. **Human impacts on the land Candidate ESESV 6: Land cover and condition**

How essential do you consider land cover and condition, as a candidate ESESV, in the TRC?

Mark only one oval.

	0	1	2	3	4	5	
0 (N	◯	◯	◯	◯	◯	◯	5 (Most essential)

26. In terms of monitoring land cover and condition, please indicate how essential you consider the following as potential indicators of land cover and condition.

Mark only one oval per row.

	0 (Not essential)	1	2	3	4	5 (Most essential)
Potential indicator 6.1: Woody Invasive Species cover	◯	◯	◯	◯	◯	◯
Potential indicator 6.2: Grassland condition	◯	◯	◯	◯	◯	◯
Potential Indicator 6.3: Landscape Function	◯	◯	◯	◯	◯	◯
Potential indicator 6.4: Land cover change	◯	◯	◯	◯	◯	◯
Potential indicator 6.5: Land use intensity	◯	◯	◯	◯	◯	◯

27. Would you modify the candidate ESESV 'land cover and condition'? If so, please specify?

    Similarly would you add/modify any monitoring indicators associated with land cover and condition?

28. **Human impacts on the land Candidate ESESV 7: Soil Erosion (related to human actions on the land)**
    How essential do you consider soil erosion (related to human actions on the land), as a candidate ESESV, in the TRC?

    Mark only one oval.

1	2	3	4	5
◯	◯	◯	◯	◯

29. In terms of monitoring soil erosion, please indicate how essential you consider the following as potential indicators of soil erosion (related to human actions on the land)

Mark only one oval per row.

	0 (Not essential)	1	2	3	4	5 (Most essential)
Potential indicator 7.1: Soil Erosion (by anthropogenic practices)	◯	◯	◯	◯	◯	◯
Potential indicator 7.2: Soil Erosion as an (abiotic-economic*) ecosystem disservice	◯	◯	◯	◯	◯	◯
Potential indicator 7.3: Mass stabilization and control of erosion rates	◯	◯	◯	◯	◯	◯

30. Would you modify the candidate ESESV 'soil erosion related to human impacts'? If so, please specify?

Similarly would you add/modify any monitoring indicators associated with land cover and condition?

31. Would you add any other candidate ESESVs for human actions on the land? If so, please specify?

Essential Social-Ecological Systems Variable Layer: Climate Change Adaptation

Each ESESV will be accompanied by a number of potential indicators for monitoring. Please punctuate each candidate ESESV and its potential indicators according to what you consider to be their relevance as "essential" to measure in order to understand and manage the Tsitsa River Catchment social-ecological system (in relation to the vision of the Tsitsa Project "To support sustainable livelihoods for local people through integrated landscape management that strives for resilient social-ecological systems and which fosters equity in access to ecosystem services").

The scale goes from 1 "least essential" to 5 "most essential" to monitor, with 0 being "not essential". Please keep your selection criteria to determine 'essentiality' from section 2 in mind.

32. **Climate Change Adaptation Candidate ESESV 8: Climate Change Adaptation**
How essential do you consider climate change adaptation, as a candidate ESESV, in the TRC?

Mark only one oval.

	0	1	2	3	4	5	
0 (N	◯	◯	◯	◯	◯	◯	5 (Most essential)

33. In terms of climate change adaptation, please indicate how essential you consider the following as potential indicators of climate change adaptation.

Mark only one oval per row.

	0 (Not essential)	1	2	3	4	5 (Most essential)
Potential indicator 8.1: Interventions to manage the grassland	◯	◯	◯	◯	◯	◯
Potential indicator 8.2: Interventions to grow climate smart crops	◯	◯	◯	◯	◯	◯
Potential indicator 8.3: Interventions to store, capture and protect water	◯	◯	◯	◯	◯	◯
Potential indicator 8.4: Interventions to alleviate heat stress (for humans and livestock)	◯	◯	◯	◯	◯	◯

34. Would you modify the candidate ESESV 'climate change adaptation', or add another candidate ESESV associated with climate change? If so, please specify?

    Similarly would you add/modify any monitoring indicators associated with climate change adaptation?

Overall Comments and Suggestions

35. Are there any ESESVs or associated indicators that are missing from this survey which you feel are essential to understand and monitor the social-ecological systems functioning of the TRC? Please specify

36. Please feel free to share any ideas, questions, comments or suggestions related to this survey on the essential social-ecological system variables and monitoring of the TRC.

13. Workshop 3 Guiding Worksheet

Follow-up Workshop 3: Essential Social-ecological System Variables to Monitor the Tsitsa River Catchment (08/03/2023)

Facilitated by Adela Itzkin.

A worksheet was developed to guide a final workshop session (Workshop 3), held on 8 March 2023, where participants discussed and verified the feedback from the Essential Variable survey (Appendix 12). At the workshop participants reflected on the value of SES essential variables as an alternate entry point to integrated monitoring, which has been a key challenge in the Tsitsa River Catchment and in wider SES research.

The guiding worksheet is available upon request.