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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

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

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].

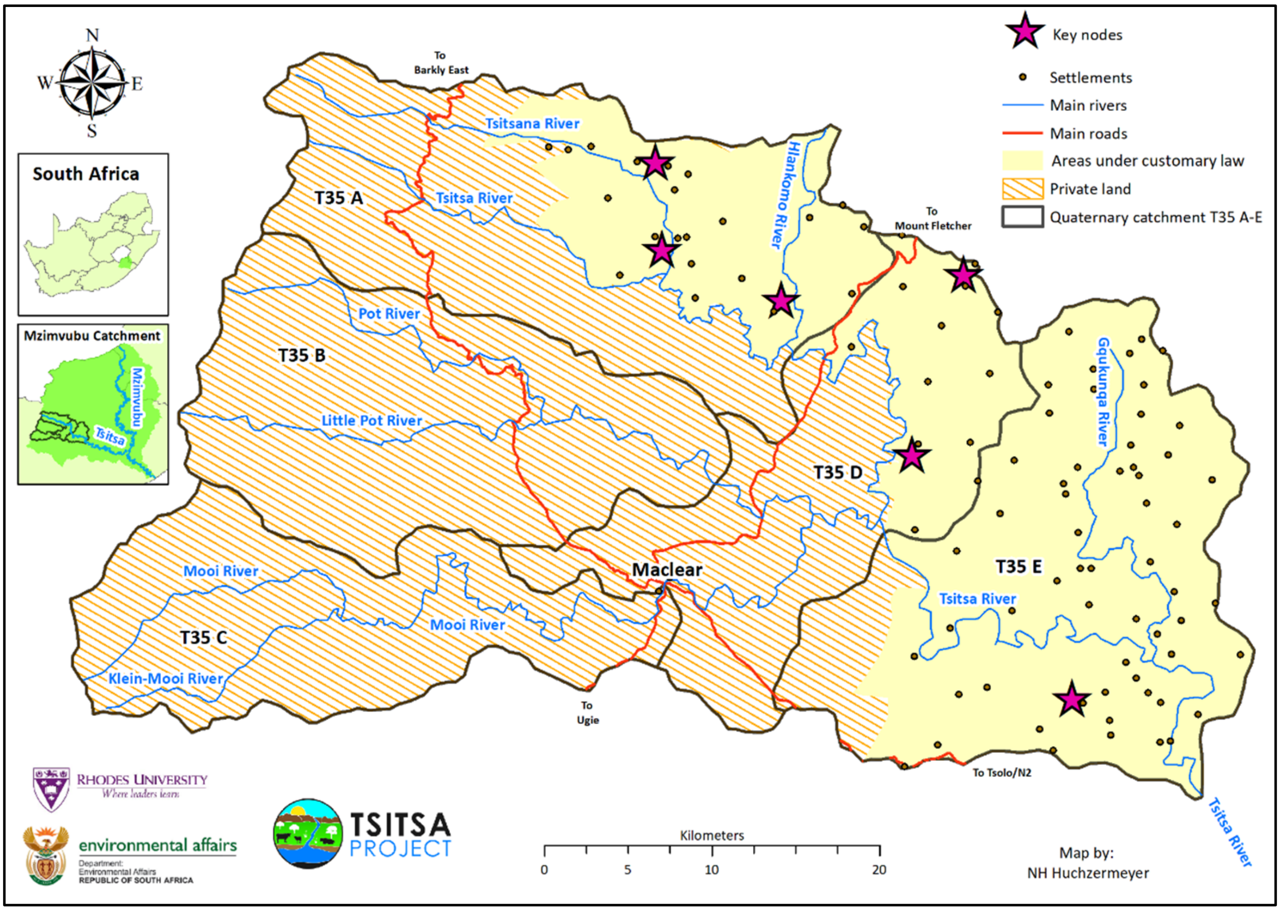

Figure 1. Map of the Tsitsa River Catchment. Quaternary catchments are hydrological delineations of sub-catchments (numbered by the South African system of T35 A–E); and key nodes refer to focal areas for the Tsitsa Project's engaged research and restoration work. Map by N.H. Huchzermeyer.

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.

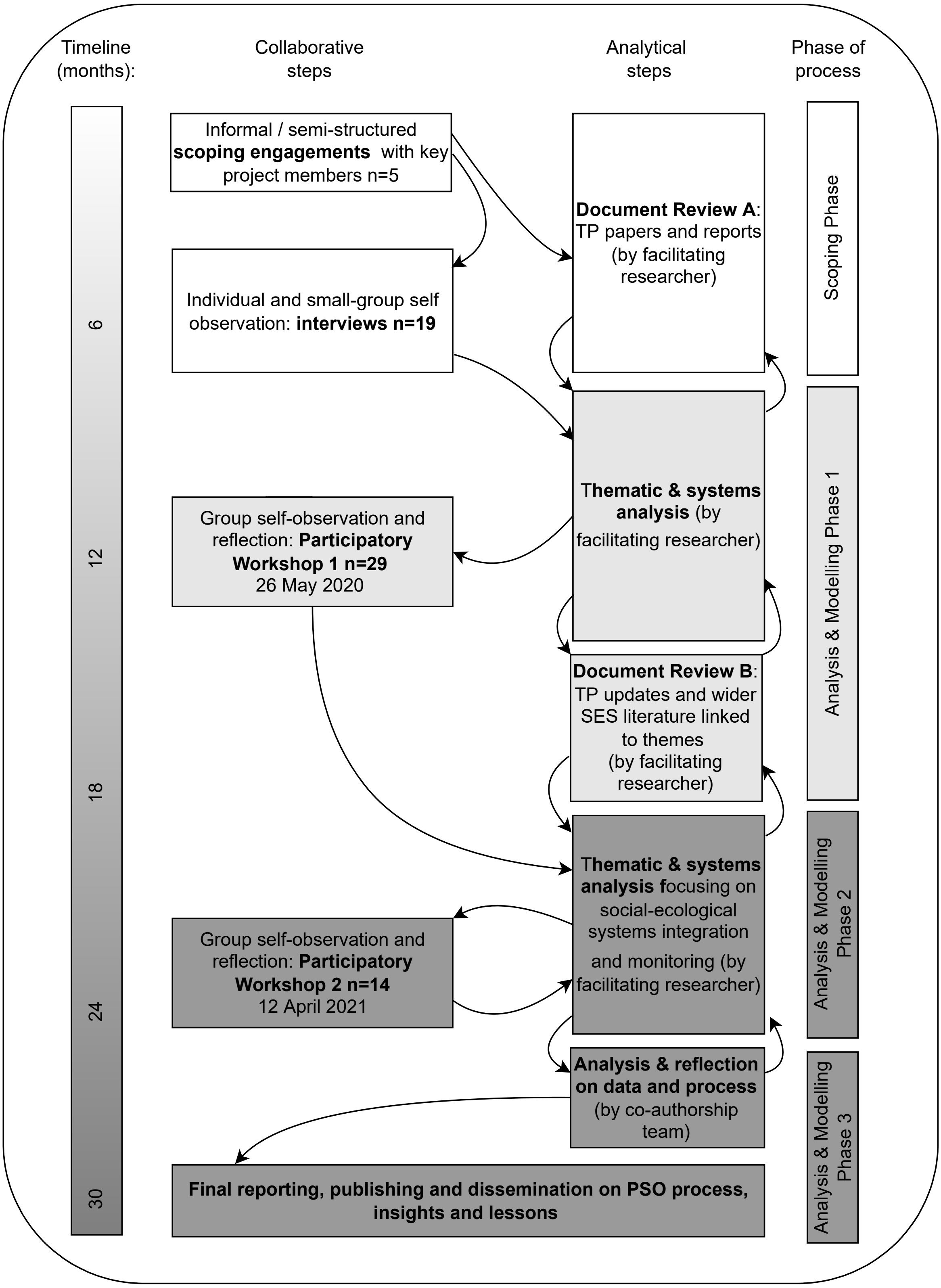

Figure 2. Research process that developed into a 'participatory self-observation process' as a social learning process to collaboratively better understand the Tsitsa Project. The process included iterative rounds of collaborative self-observation and reflection by participants. Rounds of analysis and 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).

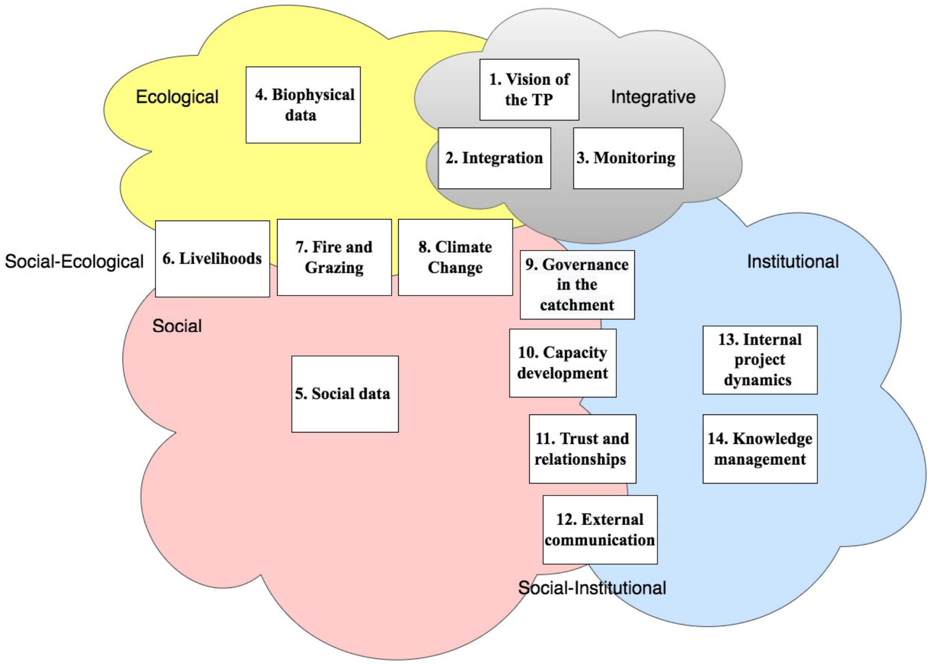

Figure 3. Key issue constellation that shows the fourteen themed key issues gathered from engagement with participants of the Tsitsa Project between 2019 and 2021. The key issues have been categorized as integrative (1, 2, 3), biophysical or ecological (4), social (5), social-ecological (6, 7, 8), social-institutional (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	10. A catchment coordinator who is a key enabler of integration. 11. Worked together more (because we do not have enough funding).	16. To focus our joint intellectual effort in an integrated way on the questions of scale.
Updates on integration from PMERL Project Documentation (D) March 2020–December 2020	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.	
Updates on integration from Workshop 2 (W2) April 2021	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.	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.	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	9. Climate change indicators proposed (Q1 2020) 10. Reflection reports now review of progress against objectives, NB for tracking (Q1 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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