Appendix A

Different communities have used various criteria to select and define their essential variables (EVs). Below is a table (Table A.1) presenting ten potential selection criteria for participants to prioritize in the survey. Participants were also encouraged to suggest additional criteria they felt were important for this case study. Criteria such as 'Feasible,' 'Relevant,' and 'Cost-efficient' were included as they form the foundation of selection criteria in early EV literature. The remaining criteria were tailored to the objectives and framing of essential social-ecological system variables (ESEVs) for this specific project and case study. While not exhaustive, they offer a reference list for ESEVs that can be adapted or expanded in other contexts. Criteria like 'Captures System Essence' and 'Covers Key Social-Ecological Relations or Interactions' were included because they align with the systems thinking and relational SES framing of the case study and ESEV concept as defined in this research. Criteria such as 'Integrates Existing Observations from Space and Ground' and 'Multi-purpose' emerged from the participatory research process as desirable characteristics for monitoring, and are reflected in some EV literature. Although 'Resident-selected' and 'Resident-monitored' do not appear in the EV lists reviewed, they were added due to their importance in the Tsitsa Project (Botha et al., 2017; Cockburn et al., 2019; Kotschy et al., 2021), where citizen technicians are deliberately involved in monitoring efforts (Bannatyne et al., 2017).

Table A.1. Potential selection criteria that participants used to prioritize in order to guide the selection of Social Ecological Essential Variables for the Tsitsa River Catchment on a scale goes from 1 "least essential" to 5 "most essential" to monitor, with 0 being "not essential". Definitions and references to similar selection criteria in the Essential Variable literature are provided.

Potential Selection Criteria	Definition/s	Appears in the following Essential Variable literature:
Feasible	The state or degree of being easily or conveniently done (using proven, scientifically understood methods) within the context of the specific cultural, economic and social norms of the system of interest.	(Bojinski et al., 2014; Lehmann et al., 2020; Pereira et al., 2013)
Relevant	Indispensable/foundational for tracking the system.	(Bojinski et al., 2014; Constable et al., 2016; Hayes et al., 2015; Pereira et al., 2013). Foundational is also mentioned under 'indispensable' in (Reyers et al., 2017)
Cost-efficient	Generating and archiving data on the variable is affordable, mainly relying on coordinated observing systems using proven technology, taking advantage where possible of historical datasets.	(Bojinski et al., 2014; Constable et al., 2016)
Captures System Essence:	Represents the key features, processes and interactions driving SES dynamics over time and space.	(Reyers et al., 2017)
Covers 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., 2019; Wu et al., 2021)
Integrates existing observations from space and the ground	The use of remote sensing and other cutting-edge data collection methods in combination with ground measurements.	(Wu et al., 2021)

Expert-selected	Selected by experts in the subject area/s.	Not stated as a selection criterion but de-facto the main criteria used in (Pacheco-Romero et al., 2020) and used as method in many other EV processes. (Balvanera et al., 2022) suggest that interdisciplinary expert teams be formed to focus to assess appropriate indicators on individual ecosystem services.
Resident-selected	Selected by residents of the study area.	-
Resident-monitored	Monitored by residents of the study area.	-
Multi-Purpose	Data at the nexus of many processes could be collected once, but analyzed differently for different essential variable themes, thus effectively reducing the number of priority indicators for monitoring.	(Constable et al., 2016; Pereira et al., 2013; Reyers et al., 2017)

Table A.2. Essential Social-Ecological System Variables (ESEVs) and Indicators for Monitoring the Tsitsa River Catchment in Relation to Tsitsa Project (TP) Goals. This table incorporates feedback from surveys, workshops, and follow-up meetings, with references to similar variables and indicators in the literature.

- **Priority ESESVs and indicators from the survey are in bold.**
- Indicators previously selected by expert-driven processes in the TP are in green.
- Additional ESEVs and indicators suggested by 5+ survey participants, though not in the survey, are in blue. These were deemed essential in follow-up workshops and interviews, though their priority could not be established in the same manner as those originally in the survey.

Theme	Candidate ESEV *Priority level*	Summary of rationale/s for candidate ESEV	Potential indicators	Literature featuring similar EVs and/or indicators:
Human Impacts on the Environment	**Soil Erosion** (related to human actions on the land) **(SE-EV)** *Priority level 1*	Result of interacting ecological and anthropogenic factors and hypothesized to be a key driver of land degradation in the SES.	**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]: Percentage vegetation/ground cover (G[2]) SE[5]: Suspended sediment concentration	Reference list of variables for SES monitoring, ESDGVs for land degradation monitoring (Pacheco-Romero et al., 2020; Zhao et al., 2023)
	Land Cover and Condition (LC-EV) *Priority level 3*	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.	**LC[1]: Grassland condition (G[1])** **LC[2]: Land cover change** **LC[3]: Woody invasive species cover**	ESDGVs, reference list of variables for SES monitoring (Fukui et al., 2021; Pacheco-Romero et al., 2020)
Governance	**Participatory Natural Resource Governance (P-EV)** *Priority level 2*	'Governance in the catchment' is positioned as key SES driver (Itzkin et al. 2021). Governance is 1 of 5 'Change Domains' in the TP[1]. Natural Resource Governance is social-ecological	**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**	Governance was found to be important and was one of 13 classes in Pacheco-Romero and others' 2020 reference list of variables for SES monitoring (Pacheco-Romero et al., 2020)
	Local Governance System (GS-EV) *Priority level undetermined*	The state of the 'local NRM governance system' was proposed as a potentially critical driver of SES dynamics in the catchment over time.	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, GS[5]: Positive collaboration of land users with governance actors – measures rational trust GS[6]: Natural Resource Management Rules (in form and in use)	ESDGVs, linked to Ostrom's work on land user trust with local governance system (Fukui et al., 2021; Ostrom, 2014, 2003, 1990)

Sustainable Livelihoods	Sustainable Grazing and Rangelands (G-EV) *Priority level 3*	Sustainable grazing and rangelands were combined into a single ESEV due to their interconnectedness. Participants (W2, S, & W3) noted that many indicators could track the sustainability of both, highlighting their co-dependence. Sustainable livestock and grazing practices have been proposed as key interventions to improve rangeland condition and the sustainability of related livelihoods in the catchment (Itzkin et al., 2021). This consolidation ensures the ESEV captured key social-ecological processes driving sustainability in the catchment.	**G^1: Rangeland condition (LC^1)** G^2: Vegetation cover (SE^4) G^3: Livestock management G^4: Livestock density G^5: Income related to sustainable livestock livelihoods G^6: Sales rates of agricultural products G^7: Livestock theft G^8: Livestock ownership patterns G^9: Willingness to practice sustainable grazing G^{10}: Fire Regime	EDVs, reference list of variables for SES monitoring (Pacheco-Romero et al., 2020; Wu et al., 2021b)
	Access to Natural Resources (NR-EV) *Non-Priority*	Access to natural resources is the TP's first Change Domain[1].	**NR^1: Access to potable water (W^2)** NR^2: Access to natural resources by sub-category (food types & sources, firewood, thatch, medicinal plants, water from the natural environment, and sand for building)	Linked to Nature's contributions to people in EESVs and EBVs (Balvanera et al., 2022; Kim et al., 2023)
	Sustainable Cropping (C-EV) *Non-Priority*	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.	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 C^5: Proportion of households using conservation agriculture in their fields or food gardens	Food Workflow-Food energy water nexus for SDGs, ESDGVs for land degradation monitoring (Mccallum et al., 2020; Zhao et al., 2023)
	Sustainable Forestry (F-EV) *Non-Priority*	Definition to be determined in relation to context. Forestry did not come up 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.	F^1: Progress towards sustainable forest management (methods of forestry) F^2 : Forest area as a proportion of total land area F^3: Income from sustainable forestry products	Reference list of variables for SES monitoring, EFVs and ESDGVs for land degradation monitoring (Pacheco-Romero et al., 2020; Zhao et al., 2023; Zhao and Wu, 2019)

Climate Change Adaptation	Climate Change Adaptation (CC-EV) *Non-Priority*	Climate change adaptation is a variable that reflects the outcomes of a set of social-ecological relations.	**CC[1]: Interventions to store, capture and produce water (W[1])** CC[2]: Interventions to manage the grassland (level 4) CC[3]: Interventions to grow climate smart crops (non-priority) CC[4]: Interventions to alleviate heat stress (for humans and livestock) (non-priority) CC[5]: Participatory governance, management or decision-making around climate change adaptation CC[6]: Interventions to adapt to climatic shocks and extremes (such as floods, fires, droughts)	This approach is not covered in EV literature. CC[1] to CC[4] are derived from Kate Rowntree's work in the Tsitsa Project, following guidelines for community-based climate adaptation. (Ayers et al., 2012)
Water	Access to Water (W-EV) *Priority level undetermined*	Emerged strongly as a potential addition during the gap analysis. Two of the highest priority indicators identified in the survey (CC[1] and NR[1]) are water-related.	**W[1]: Interventions to store, capture and produce water (CC[1])** **W[2]: Access to potable water (including source & distance) (NR[1])** W[3]: Access to water from the environment (including source & distance)	Reference list of variables for SES monitoring (Pacheco-Romero et al., 2020)
Human Well-being	Human Well-Being in the Tsitsa River Catchment *Priority level undetermined*	Survey input emphasizes that failing to address human well-being dimensions results in an incomplete understanding of SES dynamics, as these dimensions strongly interact with the identified variables. Workshop 3 consensus was that, "*We must try measure it somehow, although it is not perfect, it's something."* Links to Tsitsa Project's Change Domains[1]	WB[1]: A 'good life in the catchment' WB[2]: Sense of place and identity WB[3]: Ritual value from SES	ESGDVs, linked to relational values in EESVs (Balvanera et al., 2022; Fukui et al., 2021)

[1] The Tsitsa Project focussed on five change domains that it considered the most important levers for sustainability, and help monitor progress (Human, 2019 p 120). 1. access to natural resources, 2. agency (in relation to natural resources or livelihoods), 3. land-use management, 4. governance, and 5. well-being; all of which it framed socio-ecologically.

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