Funded by the European Union

Marine SABRES Deliverable 3.1

Review of the Literature on Social-Ecological Systems.

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DOCUMENT INFORMATION

	Date	Description			
		Responsible	Authors	Reviewed by	Approved by
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2	24/01/2023	WP3	Jonathan Atkins and Amanda Gregory	Gemma Smith	
3	21/02/2023	WP3	Gemma Smith	Michael Elliott	
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Abstract

This literature review explores existing Social-Ecological System (SES) frameworks, with the aim of identifying and recommending an approach for the Marine SABRES project to create a Simple SES. Through this systematic literature review, various SES frameworks were analysed using a Strengths, Weaknesses, Opportunities, and Threats (SWOT) approach, considering the specific objectives of Marine SABRES. Nine SES frameworks were reviewed: Ecocycle Framework, Ecosystem Services Framework, Integrated Ecosystem Assessment, Integrated Systems Analysis, Social-Ecological System Framework, Social-Ecological Action-Situation Framework, Sustainable Livelihoods Approach, Systems Analysis Framework, and Turner Vulnerability Framework. Following this study, the Integrated Systems Analysis (ISA), tailored with beneficial elements from existing frameworks and techniques from the systems discipline, was identified as the most suitable framework due to its comprehensive and inclusive approach, stakeholder integration, and communication utility across different operations levels. The Integrated Systems Analysis framework was recommended as the most suitable, with aspects of the Systems Analysis Framework also advised for incorporation. Relevant systems concepts such as Panarchy and variety engineering were reviewed to complement the Integrated Systems Analysis approach in operationalisation. An adapted Integrated Systems Analysis framework was proposed for use by the Demonstration Area case-studies, incorporating a Process and Information Management System (PIMS) and the DAPSI(W)R(M) problem structuring method at the heart of the framework. This adapted approach aims to provide a simple yet holistic methodology for understanding and managing marine social-ecological systems.

Introduction

This document reviews the literature on Social-Ecological Systems (SESs). The term Social-Ecological System (SES) was first coined by Ratzlaff in the 1970s (Colding, 2019) and first defined by Cherkasskii in the 1980s as a system ‘consisting of two interacting subsystems: the biological (epidemiological ecosystem) and the social (social and economic conditions of life of the society) subsystems, where the biological subsystem plays the role of the governed object and the social acts as the internal regulator of these interactions’ (Cherkasskii 1988:321). The concept first became a framework for the study of intertwined human and natural systems by Berkes and Folke (1998) and, since then, various SES frameworks have been developed. The SES approach to representing an area and ecosystem considers both ecological and social factors that may interact within a system. It takes the view that humans are part of the overall ecosystem, and that the SES is a holistic concept that manages the human influence and role within the bigger system (Knaps et al., 2022).

SES frameworks may be regarded as an important part of an ecosystem-based management (EBM), also known as the ecosystem approach, toolkit. EBM is a holistic approach to resource management and the control of human activities based on the best available scientific knowledge about an ecosystem and its dynamics (O’Higgins et al., 2020; Wienrich et al., 2022). Balancing both ecological elements and human well-being in the long-term maintenance of an ecosystem is required for sustainable resource management (Tam et al., 2017). This EBM approach uses data to identify influences critical to the health of ecosystems and promotes the management of these influences, thereby achieving sustainable use of ecosystem services and societal goods and benefits (Sandström et al., 2015; O’Hagan, 2020; Elliott, 2023). By recognising the interconnectedness between species and the ecosystem as a whole, this approach allows for long-term management of ecosystem health and functioning to sustain goods and services for current and future generations to use (Elliott, et al, 2017; O’Higgins et al., 2020).

In light of the above, it can be argued that developing and making available SES frameworks that are theoretically well-informed and fit for use in practice is essential for EBM and ultimately the sustainable provision of ecosystem services and societal goods and benefits. Hence, WP3 of the Marine SABRES project (see Appendix I for a summary) seeks not only to address the challenge of conceptual clarity set by Colding and Barthel (2019) but also to review of existing SES frameworks as the basis for further development. Outputs from previous projects are considered within this literature review especially given that SES frameworks have been used in a series of European projects to tackle marine and freshwater environmental management problems for over a decade. Notable previous projects include SPICOSA (FP6), ODEMM (FP7), KNOWSEAS (FP7), DEVOTES (FP7), CERES (H2020) and AQUACROSS (H2020); full names and further projects are detailed in Appendix 3. Within these projects, the multidisciplinary tools and approaches from the social sciences have been explored such as the social-ecological accounting framework (KNOWSEAS), the TAPAS smart and toolbox (TAPAS Project), and guidance on co-creation of ecosystem models and decision support tools (MAREFRAME). Furthermore, exploration of natural sciences, for example developing feasibility testing of solutions on ecosystems (TIDE INTERREG) and development of the use of bow-tie analysis framing of ecological issues (VECTORS, CERES) (Cormier et al.

2019). Building on the knowledge accrued in these previous projects, the Simple SES aims to incorporate user needs through co-design, to be informed by the priority components delivered from work package 2 of the project.

This study's literature review revealed there to be 9 relevant SES frameworks:

1. Ecocycle Framework
2. Ecosystem Services Framework
3. Integrated Ecosystem Assessment
4. Integrated Systems Analysis (DAPSI(W)R(M))
5. Socio-Ecological System Framework
6. Socio-Ecological Action-Situation Framework
7. Sustainable Livelihoods Approach
8. Systems Analysis Framework
9. Turner Vulnerability Framework

Criteria defined in the Marine SABRES project combined with an assessment of the Strengths, Weaknesses, Opportunities and Threats (SWOT) were used to evaluate each of the identified SES framework. In the light of this evaluation, it was revealed that some SES frameworks are aligned with the Marine SABRES project than others and may be seen as complementary with the strengths of one approach compensating for the weaknesses of another. Hence, the preferred approach to be chosen for use in the project, and the best parts/approaches for a composite SES should satisfy the requirements of the Marine SABRES project, including being robust and sufficiently flexible to incorporate the social and ecological components of each of the project's three Demonstration Areas (DAs). The preferred approach will then lead to guidance for its use at the DAs and include the functionality to be useful and useable by all end users, after field-testing and validation, in wider areas outside the project. In a further effort to address the revealed weaknesses of the proposed SES, consideration was given to how concepts, theories, and associated methodologies from the systems discipline might enhance SES frameworks, and their use in practice.

This review is divided into five sections:

A. Review of the literature on SES frameworks
    1. Definition of the SES concept
    2. Key SES definitions
    3. The origins of SES framework theory
    4. Literature review method and Identification of key SES frameworks
B. SES framework evaluation
    SES framework summary description and literature-based evaluation
    i. Ecocycle Framework (EF)
    ii. Ecosystem Services Framework (ESF)
    iii. Integrated Ecosystem Assessment (IEA)
    iv. Integrated Systems Analysis (ISA)
    v. Socio-Ecological System Framework (SESF)
    vi. Socio-Ecological Action-Situation Framework (SEAS)

      - *vii.* *Specification of evaluation approach and criteria*
      - *viii.* Sustainable Livelihoods Approach (SLA)
      - *ix.* Systems Analysis Framework (SAF)
      - *x.* Turner’s Vulnerability Framework (VF)
      - *xi.* Evaluation summary
- C. Identification of the SES framework(s) most fit for the purposes of the Marine SABRES project
- D. Review of relevant concepts, theories, and associated methodologies from the systems discipline to enhance SES theory and practice.
    1. The twelve principles of the Ecosystem Approach (CBD, 2000)
    2. Identification and summary review of systems concepts, theories, and methodologies relevant to the theory and practice of the twelve principles
    3. Integrating systems concepts, theories and methodologies identified as most fit for the purposes of the Marine SABRES project.
- E. Presenting the Simple SES Approach

PART A Review of the literature on SES frameworks

Definition of the SES concept, key definitions, and the origins of SES framework development

Colding and Barthel (2019) explored the 20-year evolution of the SES concept and associated frameworks. Their systematic review of the literature revealed a significant body of work, although 61% of the papers analysed did not provide a definition of the term social-ecological system. Having revealed a lack of conceptual clarity, Colding and Barthel urged SES scholars to be 'more meticulous in making explicit what they mean by a social-ecological system when conducting SES research'. Colding & Barthel, (2019) also identified three SES frameworks that 'authors seem to be most commonly inspired by', these being Berkes and Folke (1998), Ostrom (2007), and Anderies (2004).

The terms social-ecological and socio-ecological system (SES) are often used interchangeably but Berkes (2017) adheres to the former because "social-ecological emphasizes that the two subsystems are equally important, whereas socio- is a modifier, implying a less than equal status of the social subsystem". In recognition of this distinction, Colding and Barthel (2019) focussed their exploration on social-ecological systems through a two-phase systematic review of the Scopus database from the Stockholm University Library undertaken on 20 August 2017:

> In the first phase, the words "social-ecological systems" was entered in all fields in order to retrieve articles and other documents dealing with SES, such as proceeding papers, books, book chapters, or doctoral theses, and searched in the options "all text," "article title," "abstract," and "keywords." From this search, 12,990 documents were retrieved and analysed regarding publication date, document type, subject area, and author name. As the Scopus database does not distinguish between the term social-ecological systems cited in the reference lists and the main text of publications, a further study was undertaken which only included the title, abstract, and/or as a keyword.
>
> In the second phase, the words "social-ecological systems" was entered in all fields and searched in the options title, abstract, and keywords, and limited to journal articles. This resulted in a sample of 1598 publications. Fifty of these were selected using a random number generator (i.e., http://gallerit.se/slumptal/). Out of the 50 articles, one was dropped because the main text was in Chinese. The 49 remaining articles were assessed for: (1) number and proportion of articles that define SES; (2) definitions of SES employed, and (3) main sources of inspiration.

Whilst the second phase of the Colding and Barthel (2019) analysis revealed that 61% of articles did not contain a definition of SES, the review of those articles that did contain a definition revealed that the concept 'social-ecological system' had been defined in various ways (presented here chronologically):

> "an ecological system intricately linked with and affected by one or more social systems. An ecological system can loosely be defined as an interdependent system of

> organisms or biological units. “Social” simply means “tending to form cooperative and interdependent relationships with others of one’s kinds.” (Anderies et al. 2004)
>
> “a system that includes societal (human) and ecological (biophysical) subsystems in mutual interactions” (Harrington et al. 2010)
>
> “a system of people and nature” (Thomas et al. 2012)
>
> a system that “includes the entities of common-pool resource, resource users, public infrastructure, infrastructure providers, institutional rules, external environment and the links between these entities” (Özerol 2013)
>
> a system “where social and ecological systems are mutually dependent” (Fidel et al. 2014)
>
> “complex adaptive systems with key characteristics such as: (1) integrated bio—geo-physical and socio-cultural processes, (2) self-organization, (3) nonlinear and unpredictable dynamics, (4) feedback between social and ecological processes, (5) changing behaviour in space (spatial thresholds) and time (time thresholds), (6) legacy behavioural effects with outcomes at very different time scales, (7) emergent properties, and (8) the impossibility to extrapolate the information from one SES to another” (Delgado-Serrano et al. 2015).
>
> “interdependent and linked systems of people and nature that are nested across scales” (Bouamrane 2016)

The present study follows the Glaser (2012) definition: “A social-ecological system consists of a bio-geo-physical units and its associated social actors and institutions. Social-ecological systems are complex and adaptive and delimited by spatial or functional boundaries surrounding particular ecosystems and their problem context.” This is an appropriate definition as it addresses the interaction between ecological and societal elements, and recognises the complexity of the system together with how spatial and functional boundaries may need to be addressed in applying an SES. Other definitions as detailed in the work of Colding and Barthel (2019), were not as aligned with the Marine SABRES project as the Glaser (2012) definition as they did not address the elements of a SES, how they interact and the consideration of spatial and functional boundaries in a clear manner.

Key definitions

Other key definitions are essential to provide clarity of terminology used in the context of the Marine SABRES project.

‘Simple’

The MarineSABRES project was charged with creating a ‘Simple’ SES, and hence it is appropriate to consider this term in the domain of systems thinking. Simple refers to the ‘minimum necessary variety’ (Beer, 1984) which, when translated for the project, is regarded as being useable in the DAs through the minimum complexity necessary to make informed decisions. Collins (2023), for further clarity, suggests that the definition of the term ‘simple’ (sensu Marine SABRES) varies depending on the application: possibly as: *“not complicated, therefore easy to understand”;* when used to describe people or objects, it is defined as: *“having all the basic or necessary things required but nothing extra”, or*, when describing a task, defined as *“easy to do”.* Therefore, it is proposed that in the present context, the simplicity of an SES can be defined as:

“*Comprising those basic elements necessary to achieve the objectives in an easily conducted and understood manner through the minimum complexity necessary.” (Collins, 2023; Beer, 1984)*

Such a definition can then be used to interrogate and illustrate methods of creating and achieving a Simple SES. In particular, it is emphasised that there is the need to create easily conducted and understood approach by analysing recent approaches (Elliott et al., 2017b). An alternative explanation of simple that may be applicable within the Marine SABRES DAs is that it relates to an area with fewer interactions, i.e. fewer activities, i.e. a simple area.

‘System’

A universal definition of a system is yet to be agreed upon by the systems science community, however, the evolution of the term is valuable in the SES context. Traditional methods of understanding a system are rooted in reductionism; where individual parts are identified and studied to make up a whole (the system) (Vollmer, 1984). Reductionism is the assumption of understanding of the whole through examination of individual parts (Vollmer, 1984; Jackson, 2019). However, a system is not defined by the component parts, but rather by the whole, including the networks of connections between the parts (Jackson, 2019). The interconnectedness of the parts within a whole gives rise to the sustainable composition and viability of the (self)organised parts as a whole. The function of boundaries to be established is necessary within the scope of an SES and will need to be defined on a spatial/temporal scale with regard to the study sites (Demonstration Areas). However, the consideration of a larger system and environment occurring outside of the system requires to be acknowledged as well as the smaller parts within the system. This is appropriately described as a nested hierarchy (Beer, 1984).

In particular, processes and structures in ecological and societal complexity can be regarded as a hierarchical set of ‘black boxes’ creating levels of organisation (Figure 1). While each level in the hierarchy will have both inputs and outputs which may be known, and we may know of the linkages and processes within each level in the hierarchy, it is likely that our understanding may not extend to processes within such a level, hence the term ‘a black box’ (Odum, 1987). By observing the input-output relationship for any component (box), it may be possible to predict the structure and functioning of the system without understanding the internal behaviour of each part of the system.

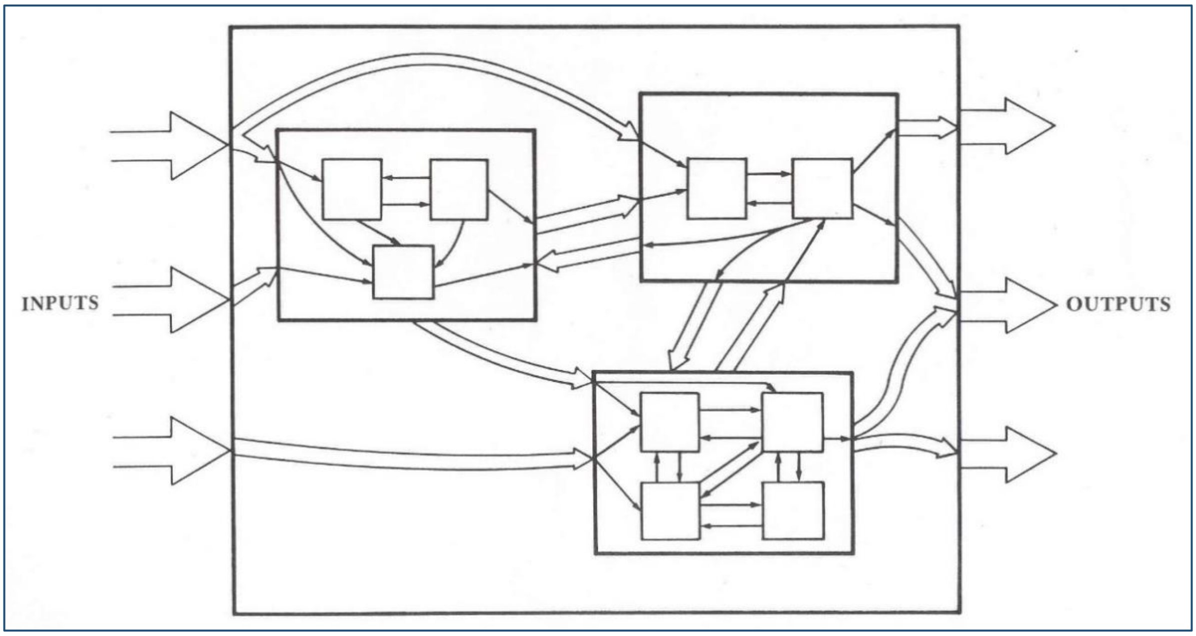


Figure 1: Processes and structures in a hierarchical system of organisation of ecological and societal complexity, e.g. as shown in a 3-level hierarchy (Odum, 1987).

Hence, for the purpose of this study, a system is a whole, encompassing interconnected elements which are networks of interactions, which together work to create allow the achievement of a common goal or purpose (Jackson, 2019; Elliott et al., 2020b). It may consist of processes, principles, mechanisms, or other components that are organized and arranged in a specific way. A process, on the other hand, by definition is a series of steps or actions that are taken to achieve a specific result (Luhmann, 2006). Further terms relevant to this literature review are presented in table 1.

Table 1: Definitions for terms related to SES used in the current review.

Term	Definition
Framework	Frameworks are described as an organisational and prescriptive tool to identify and order elements and relationships between them (Ostrom, 2011; Elliott et al., 2020b).
Governance	The structures and processes in that people in societies make decisions and share power, create the conditions for ordered rule and collective power (Folke et al., 2005); more specifically the sum of the policies, politics, administration and legislation required in adaptive environmental management (Cormier et al., 2022).
Holism	Holism in this context refers to systems and their properties should be viewed as interconnected entities, not merely as a collection of individual parts (Capra, 1996).
Simple	"Comprising those basic elements necessary to achieve the objectives in an easily conducted and understood manner through the minimum complexity necessary." (Collins 2023; Beer, 1984).

Social-ecological system	“A social-ecological system consists of a bio-geo-physical unit and its associated social actors and institutions. Social-ecological systems are complex and adaptive and delimited by spatial or functional boundaries surrounding particular ecosystems and their problem context.” (Glaser et al., 2012)
System	A system is a whole, encompassing interconnected elements which are networks of interactions, which together work to create achievement of a common goal or purpose (Jackson, 2019; Elliott et al., 2020b).
Systems Thinking	Reynolds and Holwell (2020) describe ‘systems’ as being constructs for engaging with and improving situations of real-world complexity”, hence, in this context systems thinking can refer to any approach that adopts a holistic approach to analysis (Reynolds and Holwell, 2020).

SES theory

Colding and Barthel (2019) found three major sources of inspiration for work on SES frameworks:

Firstly, Berkes and Folke (e.g. Berkes and Folke1998, Berkes et al. 2003) provided an analytical structure for studying the local resource management systems for natural, nested ecosystems, and management practices embedded in nested institutions (see Fig. 2). The critical distinction was that the linkage between the ecosystem and management practice was provided by ecological knowledge and understanding of the local ecosystem of the resource users, or the resource base on which they depended because, without this, the likelihood for sustainable use was assumed to be severely reduced (Folke and Berkes 1998).

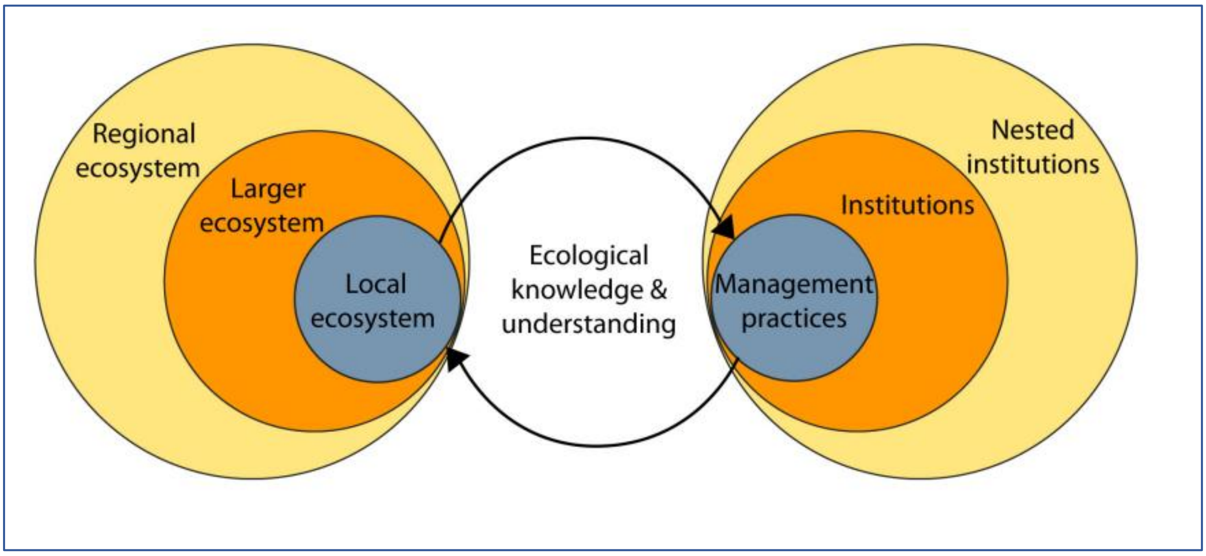


Figure 2: A conceptual framework for the analysis of linked social-ecological systems (From Colding and Barthel, 2019).

Secondly, Anderies et al. (2004) developed a conceptual model for examining robustness and resilience based on the interaction of the designed and self-organizing components of a SES (see Fig. 3). The model examines the key interactions within an SES and considers these in line with robustness (Anderies et al., 2004).

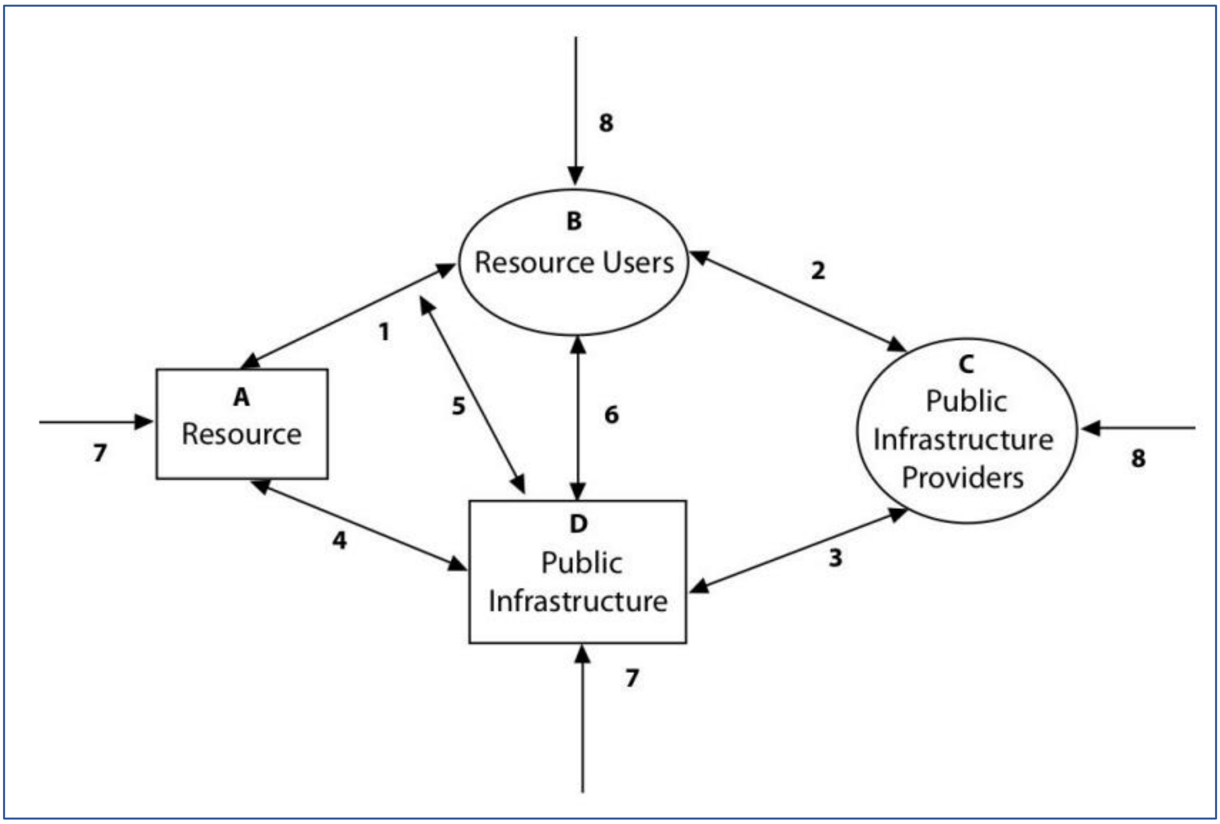


Figure 3: Basic feature of a social-ecological system model. From Colding and Barthel (2019). The resource (A) is used by resource users (B) and public infrastructure providers (C). Public infrastructure (D) refers to physical capital (i.e., any engineered works such as dikes, irrigation canals, etc.) and social capital (i.e., the rules used by those governing, managing, and using the system including monitoring and enforcement of these rules). In the examination of robustness, external disturbance (Arrow 7) can be addressed (i.e., biophysical disruptions such as floods, earthquakes, landslides, and climate change) as well as socioeconomic changes (Arrow 8), e.g., population increases, economic and major political changes that impact on the resource users (B) and the public infrastructure providers (C). Arrow numbers in the figure signify interaction as follows: (1) between resource and resource users; (2) between users and public infrastructure providers; (3) between infrastructure providers and public infrastructure; (4) between public infrastructure and resource; (5) between public infrastructure and resource dynamics; (6) between resource users and public infrastructure; (7) external forces on resource and infrastructure; (8) external forces on social actors. Source: Anderies et al. (2004).

Thirdly, Ostrom (2007, 2009) challenged "the presumption that scholars can make simple, predictive models of social-ecological systems (SESs) and deduce universal solutions, panaceas, to problems of overuse or destruction of resources". She embraced a more serious study of complex, multivariable resource management systems clarifying the structure of an SES in order to understand how a particular solution may support or undermine management outcomes. In opposition to the preference for simple solutions to complex governance problems, Ostrom (2007, 2009) argued for embracing complexity and for developing better diagnostic methods. Such a view was reinforced by Levin et al. (2012) in arguing that simple linear and reductionist dynamics can give a misleading representation of how social-ecological systems work. In recognising the multitude of variables in studies of SESs, Ostrom (2007, 2009) created a multi-tier framework for structuring and organizing these variables (see Fig. 4) that enabled researchers to organize variables in a nested fashion, to recognize and better understand the effects of larger socioeconomic, political, and ecological settings.

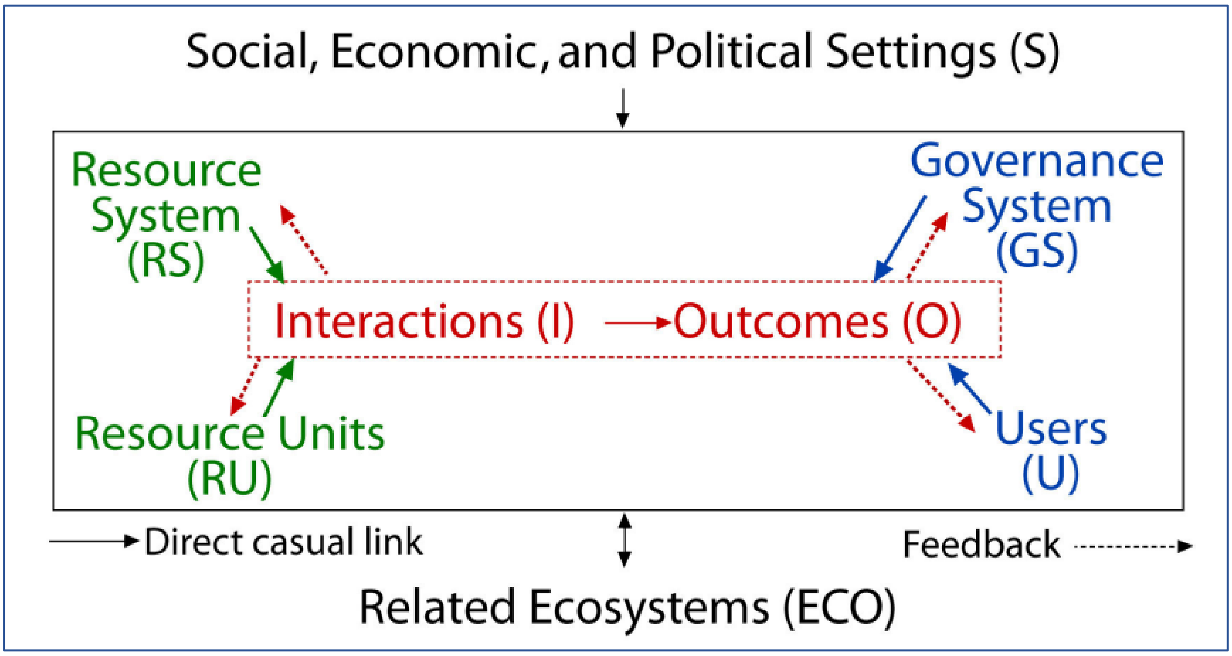


Figure 4: A general framework for the highest-tier variables that require to be analysed when examining linked social-ecological systems. From Colding and Barthel (2019) based on and modified from Ostrom (2007).

The broad historic overview of SES given by Colding and Barthel (2019) provides a basis for the work to be undertaken for Marine SABRES but more recent studies also need to be considered. Also, given the specific focus and aims of MarineSABRES, the adoption of a narrower perspective (in terms of the search terms employed and literature reviewed) is required in relation to the project goals.

Literature review method and Identification of key SES frameworks

Previous reviews of the SES literature surrounding concepts and frameworks are present in papers such as Binder (2013), Barthel and Colding (2019), and Refulio-Coronado (2021). Also, given the specific focus and aims of Marine SABRES, a narrower perspective (in terms of the search terms employed and literature reviewed) is required. This study is also informed by the literature review methodology used in previous studies (Binder, 2013;Barthel and Colding, 2019;Refulio-Coronado, 2021). The use of Scopus (REFM< REF) was undertaken together with the Web of Science (BIOSIS) and Academic Search Premier.

The following keywords were entered into all three search engines to identify potential papers which looked at SES approaches, models, frameworks or methods: *("social-ecological*" OR "socio-ecological*" OR socioecological* OR "human-environment*") AND (marine OR ocean* OR coast* OR estuar* OR* *environment*) AND TI (model* OR framework* OR approach* OR method*) AND (manag* OR "Decision-Making" OR "Decision Making")*

This search returned on each search engine:

Scopus: 1,411 document results

Web of Science: 1,573 document results

Academic Search Premier: 1,713 document results

After compilation (a total of 4697) and duplicates were removed, 1570 papers remained for a title and abstract screening. This number was then reduced by screening the titles and abstracts for papers relating to the use of SES frameworks within coastal and marine managment. Following this stage, the remaining 67 papers were screened against the inclusion criteria.

In screening the title and abstract, papers that included decision support tools (DSTs) and modelling were removed due to the scope of WP3 regarding the creation of the Simple SES (Appendix 1), as WP5 and WP6 aimed to consider DSTs and scenario modelling. Moreover, papers that did not detail the outcomes of a process or method to conduct the framework were removed.

The primary criterion for deciding which frameworks to include in the paper was if they incorporate social and ecological components and how these interact. Moreover, frameworks were included that provided key concepts for the operationalisation of the SES. Also, the frameworks had to be general in the sense that they were explicitly designed for use by a community of researchers larger than a specific project in one sector (Binder et al., 2013). A further criterion, to select frameworks that were primarily conceptual, considered how the desired framework system is examined and understood. Therefore this disregarded existing procedural frameworks, such as Integrated Coastal Zone Management (ICZM), Integrated Water Resources Management (IWRM), and Strategic Environmental Impact Assessment (SEIA).

56 papers were remaining following the screening of the papers against the inclusion and exclusion criteria (Appendix 4). The resulting papers were directly from the literature results, except for the Ecocycle framework that was identified through citation of Berkes (2015) and Kharrazi, et al. (2016).

These frameworks included:

- Ecocycle Framework
- Ecosystem Service Framework
- Integrated Ecosystem Assessment
- Integrated Systems Analysis (DAPSI(W)R(M))
- Socio-Ecological System framework
- Socio-Ecological Action-Situation Framework
- Sustainable Livelihoods Approach
- Systems Analysis Framework
- Turner Vulnerability Framework

SES evaluation approach and criteria

A SWOT analysis together with the aims of the Marine SABRES project, which align with goals of sustainable and successful marine management, were used to evaluate the SES frameworks identified in the previous section. A SWOT analysis was used to evaluate Strengths, Weaknesses, Threats, and Opportunities in the various frameworks (see Table. 1) by considering previous analyses and applications of the evaluated frameworks relating to the Marine SABRES goals. Hence, this literature review highlights the appropriate systems approach for promoting biodiversity resistance to and resilience from environmental change and ecosystem sustainability within the marine environment.

Table 1: The SWOT approach for analysing SES frameworks.

	Positive	Negative
Internal	**Strengths**	**Weakness**
	• What are the merits of the SES? ○ Do these merits best apply to the goals of sustainable and successful marine management (included in the project goals are found in Appendix 2)? • Does the framework have a holistic and integrated approach? • What are the Strengths of the SES framework to achieve: ○ Well-informed decision-making. ○ Consideration of both conservation and protection of biodiversity and the delivery of societal goods • Are stakeholders directed to be engaged appropriately in the approach? • Are stakeholders directed to be engaged appropriately in the approach?	• What areas of the framework need improvement? • Does the framework gather sufficient information? ○ Can this approach be applied simply to defined marine areas? • Are there barriers present within the framework to achieve a holistic and integrated approach? • Are there aspects of the goal this framework does not achieve? ○ Do other frameworks do these things better? • Is there any bias to the social or ecological expected outcomes that negatively impact the application to balance the two competing interests?
External	**Opportunities**	**Threats**
	• What Opportunities exist within the larger sphere that might support application of the framework to help achieve these goals?	• What threats exist within the larger sphere that might undermine the application of the framework to help achieve these goals? • Are there other factors for the SES to consider?

To further ensure that the SES framework identified through the evaluation process is appropriate for the goals of Marine SABRES, a list of desirable characteristics (see Table 2) was derived from the goals and objectives specified in the project proposal; this was used together with the SWOT analysis in the evaluation of the identified SES frameworks. The desired characteristics were a binary assessment of whether or not the framework satisfied the descriptive question; for example, to consider whether an approach possessed fundamentals such as guidance to consult stakeholders throughout the process. In that case, the question of 'Is the framework based on an inclusive approach to the engagement of stakeholders?' would have been awarded this characteristic.

Table 2: Desired Characteristics of SES frameworks as per the Marine SABRES project goals and project outlines.

Characteristic	Description
Simple in application	Is the framework and approach clear and concise, and does it include a prescribed set of application steps?
Resilience and adaptive features	Is the framework capable of adapting and evolving according to changing circumstances?
Unbiased	Can the framework able to balance the consideration and inclusion of natural and social factors?
Cross-scale	Is the framework able to capture evolving cross-scale dynamics?
Holistic	Is the framework critical of all types of decisions regarding boundaries for inclusion/exclusion and does it include critical justification for where and how boundaries are being drawn?
Learning from implementation in practice	Is the framework responsive to local conditions but also sufficiently rigorous to enable cross-application comparison and learning?
Stakeholder inclusive	Is the framework based on an inclusive approach to the engagement of stakeholders?
Applied in the marine environment	Has the framework been applied to marine circumstances previously?

PART B: SES Frameworks and Evaluations

Ecocycle Framework (EF)

This framework can be found in the work of Holling (1987) and further explored in Hurst & Zimmerman (1994). The Ecocycle Framework aims to analyse different activities and relationships within a system to identify obstacles and opportunities for progress. The four phases, - exploitation, conservation, creative destruction, and renewal (Figure 5), - characterise how the system operates within its wider environment (Holling, 1994). The Ecocycle differs from regular life cycles through the 'back loop' illustrated through the dashed line in Figure 5, as life cycles do not possess regenerative features. The x-axis illustrates the amount of potential capital (e.g. economical, ecological or other types of capital dependent on the context) accumulated and retained by the system, this sum consisting of the possible outcomes multiplied by the value of the outcomes. The potential can be positive or negative and hence is heavily affected by outcomes. The y-axis reflects the connectedness and organisation of the system (Hurst & Zimmerman, 1994). Connectedness and organisation represent properties of density, connectivity, and hierarchy of networks; for example, a highly connected system would contain elements which would affect each other directly and continuously, rather than eventually, indirectly and occasionally (Hurst & Zimmerman, 1994).

Under this framework, a complex system is composed of smaller systems. Hence, the overall cycle will emerge in individual changes in the system elements, their interactions, and exchanges with the external environment. Complex systems possess two main interacting characteristics in the Ecocycle framework, these being (1) multiple agents and dispersed control and (2) perpetual novelty. Perpetual novelty follows dispersed control as the system will contain many niches, which promote further niches, so the possibility of balancing elements (the equilibrium) in a complex system is not possible (Hurst & Zimmerman, 1994).

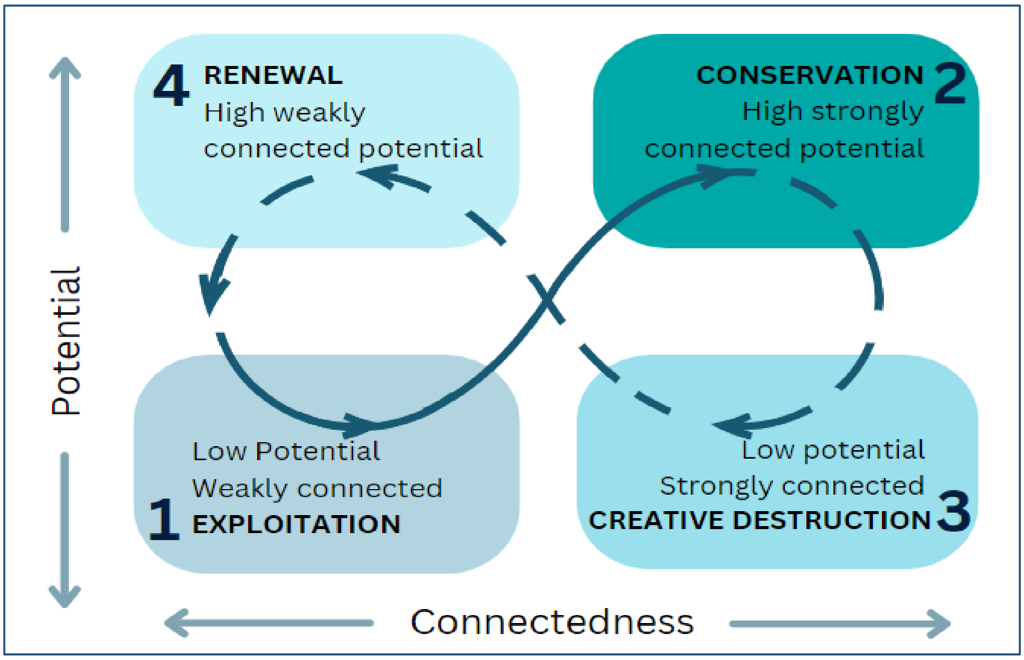


Figure 5: The Ecocycle framework dimensions of phases within the cycle, (redrawn from Hurst & Zimmerman, 1994).

Phase 1: Exploitation

Hurst and Zimmerman (1994) describe exploitation as motion to act with effect, this was distinguished from the negative connotation with the word, which is commonly associated within the context of the environment. The exploitation phase refers to the systems processes of planning or new opportunity that promotes rapid colonisation/ progression regarding a resource (Holling, 1994). For example, in an ecological context, if there was opportunity in an unexploited marine area for a particular resource, this would warrant exploitation.

Phase 2: Conservation

Conservation within phase 2 incorporates processes of improving the system's capacities to perform. The Ecocycle framework emphasises the system's ability to understand the effects of turmoil (for example, recessions, state changes and revolutions) through systemic mapping explanations (Hurst & Zimmerman, 1994). For example, seagrass beds expand rapidly at first when colonising new areas (phase 1), but eventually slow down as they fill in all available space. The seagrass then functions to maintain meadow density, reproduce vegetatively, and store resources in rhizomes to consolidate gains, hence the conservation phase.

The use of Pearl-Verhulst logistics relationships (Miner, 1933) is used to demonstrate the difference between phase one and phase two through understanding ecological r and k strategies. The r strategy refers to high turnover, short-lived, smaller and high reproductive species, whereas k-strategists are long-lived, slow growing, often mid- to larger sized and have lower reproductive output. The rule of this logistics state 'where the rate of growth of the population (X) over time (t) is a function of both natural reproductive rates (r) in the population and carrying capacity (K) of the environment.'

Table 3: The r-selection and k-selection equation for change over time (Hurst & Zimmerman, 1994).

$$\frac{DX}{dt} = \frac{rX\,(K-X)}{K}$$

Hence, when the population and carrying capacity (K) is large in comparison to the growth rate in population (x), the growth rates will be closer to the natural reproductive rates. Further, as the population and carrying capacity grow, the capacity of the environment becomes more of a growth-constraining factor until growth of the population is equal to the carrying capacity, when no more growth is possible (Hurst & Zimmerman, 1994). This relationship generates the S-shape between Phase one and two (Figure 5). Hence the differing r and k strategies in growing a system (r-strategy / Phase 1) and improving the system's ability to perform (k-strategy / Phase 2).

Phase 3: Creative destruction

This phase regards the partial destruction of the system to allow for renewal; Hurst and Zimmerman (1994) argue that this is where the most potential is released in natural systems. This stage's applicability to negatively impact a system's strong connectedness and rigidity (if the system has low variety and lacks resilience) makes the system's strengths a vulnerability. Hence, a threat for which a system is unprepared and unable to adapt will threaten the viability of the system. Following the seagrass example, after a period of stability and consolidation, the seagrass ecosystem could be negatively impacted by a severe storm which generated disturbances that opened up new niches, increased diversity, and allowed reorganisation into a layout more resilient to high temperatures. The result was renewal into a new ecological state, although excessive destruction could have threatened ecosystem viability.

Phase 4: Renewal / mobilisation

The final phase considers how a system changes following creative destruction/turmoil. The paradox of creative destruction accounts for abrupt changes within a system which may be detrimental to some elements, whilst simultaneously providing opportunity for growth in other elements. For example, if the creative destruction of seagrass was successful, the increased diversity in the layout of the seagrass may have opened up access to resources that were previously monopolised in the consolidated meadow. This enables new seagrass species and associated fauna to establish and grow and the renewed ecosystem emerged with greater resilience and adaptability to persist under the new environmental conditions. However, if the adaptive and resilient features are not present, the disturbances may exceed resilience thresholds or tipping points, causing widespread seagrass die-offs. Hence, the renewal phase requires destruction as a prospect to provide an opportunity to destroy monopolising structures on the common resources.

The Adaptive theory underpinning the Ecocycle framework:

As a sustainability-based framework, the underpinning adaption and resilience theory can be applied to different scales and the linkages between them. Understanding the resilience, i.e. the ability and capacity to anticipate and recover from shocks, as a function of adaption can instigate change over time (Biggs et al., 2021). The complementing framework within which the EF can be embedded is known as Panarchy, which connects hierarchies of nested adaptive cycles (each of which can be characterised as an EF) (Garmestani et al., 2009). The time scales of change for the adaptive cycles in relation to the bigger scales show that at the top levels, where change occurs on a larger scale at a slower rate, memory of experience of the systems cycle will instigate this change and adaption. In contrast, on smaller scales, the fast and smaller changes are described as actions of revolt to a system (Gunderson & Holling, 2002). The Panarchy framework (Figure 6) explains how system resilience can promote adaptation and change over time, emphasising how changes in a system at one level are affected by the larger-scale systems within which they are embedded, and the smaller-scale systems embedded within them. Panarchy describes the existence of systems in a nested and interconnected hierarchy accounting for the various stages as detailed in the Ecocycle (Cosens et al., 2018).

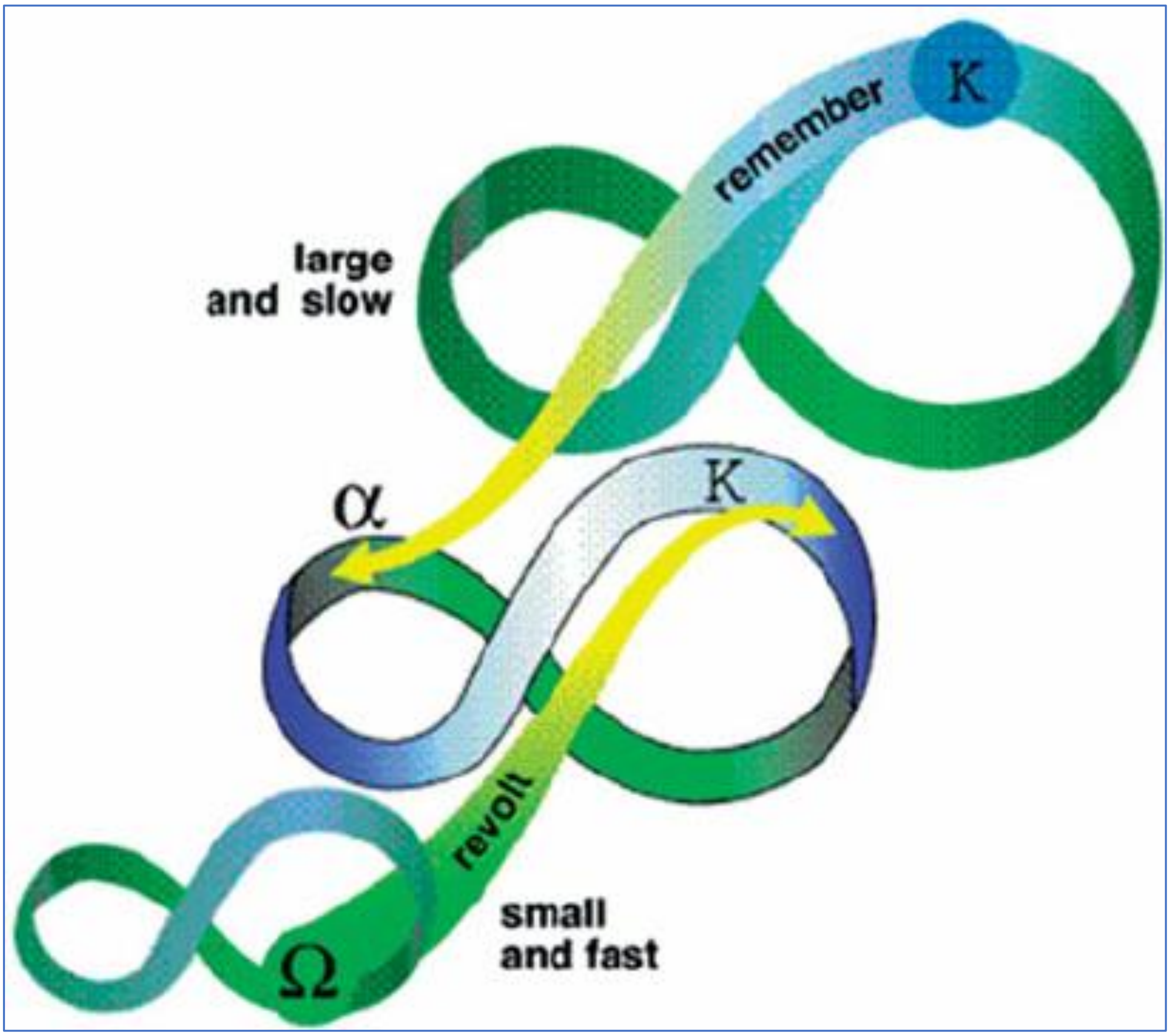


Figure 6: Panarchy scale, (taken from Randle. et, al. 2014).

SWOT analysis of the Ecocycle framework:

Strengths:

- The Ecocycle framework is a comprehensive tool that helps organisations understand the flow of resources through their operations and the impact of their decisions and actions on the environment.
- The assumption of decline being inevitable can allow management actors to effectively map the system and strategically introduce creative destruction that improves the existing capacity of variety within the system (Holling, 1994).
- It can be used to identify opportunities for resource conservation, waste reduction, and sustainable business practices (Crossan and Hurst, 2006).
- It can be applied to a wide range of industries and sectors, including marine management (Gunderson & Holling, 2002).
- The ability to consider scales of application is a predominant strength within this approach, the use of Panarchy addresses where different scales and disciplines intersect

and how change on the different scales can occur and be orchestrated (Gunderson & Holling, 2002).

Weaknesses:

- There is a paradox in success of operations that reduce the ability to change and stay adaptable in its wider environment (Holling, 1994).
    - For actors within a system – this will create barriers for consistent management actions and may be difficult for which actors can comply. The Ecocycle framework can be complex and may require specialised knowledge and skills to be used effectively (Rocha, et al. 2022), hence being a barrier for operationalising the approach.
- The framework may not consider all potential environmental impacts and may not capture the full range of stakeholders and their interests; the lack of direction to include stakeholders in the SES is indicative of this weakness.

Opportunities:

- The ability to engineer variety strategically may provide resilient structures in facing new external problems.
- The Ecocycle framework can help organisations demonstrate their commitment to environmental sustainability and meet regulatory requirements related to marine management (Hurst & Zimmerman, 1994).
- It can provide a structured approach upon cross-scale levels for identifying and addressing environmental impacts in marine environments (Rocha, et al. 2022).
- It can support interdisciplinary research and collaboration between the natural and social sciences (von Wehrden et al., 2018).
- It can help to inform policies and decision-making at local, national, and global levels (Seddon et al., 2016).

Threats:

- The paradox in the success of operations that reduce the ability to change and stay adaptable in its wider environment and against exogenic pressures (Hurst & Zimmerman, 1994).
- The Ecocycle framework may not be suitable for all types of operations or industries and may not provide a complete picture of the environmental impacts of an organisation's activities, such as determining focal issues and non-expertise teams.
- It may face resistance from stakeholders who have vested interests in maintaining the status quo, or who may see the framework as a threat to their interests (Schlüter et al., 2019).
- The impacts of climate change on marine ecosystems could offer additional unforeseen impacts that the framework may not be equipped to tackle.

Overall, the Ecocycle framework can be a valuable tool for marine management, although characteristics such as stakeholder inclusive and simple in application are lacking in the approach.

Ecosystem Services Framework (ESF).

The ESF evolved from the Ecosystem Approach, detailed in the Convention on Biological Diversity (STOCK, 1992), and it analyses and integrates information of the benefits of Ecosystem Services (ES) into management actions (Turner & Daily, 2007). ES originated within the natural and social sciences and are largely founded upon system science through acknowledging the role they play within the ecosystem and what value this holds. ES were developed to protect and acknowledge ecosystem functions through assigning value to basic ecological structures (Binder et al., 2013; Groot et al., 2002). The aim of this approach is to identify and provide win-win outcomes through protection of ecosystems so they can provide services, goods and benefits, and to identify win-lose and lose-lose outcomes as a result of ES management. This framework adopts a complete ecosystem services-based decision support process which includes mapping and valuing various ES provisions (Tallis et al., 2008). It encompasses a process that initially identifies ecosystem service provisions and the social, economic, and politico-cultural contexts in relation to the ecosystem (Binder et al., 2013).

There is no single, fixed method for implementing the ESF, as it aims to be applicable within a variety of contexts and at different scales. While Turner and Daily (2007) visualised the ESF process, as illustrated in figure 7, there are five steps usually followed when using the ecosystem services framework:

1. **Identification** of the ES being provided by a particular area. This may involve conducting a literature review, gathering secondary data and local knowledge, and carrying out field assessments for primary data.
2. **Quantification** of the ES that is being provided. This may involve using models, data, and other tools to estimate the extent to which each service is being delivered (Tallis et al., 2008).
3. Monetary **Valuation** of the ES that is providing goods and benefits. This may involve using economic techniques to estimate the monetary value of each service, or using other methods, such as the willingness-to-pay approach or the replacement cost approach (Turner & Daily, 2007). During valuation, the amount of physical, chemical and material (of the ecological elements) may be regarded in economic values; this can translate to the final ecosystem goods and services (FEGS). FEGS are the biophysical quality or feature which requires minimal translation for relevance when looking at the impact on human welfare (O'Higgins et al., 2020).
4. **Develop strategies** for conserving and enhancing the ES being provided in the area. This may involve identifying the drivers of change that are impacting the ecosystem and the services it provides and developing interventions to address those drivers (Turner & Schaafsma, 2015).
5. **Implementation and monitoring** of the strategies that have been developed. This may involve working with local communities and other stakeholders to put the strategies into action and tracking their effectiveness over time (Turner & Schaafsma, 2015).

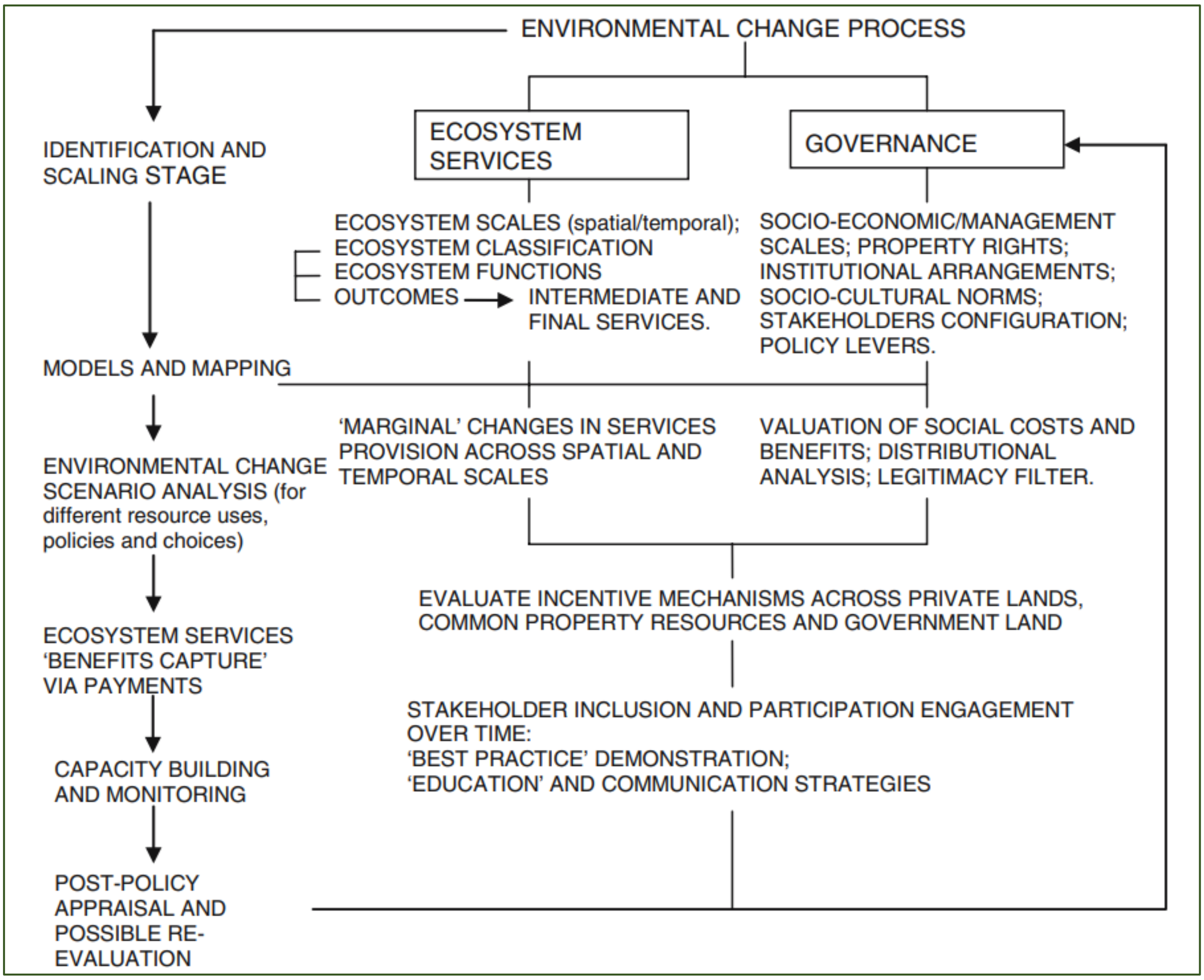


Figure 7: ESF approach diagram detailing the broad stages and their features, (taken from Turner & Daily, 2007).

Overall, the ESF is a flexible and broad approach that can be tailored to the specific needs and context of each application. The framework emphasises the long-term importance of ecosystem health and the roles these systems play in sustainable human development and wellbeing (Turner & Daily, 2007).

SWOT analysis of the ESF:

Strengths:

- The ESF recognises the interconnectedness and complexity of ecological systems, and the multiple functions and values of ecosystems.
- It provides a holistic and integrated approach to environmental management and conservation.
- It emphasises the importance of involving all stakeholders in decision-making, and supports the integration of economic, social, and environmental considerations.
- It can support interdisciplinary research and collaboration between the natural and social sciences (von Wehrden et al., 2018).
- It can help to inform policies and decision-making at local, national, and global levels (Seddon et al., 2016).

- The ESF described by Turner and Daily (2007) recognises that the maintenance of biodiversity is both a final ecosystem goods and benefit and an intermediate service since biodiversity is a major component of ecosystem structure, processes and services and benefits outcomes (Turner & Daily, 2007). This aligns with the Marine SABRES goals and criteria well in biodiversity conservation and reversing biodiversity decline.

Weaknesses:

- The ESF is a broad and abstract concept, which can make it difficult to apply in practice. Previous work claims that the ambiguous language of the ESF highlights the need for greater methodological and terminological consistency within the approach (Bull et al., 2016).
- It may not always provide clear guidance on how to address specific environmental challenges and may require additional frameworks or tools to support implementation (Weitzman, 2019).
- The lack of a singular accepted approach to the ESF may hinder application in different areas to their understanding and opinion of how this is to be implemented (Weitzman, 2019).
- It may face resistance from stakeholders who have vested interests in maintaining the status quo, or who may see the framework as a threat to their interests (Schlüter et al., 2014). This offers threats to the effectiveness of the framework and could include competing interests and priorities among stakeholders.

Opportunities:

- The ESF can provide a valuable framework for addressing complex environmental challenges, such as climate change, biodiversity loss, and natural resource degradation (Turner & Schaafsma, 2015).
- It can support interdisciplinary research and collaboration between the natural and social sciences through the approach including ES valuation.
- It can help to inform policies and decision-making at local, national, and global levels (Seddon et al., 2016), together with the potential to promote alignment with existing policies (Bull et al., 2016).

Threats:

- It may be vulnerable to changing political and economic conditions, which could impact funding and support for research and implementation (Bull et al., 2016).
- It may face challenges in achieving widespread adoption and implementation, due to the complexity and abstract nature of the framework. The approach can be considered dated in that it includes both ecosystem services and goods/benefits within the term of ‘Ecosystem Services’ rather than the recent discussions that Ecosystem Services relate to the natural system whereas societal goods and benefits relate to the social system (Elliott 2023). Hence the lack of standardisation throughout the approach may hinder application within the wide sphere of marine EBM.

Integrated Ecosystem Assessment (IEA)

Integrated Ecosystem Assessment (IEA) is an approach that incorporates not only scientists and managers, but the other relevant stakeholders to integrate all components of an ecosystem. This is including human needs and activities as part of the ecosystem together with the biological and physical ecosystem components (Dickey-Collas, 2014). The approach, including society as part of the ecosystem, promotes decision-making to balance trade-offs and determine what is more likely to achieve the management desired goals, with consideration of both social and ecological components (Levin et al., 2009).

Initially developed by Levin (2009) and further developed and operationalised by the National Oceanic Administration Association (NOAA), an IEA aims to provide an efficient and transparent summary of the status of an ecosystem, the potential risks it faces and management strategies that could be introduced in response to those risks (Monaco et al., 2021; Spooner et al., 2021). Consisting of five main steps given in Figure 8 (Monaco et al., 2021), the IEA guides users to scope objectives and goals, develop relevant indicators, analyse the risk of activities to the ecosystem through changes in those indicators, assess the overall management strategy and ecosystem, and evaluate and monitor the developing process (Levin et al., 2009). These five steps are further detailed below.

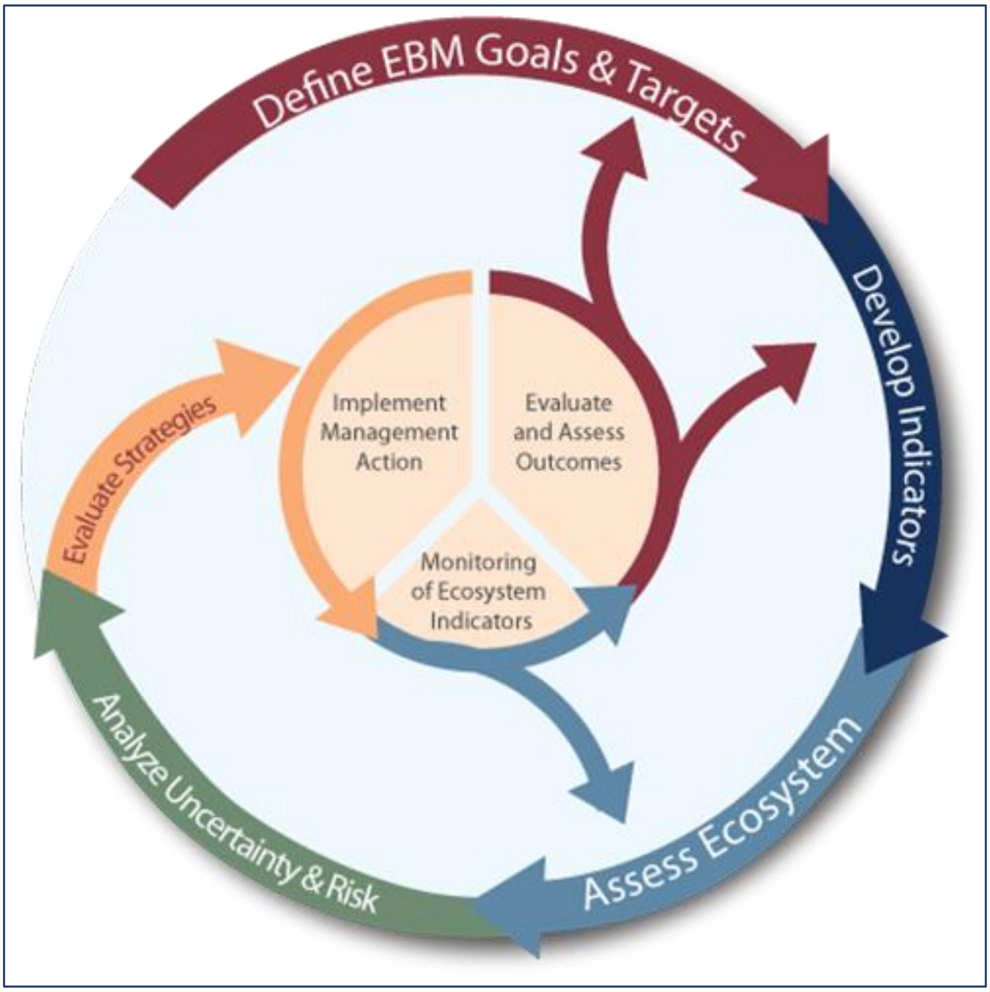


Figure 8: The IEA loop of steps in the framework a feedback loops illustrated, (taken from Monaco et al., 2021).

Step 1: Scoping

In this initial stage, stakeholders are consulted to identify the boundary of the system and define a healthy ecosystem for the area. The interrogation of an ecosystem can often identify subsystems which are the components most at risk of threats to the health of the ecosystem (Monaco et al., 2021). These sub-systems can have the role of a key indicator at later stages in the process as a recognised important sub-system which indicates if goals and objectives are being achieved (Szymkowiak & Kasperski, 2020; Monaco et al., 2021). The approach encourages the inclusion of relevant managers, scientists, and stakeholders throughout the whole process but emphases the importance of using stakeholders in both the scoping and indicator development, as these complement understanding of the SES, particularly with regard to social elements and linkages that exist between the local community and the marine ecosystem (Spooner et al., 2021).

Step 2: Indicator development

This step identifies and validates the state of the ecosystems baseline conditions regarding key indicators outlined in the scoping stage (Monaco et al., 2021). The approach is mainly quantitative at this stage as data gathered by stakeholder perceptions are typically language-based. Co-production of the indicators can be illustrated through previous application of IEA. Szymkowiak and Kasperski (2020) consulted stakeholders using scientific publications on the subsystem elements to incorporate key biological, physical, social, and economic connections in conceptual models; workshops were held with relevant stakeholders to discuss the various elements (Spooner et al., 2021). Stakeholders, during workshops, were able to improve the conceptual models through adding missing components, and/or correcting linkages (Szymkowiak & Kasperski, 2020; Spooner et al., 2021). The stakeholder were also able to indicate a range of indicators such as job security and sense of place, from fishery resources in this example (Szymkowiak & Kasperski, 2020).

Step 3: Risk analysis

This stage includes both quantitative and qualitative approaches in comparison to the previous stages, by evaluating the risk posed by human activities and natural processes on the key indicators (Monaco et al., 2021). This step aims to determine, in both qualitative and quantitative terms, the probability that an indicator will reach or remain in a poor state, i.e., a threshold to whether a goal or objective can be achieved. These thresholds will guide management strategies and priorities in the next step of the process (Monaco et al., 2021).

Step 4: Management strategy assessment (Levin et al., 2009) and overall ecosystem assessment (Monaco et al., 2021)

Using the information gathered in Steps 1-3, modelling frameworks are created to evaluate the difference in effects between current potential management actions which influence the key ecological and social system indicators (Levin et al., 2009). The results from the risk analysis (Step 3) quantifies the overall status of the ecosystem in relation to the goals and objectives set out in the scoping stage (Monaco et al., 2021).

Step 5: Monitoring and evaluation

The final step requires continued monitoring and evaluation, providing feedback on the goals and objectives, indicators, and the ecosystem assessment, implying the approach has an adaptive quality (Figure 8) (Dickey-Collas, 2014). For example, in some cases a change in the management strategy may improve the state of the system without altering the goals and indicators, whereas, in other cases, feedback from evaluating and assessing the outcomes may require a change/ addition to the indicators that are required to provide more efficient and relevant information in assessment.

SWOT analysis of the IEA

Strengths:

- The framework is sufficiently comprehensive and takes encompasses a wide range of socio-ecological actors (Monaco et al., 2021).
- The feedback loops in the framework imply an adaptive approach which is desirable for the Simple SES.
- It has the capacity to support interdisciplinary research and collaboration between the natural and social sciences (von Wehrden et al., 2018).
- It can help to inform policies and decision-making at local, national, and global levels (Seddon et al., 2016).

Weaknesses:

- It may be time-consuming and resource-intensive to conduct and may also require expertise to analyse and synthesise complicated results, so it is not satisfactory of a 'Simple' SES as experts would be required to undertake the process (Szymkowiak & Kasperski, 2020).
- There is also a need to better incorporate other sectors and agencies with mandates within coastal and marine ecosystems to achieve full EBM with an IEA (Dickey-Collas, 2014).

Opportunities:

- It can inform the development of effective and sustainable management strategies for the ecosystem to improve the ecosystem health.
- The emphasis on the use of stakeholders can facilitate greater support for the uptake of meaningful solutions.
- It can help to identify new research questions and areas for further study in addition to providing a solid base of evidence and data set for analysis of cumulative effects (Dickey-Collas, 2014).

Threats:

- There may be limited capacity or expertise available to effectively implement the IEA approach, which could hinder its effectiveness (Szymkowiak & Kasperski, 2020).

Integrated Systems Analysis Approach (ISA)

Proposed by Elliott, et al. (2020), the ISA approach aims to integrate the environmental/ ecosystem processes, and elements with the cultural and social components of resource supply and demand. This approach works in three phases (Figure 10), with subsets in each phase, to address: (A) What goals are to be achieved; (B) What information is needed to achieve these goals, and (C) How to use the information gathered (Elliott et al., 2020b) (Figure 9). The three phases encompass 14 subsystems, described below, offering directional measures to the ISA approach.

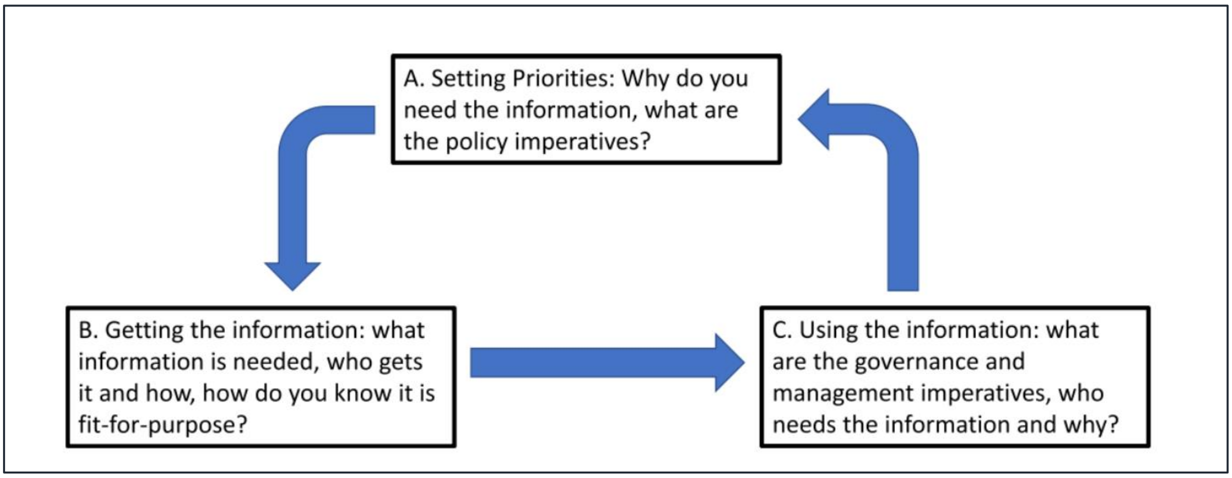


Figure 9: The three phases of the Integrated Systems Analysis approach (Elliott et al., 2020b).

Phase A: Setting priorities of what information will be needed.

Subsystem 1: Underpinning Framework

The underpinning framework of the approach is the Drivers-Activities-Pressures-State Change-Impacts (on human Welfare)-Response (using management Measures) (DAPSI(W)R(M)) framework (Elliott et al., 2017), a cause-consequence-response framework. As a problem structuring method (Gregory et al, 2013), this framework was designed to effectively address each individual aspect of a socio-ecological system, these being the Drivers, Activities and Pressures affecting ecosystems causing a State change and the consequential Impacts (on human Welfare) through changes in societal goods and benefits derived from ecosystem services. Following this identification of issues, this framework prompts creation of appropriate Response measures. However, this process is not dependent on entry at the first subsystem, there is opportunity to enter at sections such as governance (subsystem 8) to assess policy goals before assigning priorities.

Mapping of the system allows identification of hazards and risks through use of this cause-consequence-response framework to manage the ecosystem services. Once mapped, appropriate responses can be designed through the information gathered. To consider whether response measures are optimal, it is recommended by Elliott et al (2020b) that the ten-tenets be employed to reflect the complicated nature of the system given the range of actors that are managing or contributing to the management of the system (Elliott, 2013).

These tenets highlight and address different socio-economic-ecological perspectives in considering the activities and pressures requiring management.

Subsystem 2: Issue Definition

Using the underpinning framework, Subsystem 2 aims to highlight the issues by defining the priorities, these being the problems occurring, and the repercussions, which are the consequences of the issues identified. This frames the issues with the management measures aimed at tackling those issues and achieve the policy goals ceing considered. Framing issues can give preliminary information on which measures are to be implemented with regard to the priorities set. Furthermore, the categorisation of these measures in response to pressures within the system (endogenic) and external system pressures (exogenic) can change the management action from a preventative/ mitigative (for endogenic pressures) approach to an entirely reactive strategies of mitigation and recovery (for exogenic pressures).

Phase B: Collecting fit-for-purpose data and information.

Subsystem 3: The ecological system

This system focuses on gathering the information necessary to understand the ecological structure and functioning of the ecosystem. This system looks at environment-biology (E-B), biology-biology (B-B), and biology-environment (B-E) relationships (see Gray and Elliott, 2009). The E-B relationship considers fundamental properties, such as geomorphology, to assess if the area is suitable for inhabitants and creates the fundamental ecological niche. If the area is inhabitable, the B-B relationship explains the internal functioning of biota, for example predatory relationships and competition within the ecosystem. Lastly, the B-E relationship explains the influence of biota on the environment, an example being species that alter the sediment through bioturbation or the water quality through respiration (Elliott et al., 2020b). This ecological information can guide response measures by looking at cause-consequence relationships, as well as aiding the sequence and adequacy of the science in determining State changes to the physical, chemical, and ecological aspects of the ecosystem (Elliott et al., 2020b.

Subsystem 4: The socio-ecological subsystem

This subsystem gathers information on the resulting ecosystem services from the ecosystem that would deliver societal goods and benefits after inputting human capital (Elliott, 2023). An example is water quality and healthy fish populations will deliver suitable conditions for good fish yield for given fishing effort. Linking with the underpinning DAPSI(W)R(M) framework, the state changes in ecosystem services will impact on human welfare through the fish catch, a societal good/benefit.

Subsystem 5: The socio-economic subsystem

The information gathered from this subsystem will highlight the interactions between the creation of of ecosystem services and delivery of societal goods and benefits and their consequences on socio- economic factors such as employment and gross value added (e.g., the contribution to national income). This subsystem is necessary to show how drivers lead to impacts on society. Furthermore, this subsystem will translate the ecosystem services into societal goods and benefits. Elliott et al. (2020b) proposes that within this phase of the ISA, an internal cycle may depict the undertaking of an assessment of the societal goods and benefits from the marine system, together with a review of the ecosystem services needed to provide the goods and benefits (Turner & Schaafsma, 2015) using the information gathered in subsystems 3, 4, alongside 5 to evaluate ecosystem services to ensure policy is designed to reflect, in part, the value to society that an ecosystem is providing.

Subsystem 6: Resources and Delivery subsystem

Following the analysis of the previous subsystems, the required resources, facilities, and skills necessary to achieve the policy objectives are to be identified in Subsystem 6. This subsystem involves the assessment of who is available and suitable and what they can achieve, and how they do it; in doing this, it will highlight areas where further resources/research/funding is necessary.

Subsystem 7: Provenance subsystem

The provenance refers to the way in which the data can be collected in a controlled and reliable method and how these data are quality assured and suitable for analysis. Controlled data collected by the use of Standard Operating Procedures (SOPs) and/or using ISO/CEN standards will make data comparable between sectors. For example, the data collected will not be solely for policy makers, but also for other operational aspects of marine activities and blue economy, such as licensing (Elliott et al., 2020b).

Phase C: How to use the collected data.

Subsystem 8: Governance subsystem

Governance relates to the relevant policies, legislation, administration, and politics relating to the system. The governance system is made up of 4 branches of Subsystem 8, these being:

> 8(a) The legislative branch, which highlights both the vertical application of the relevant statutes on a local, national, and international scale, and the horizontal integration across the various sectors (fishing, seabed mining, etc.).
>
> 8(b) The administrative branch, which clarifies the bodies in power to enforce the legislation vertically through legislative methods, as well as horizontally between different stakeholders and marine management organisations.
>
> 8(c) & 8(d) Are coupled branches of subsystem 8 that emphasises the need for appropriate communication (branch 8(c)) methods to the various stakeholders (branch 8(d)). By using horizontal and vertical integration of information sharing, this will aid dissemination to different types of stakeholders (Elliott et al., 2020). Methods such as the accounting for what types of information different stakeholders can use could be guided by the so-called ‘Dissemination Diamond’ (Elliott et al., 2017), for example, an experienced natural scientists will be more likely to read and use detailed syntheses on marine pressures than a policy maker who is more likely to read a <2 page report (Elliott et al., 2017).

Subsystem 9: Achievement

This subsystem analyses the success of the process from phases A-C and subsystems through key indicators in the DAPSI(W)R(M) framework stages. To assess whether a management action has worked, a review of the goals and objectives of an area will need to be undertaken. Indicators at different stages in the DAPSI(W)R(M) framework are required; for example, to provide evidence on whether state changes were impacting on welfare and whether management measures were bringing about required outcomes, an indicator might be that relating to an improvement in ecosystem services and societal goods and benefits. This indicator could be fish yields (quantity and types), although with some allowance for level of effort exerted, and subsequently an improvement of well-being (a measure of fish consumption).

Subsystem 10: Feedback subsystem

The final component that completes the ISA framework cycle is the feedback system. This frames future opportunities and threats to the ISA approach and allows for mapping and management action. This loop provides an adaptive and resilient element to the management system allowing for its constant evolution with more recent information using feedback loops.

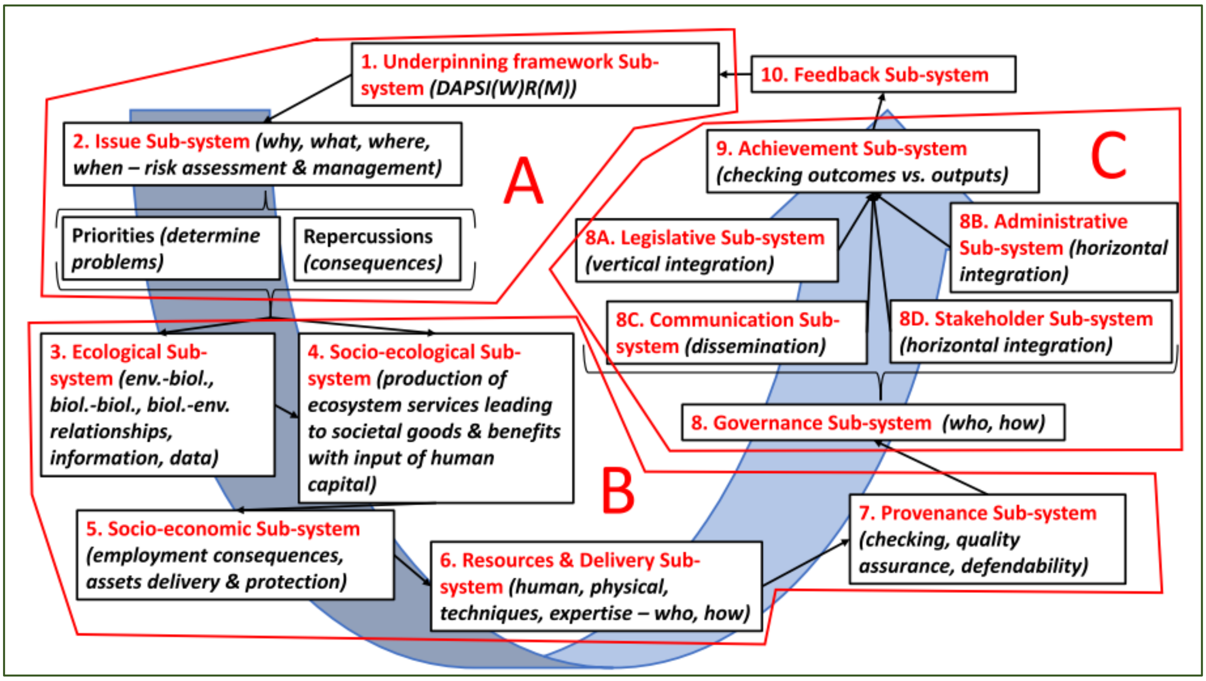


Figure 10: The ISA framework's 10 subsystems illustrated within the three A, B, and C phases (Elliott et al., 2020b).

The standard ISA framework detailed in Elliott, et al. (2020b) should be applied to address the different scales of the ecosystem. Additional developments from studies of the application of the DAPSI(W)R(M) framework when regarding the scale of application include cycles for differing sectors (i.e. DAPSI(W)R(M) ‘petals’ of analysis), to identify differing elements within the same area that can feed into the same response measures action plan (Figure 11, left) (Elliott et al., 2017a). Furthermore, when expanded to a larger scale, a linked set of nested

DAPSI(W)R(M) have been conceptualised and this provides a starting point when considering spatial upscaling of the framework (Figure 11, right).

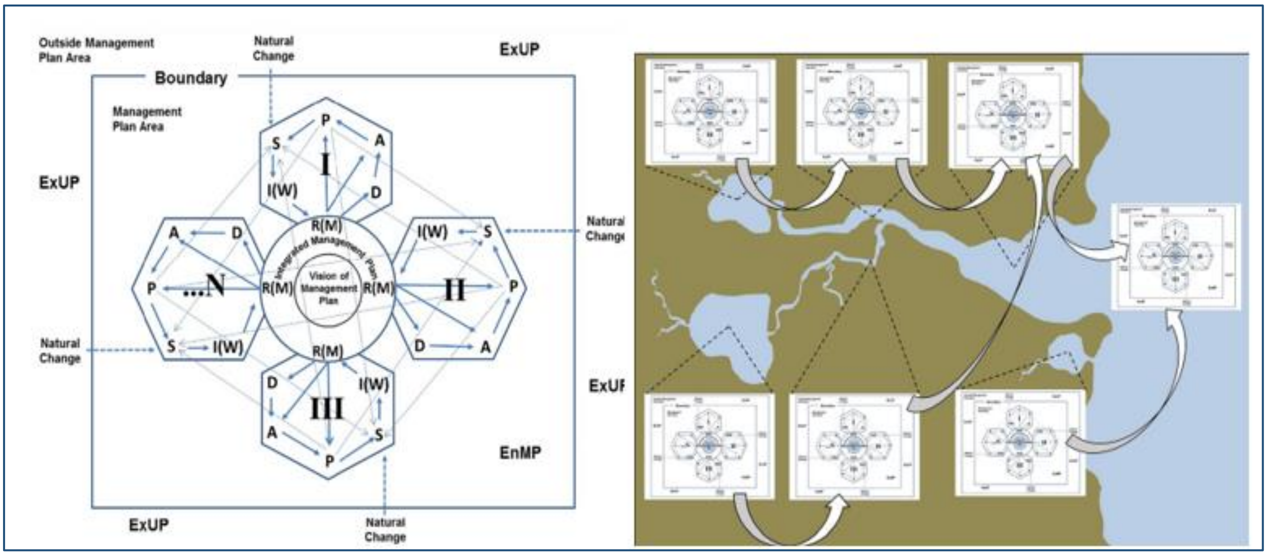


Figure 11: Left: A nested-DAPSI(W)R(M) framework for the integrated management of a hypothetical marine area. Key: D - Drivers; A - Activities; P - Pressures; S - State changes; I(W) - Impacts (on Welfare); R(M) - Responses (as Measures); ExUP - Exogenic EnMP - Endogenic Managed Pressures; I, II, III, …N - different marine activity sectors (Elliott et al., 2017a). Right: Catchment linked, networked, nested-DAPSI(W)R(M) models for freshwater lakes and rivers, estuary, coastal lagoon and sea area (Elliott et al., 2017a).

Overall, the ISA framework within the underpinning DAPSI(W)R(M) framework provides an encompassing approach to exploration and management of an SES. However, considerations are required regarding the amount of data necessary, and the operationalisation of the approach.

SWOT analysis of the ISA

Strengths:

- Considers multiple factors and their interactions, providing a holistic view of the marine environment through the DASPSI(W)R(M) underpinning framework which addresses different aspects of the marine SES through a cause-consequence approach (Elliott et al., 2017).
- Can identify key drivers of activities which enable change and understand their impacts on the ecosystem.
- The inclusion of the ten tenets encourages integration and holistic approaches between sectors and stakeholders (Elliott, 2013).
- The acknowledgement of endogenic and exogenic pressures provide good context for informed decision making for both preventative and mitigative measures (Elliott, 2011).
- The socio-economic subsystem aids relevant information on ecosystem goods and services to be considered.

- Sub-section 8(d) encourages empowerment of citizens to engage in conservation measures through horizontal integration of management (Elliott et al., 2020b).
- The framework uses consistent terminology throughout the identification and analysis of Drivers, Activities, Pressures, State Changes and Impacts (on Welfare) and the Response Measures. This consistent terminology will aid simplicity of application and upscaling in comparison of data between testing sites / regions/ countries /etc.

Weaknesses:

- This approach requires a large amount of available data and resources to be effective. Due to the systems approach of analysing different aspects of an SES, unless a substantial amount of data is readily available, the requirement of the minimum amount of data needed for the approach may still be time consuming.
- Bias is present towards anthropocentric views as the main point of focus in the framework and approach (Binder et al., 2013). However, in sub-system 3, ecological aspects are individually assessed, and management are looking to manage activities and not the environment, hence, giving an appropriate approach providing it does not entirely favour anthropocentric outcome biases, resulting in ecosystem loss of function and delivery of goods and benefits to society.
- The application of the framework requires different levels of communication across operational, governmental, and managerial systems so data that are fit-for-purpose are to be communicated accordingly. This added complexity can be a weakness in the framework's application within a Simple SES framework because it adds a layer of various communication styles to different stakeholders. However, the ISA offers complementary concepts and actions to counteract this issue, such as integrating the ten tenets (Elliott, 2013) and using the appropriate level and methods of communication to ensure understanding and reduce apparent complexity (Elliott et al., 2020).

Opportunities:

- Can inform policy decisions and guide the development of marine management plans (Seddon et al., 2016).
- Has the capacity to improve the resilience of marine ecosystems to environmental stressors and support the sustainable use of marine resources through a comprehensive and multi-scale approach to management.
- The framework feedback loops may provide opportunity for adaption and promote transferability between areas once upscaled.
- The DAPSI(W)R(M) framework when upscaled, has the capacity to overlap systems with spatial and temporal data to support predictions and mitigate cumulative effects in the form of nested iterations of the system mapping (Figure 11) (Elliott et al., 2017a).
- Opportunities to incorporate local knowledge, indigenous practices and existing management methods into the management outcomes by incorporating the viewpoints of stakeholders.

Threats:

- The ISA may not be fully accepted or implemented by all stakeholders and may be limited by the availability of data and resources when upscaled.

  - In countries where there are poor data and/or skills, this could limit the full quantitative application of the underpinning DAPSI(W)R(M) framework. Particularly in developing countries, there is a lack of historical data, capacity and skills, infrastructure, and financial resources to undertake the necessary data collection (Jorge-Romero et al., 2022).
- This framework requires many different actors to work efficiently and simultaneously in a timely manner. This may prevent consistency of outcomes and goal achievement between different countries/ areas. If these inconsistencies are large, this will inhibit comparison and use of information from data collected.
  - E.g., many legislative processes in different countries, may work at different rates, so sub-system 8(a) may alter the speed of applications depending on the area.
- The impacts of climate change on marine ecosystems could offer additional unforeseen impacts on both the ecosystem (State Change) and on Welfare respectively from a lack of ecosystem services and societal goods and benefits; the framework would require to be applied with these specific aspects in mind..

Overall, the integrated systems analysis approach to marine management has the potential to provide a comprehensive and effective approach to managing marine ecosystems. However, it also has its challenges and limitations, and it is important to consider these when implementing this approach.

Social-Ecological System Framework (SESF).

Ostrom and her co-researchers (2007;2009) developed the Social-Ecological System Framework (SESF) which encompasses theory surrounding common pool resources and collective self-governance (Cumming, 2011). Examples of common pool resources are those of natural and constructed systems of resources that cannot and are difficult to be excludable, for instance the oceans as a natural common pool resource, and the internet as a constructed common pool resource. Collective self-governance refers to actors who are the main users of the resource who also govern the use, for example tourism industry stewardship to maintain the quality of key attractions and safety within small-scale expedition cruise tourism (Linde, et, al. 2017) .

Prior to creation of the SESF, Ostrom's IAD framework is a structured analysis of policy interventions and supported understanding of how institutions develop through the analysis of contextual factors and consultation with stakeholders to create new policies as partial solutions for changing policy problems (Hess & Ostrom, 2005; McGinnis & Ostrom, 2014). The IAD framework includes the analysis of norms, institutional settings, actors, structures, and rules to study an institution. This analysis of exogenous variables and the input of these variables into the area under study (the 'Action situation') with the relevant outputs against the evaluative criteria (Figure 12), can inform upon the level of where the issue resides and offers insight on approaching a problem within an institution (Ostrom, 2009).

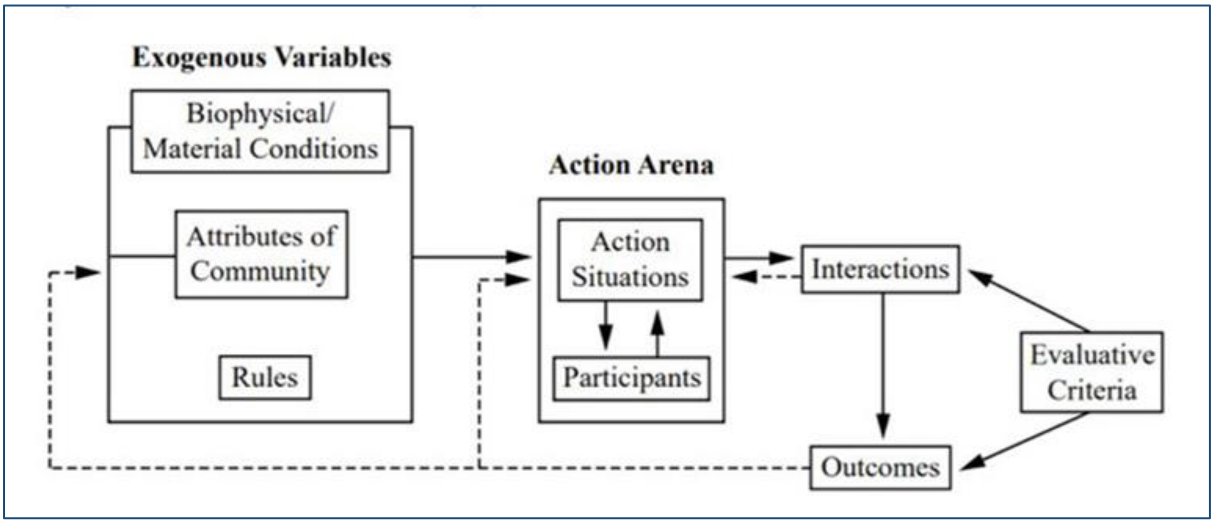


Figure 12: The IAD framework, (taken from Ostrom, 2009).

Expanding upon Ostrom's earlier work, the IAD, the SESF provides a coherent compilation of nested multi-resource systems (Hess & Ostrom, 2005; Partelow, 2018). The SESF was designed to organise, diagnose, describe, and prescribe an inquiry (Bots et al., 2015). This framework looks initially at the sub-system of the interactions and outcomes to establish a core set of variables (Figure 13) coupled with second tier variables which are sub-variables of the core variables. The core variables are the Resource System (RS), the Governance System (GS), the Resource Units (RU), and the Actors (A) surrounding focal action situations, where the focal action situations are composed of Interactions (I) and Outcomes (O) (Ostrom & Cox, 2010).

The functions of the main components surrounding the focal action situations are briefly described below (Guimarães et al., 2018):

The Resource System - this is the specific area that can include several resource units, for example, a fishery site is a resource system, i.e. the environment where resource units that may be provided are generated. The second-tier variables within this resource system include defining the system boundaries, and size of the resource system (Guimarães et al., 2018).

The Resource Units are the components generated by the system for its designed purpose, for example, a biological resource such as oysters. These are the parts of the resource system that create services through their functioning, and provide goods and benefits via complimentary capital. The second-tier variables under resource units include the classification of the resource unit, economic valuation, and growth rates (Guimarães et al., 2018).

The Actors are the individuals (and organisations) who influence, and are influenced by, the resource system and its units, for example, the fishers. The secondary variables include the number of actors, their socio-economic qualities, and their location (Guimarães et al., 2018).

The Governance System includes the organisations that manage the resource system. For example, the English Marine Management Organisation (MMO), and the government. This system makes the specific rules related to the use of the system and governs and enforces those rules. Second-tier variables include the characterization of government and non-governmental institutions, and the identification of the relevant rules (Guimarães et al., 2018).

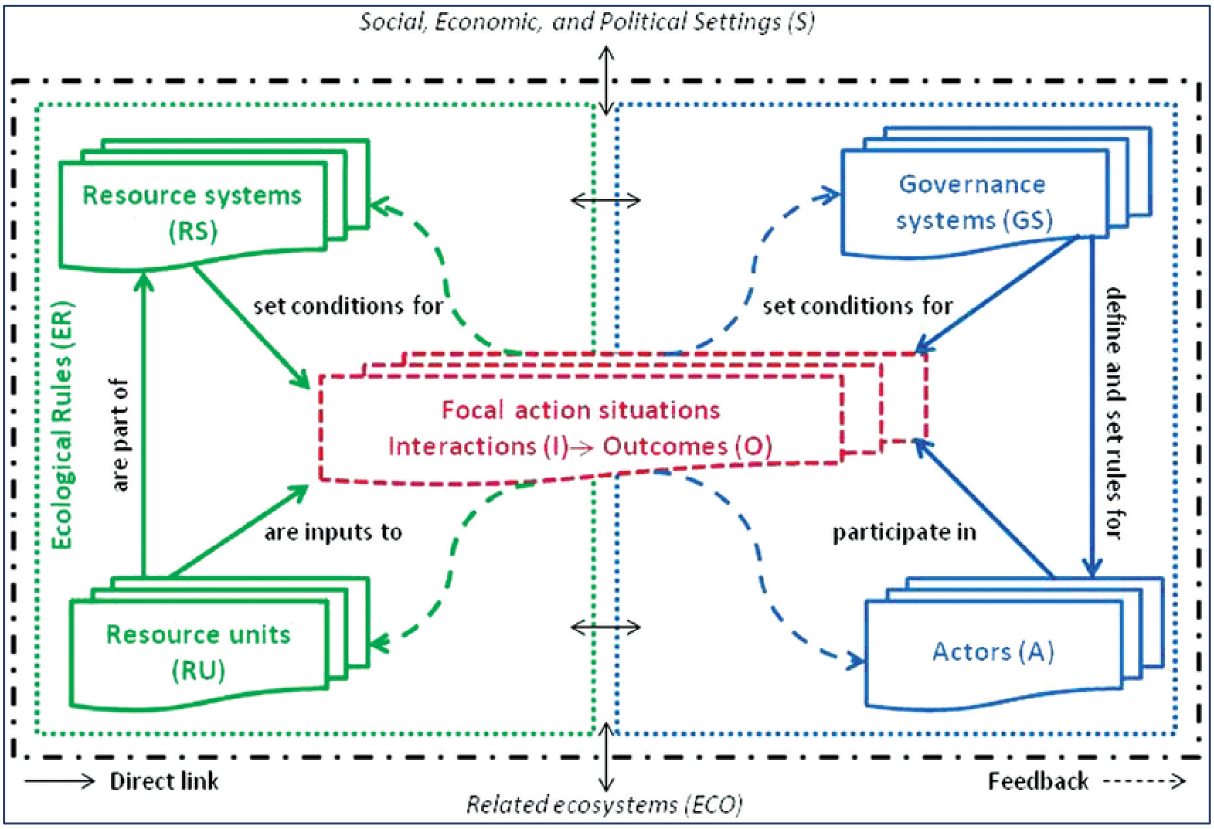
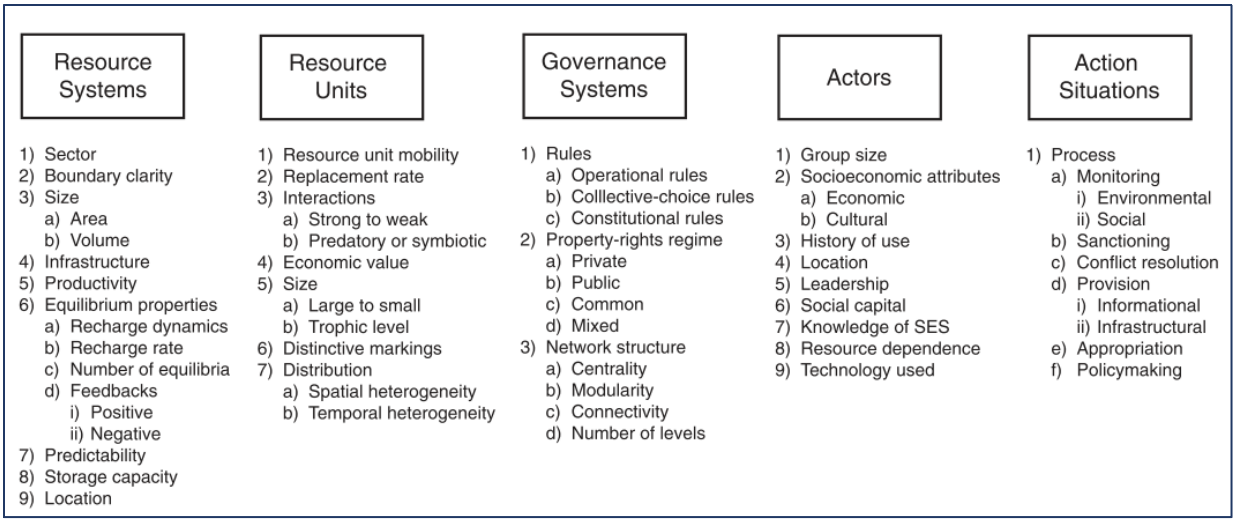


Figure 13: A schematic representation of the SESF first tier variables (Ostrom & Cox, 2010).

Figure 14 lists the secondary variables in the SESF which relate to each of the core variables. Described as an 'unpacking' of the core variables (Ostrom & Cox, 2010), these secondary variables can provide understanding of the system and indicate where problems arise.



Resource Systems

1) Sector
2) Boundary clarity
3) Size
   a) Area
   b) Volume
4) Infrastructure
5) Productivity
6) Equilibrium properties
   a) Recharge dynamics
   b) Recharge rate
   c) Number of equilibria
   d) Feedbacks
      i) Positive
      ii) Negative
7) Predictability
8) Storage capacity
9) Location

Resource Units

1) Resource unit mobility
2) Replacement rate
3) Interactions
   a) Strong to weak
   b) Predatory or symbiotic
4) Economic value
5) Size
   a) Large to small
   b) Trophic level
6) Distinctive markings
7) Distribution
   a) Spatial heterogeneity
   b) Temporal heterogeneity

Governance Systems

1) Rules
   a) Operational rules
   b) Colllective-choice rules
   c) Constitutional rules
2) Property-rights regime
   a) Private
   b) Public
   c) Common
   d) Mixed
3) Network structure
   a) Centrality
   b) Modularity
   c) Connectivity
   d) Number of levels

Actors

1) Group size
2) Socioeconomic attributes
   a) Economic
   b) Cultural
3) History of use
4) Location
5) Leadership
6) Social capital
7) Knowledge of SES
8) Resource dependence
9) Technology used

Action Situations

1) Process
   a) Monitoring
      i) Environmental
      ii) Social
   b) Sanctioning
   c) Conflict resolution
   d) Provision
      i) Informational
      ii) Infrastructural
   e) Appropriation
   f) Policymaking

Figure 14: The secondary tier variables of the SESF relating to each of the core variables (Ostrom & Cox, 2010).

Further studies of the SESF have conceptualised the application to sector-specific problems and connect related diverse cases within and among the sectors (Figure 15) (Partelow, 2018). By adding sector specific frameworks, this may develop and define generalised variables of the framework for the scope of a sector, and a resulting standard operating procedure may be required to generate the same type of data from different areas to aid comparability (Partelow, 2018). However, this may require a compromise between having a standard methodology and the need for variability and adaptation within the SES.

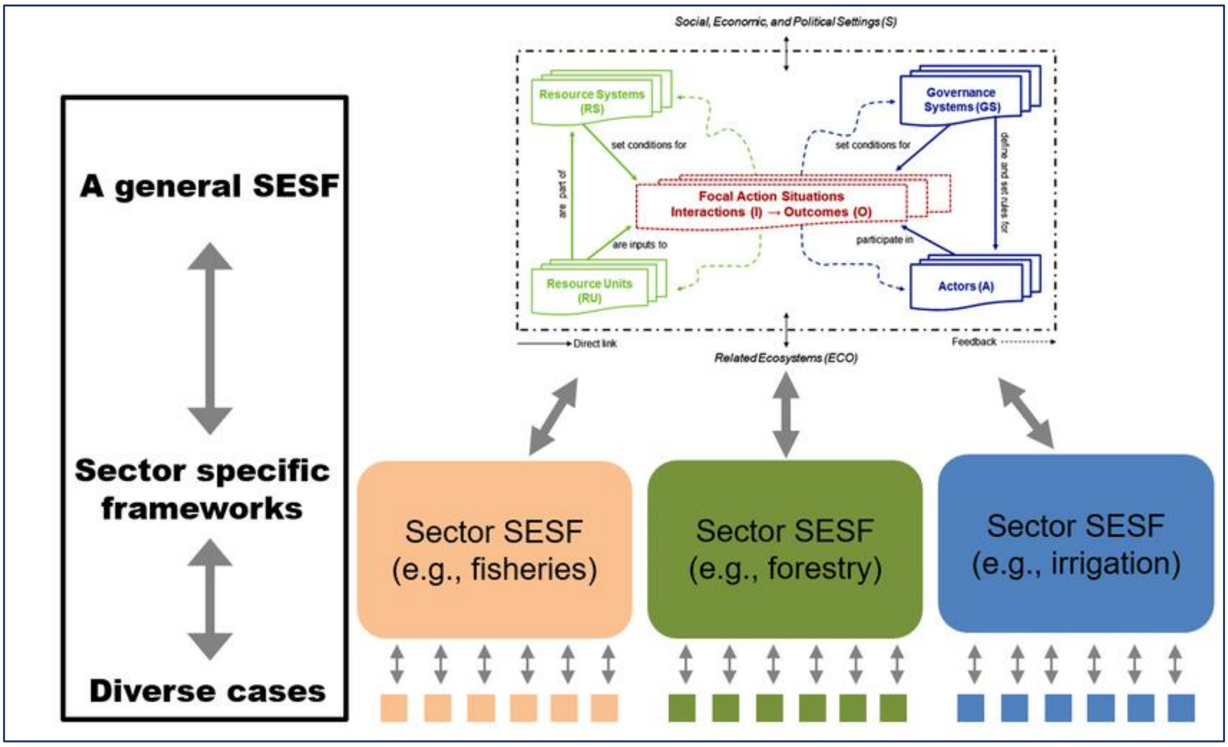


Figure 15: SESF conceptualised to illustrate the sector specific approaches that may be applicable (Partelow, 2018).

SWOT analysis of the SESF:

Strengths:

- The SESF recognises the interconnectedness of human and natural systems, and the importance of considering multiple scales and levels of organisation (Guimarães et al., 2019).
- It provides a comprehensive approach to understanding the dynamics of social-ecological systems and the impacts of human actions on the environment (Hinkel et al., 2015).
- It can help to identify opportunities for sustainable development and conservation and inform strategies for addressing environmental and social challenges (Partelow, 2018).
- SESF provides a frame for developing different degrees of specificity in differentiating different tiers.

Weaknesses:

- The SESF has been suggested to be a complex and abstract concept, which can make it difficult to apply in practice (Partelow, 2018).

- The SESF literature gives conflicting results. Hence, it is unclear how empirical data can be compared across systems in a meaningful way without substantial simplification and re-formatting of the data (Partelow, 2018).
- It may not always provide clear guidance on how to implement specific environmental or social challenges (Thiel et al., 2015). This framework is conceptually prescriptive although offers no further guidance on application, hence, its abstract nature could be a barrier to implementation.
- It may not adequately account for the political and cultural dimensions of human-environment interactions or adequately address issues of social justice and inequality (Thiel et al., 2015).
- Studies have explored the validity of the SESF claim to create a common language among actors within the SES. Analytical comparisons across cases concluded that most studies did not define concepts or present ways of measuring them transparently. (Thiel et al., 2015).

Opportunities:

- The SESF can provide a valuable lens for analysing and addressing a wide range of environmental and social issues, such as climate change and biodiversity loss.
- It can support interdisciplinary research and collaboration between the natural and social sciences (von Wehrden et al., 2018).
- It can help to inform policies and decision-making at local, national, and global levels (Seddon et al., 2016).

Threats:

- The SESF is apparently not widely adopted or recognised by policymakers, managers, and other decision-makers, which could limit its implementation and usefulness. Previously this framework has been evaluated as incomplete in identifying the full set of variables that lead to SES outcomes, with the potential to lead to policy prescriptions that fail to account for ecological processes that support or undermine the pursuit of sustainability (Vogt, et al. 2015).
- It may face resistance from stakeholders who have vested interests in maintaining the status quo, or who may see the framework as a threat to their interests (Schlüter et al., 2014).

Social-Ecological Action-Situations framework (SE-AS).

The social-ecological action-situations (SE-AS) framework is developed following the Social-Ecological Systems Framework (SESF) (Schlüter et al., 2019; Herzog et al., 2022). It focuses on the action situation (AS) as a unit of analysis and in that regard differs from its predecessors, the IAD framework and the SESF. The main difference with the IAD and the SESF relates to the outcomes produced. In the SE-AS framework, the concept of an AS is broadened to treat social actors and ecological elements on the same level, and to place their interactions at the centre of the analysis. The framework involves analysis on four levels: the individual level, the social group level, the environmental level, and institutional/ emergent SES phenomenon level.

At the **individual level**, the framework focuses on the personal characteristics, attitudes, values, and behaviours of individuals (Herzog et al., 2022). It considers how these individual-level factors influence and are influenced by the other levels of the framework as illustrated in the bottom layer of actors (A) and ecological entities (EC) in Figure 16.

At the next social-ecological level, both the human and natural elements are mapped, and the action situations are presented in the middle of Figure 12. At the **Social** action-situation (**social AS) level**, the framework focuses on the roles and relationships that individuals have with one another in groups and communities (Herzog et al., 2022). This can include family, friends, and other social networks, as well as organisations and institutions. It considers how group dynamics and social norms shape individual behaviour and decision-making (Schlüter et al., 2019). At the **Environmental AS level,** the framework focuses on the physical and natural environment in which individuals and groups live and operate (Herzog et al., 2022). This can include the natural resources, ecosystems, and other physical factors that shape human behaviour and decision-making. It considers how the environment influences and is influenced by the other levels of the framework (Schlüter et al., 2019).

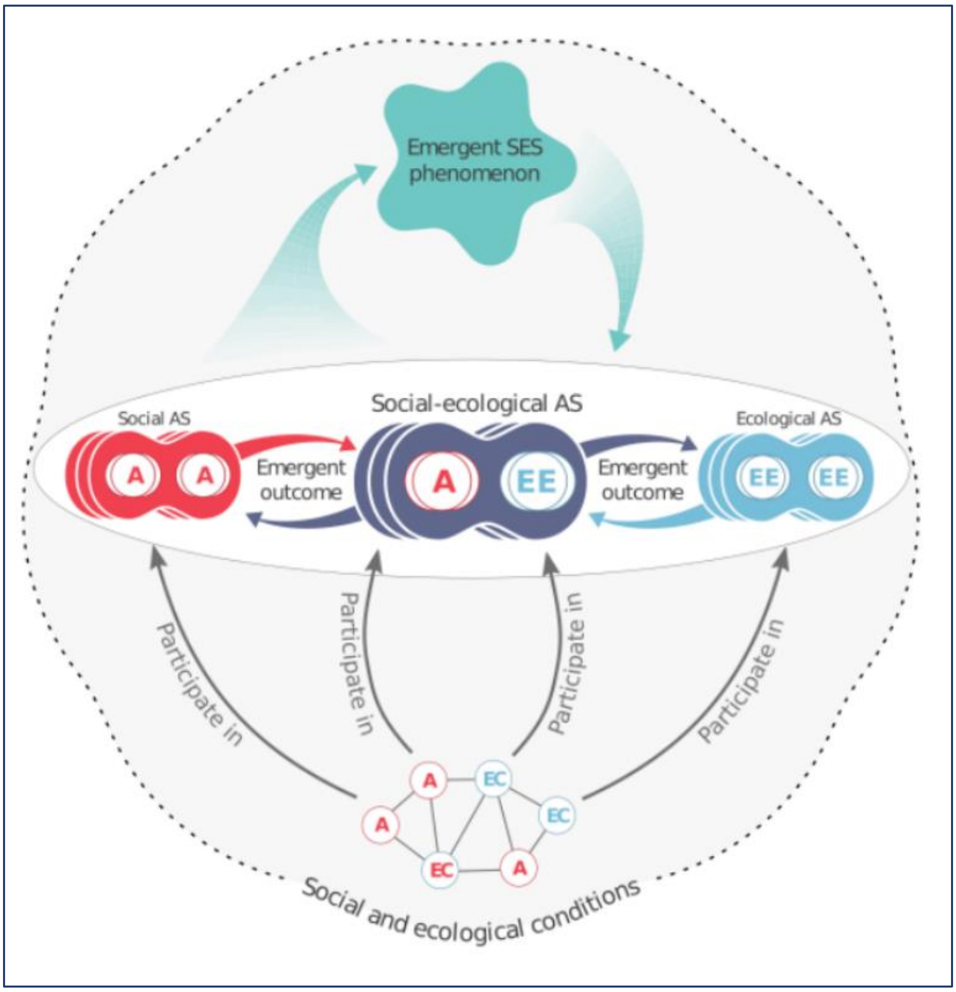


Figure 16: Schematic of the Action-Situation, social and ecological conditions and the corresponding emergent phenomenon (Herzog et al., 2022).

At the **institutional/ emergent SES phenomenon level (**at the top of Figure 16), the framework focuses on the rules, regulations, and other formal and informal structures that shape and constrain human behaviour (Herzog et al., 2022). This can include laws, policies, and other formal institutions, as well as cultural practices, norms, and values (Herzog et al., 2022). It considers how these institutional factors influence and are influenced by the other levels of the framework through emergent phenomenon (Schlüter et al., 2019). Emergent SES phenomena are outcomes or patterns that arise from the interactions of social and ecological systems. These phenomena are often the result of multiple interacting action situations, which can influence one another through their emergent outcomes (Biggs et al., 2021). Studying and understanding emergent social-ecological phenomena can provide insights into the functioning and dynamics of social-ecological systems and may help to inform management and policy decisions (Schlüter et al., 2019).

Overall, the Socio-Ecological Action-Situation framework emphasises the interconnectedness and interdependence of these different levels, and the complex interactions between them in shaping human behaviour and decision-making (Thiel et al., 2015).

SWOT analysis of SE-AS:

Strengths:

- The SE-AS framework emphasises social-ecological interactions and how they give rise to emergent phenomena (Thiel et al., 2015).
- It introduces two additional types of action situations that provide a more comprehensive view of complex social-ecological systems and reduces bias to either of the social or environmental components (Herzog et al., 2022).
- The framework has been applied to support the development of global biodiversity targets and identify mechanisms of policy change in fisheries co-management (Herzog et al., 2022).
- It can support interdisciplinary research and collaboration between the natural and social sciences (von Wehrden et al., 2018).
- Provides a helpful structure to understanding complex causal loop diagrams through separation of components (Herzog et al., 2022).

Weaknesses:

- Demands a large amount of data to work sufficiently, hence in data poor areas/ low funded areas this may hinder the implementation.
- The framework refers to societal values but not to stakeholder inclusion or communication.
- The SE-AS framework is a relatively recent development, and as such, it may not yet have been extensively tested or applied in a wide range of situations (Herzog et al., 2022). However, its application to fisheries was undertaken by Schlüter et al. (2019).
- A lack of difference between crucial and non-crucial ASs for establishing an emergent phenomenon (Herzog et al., 2022) may hinder simplicity and consistency between systems.
- It may be difficult to operationalise the framework in practice, as it involves identifying and analysing complex networks of interacting action situations (Herzog et al., 2022).

- The framework is complex for some users and may require specialist training or expertise to apply effectively (Herzog et al., 2022).

Opportunities:

- The SE-AS framework offers a unique approach to understanding and managing complex social-ecological systems. Hence, as more research is conducted using the framework, it may generate insights and strategies that can be applied in a range of contexts.
- It can help to inform policies and decision-making at local, national, and global levels (Seddon et al., 2016). The framework may be particularly useful for addressing challenges relating to sustainable development, climate change, and environmental degradation.
- The framework could potentially provide a communication tool outside academia that illustrates the role of stakeholders and ecosystem elements in an SES, while stimulating discussions on the underlying mechanisms of SES (Schlüter et al., 2019).

Threats:

- The SE-AS framework may be perceived as being too complex or abstract, which could limit its adoption and use by practitioners and policymakers (Herzog et al., 2022).
- It may be difficult to compete with more established frameworks or approaches that are already widely used in the fields of social-ecological systems and sustainable development.
- The framework focuses on the rules, regulations, and other formal and informal structures that shape and constrain human behaviour, so it may face the threat of resistance from stakeholders who have vested interests in maintaining the status quo, or who may see the framework as a threat to their interests (Schlüter et al., 2019).
- The impacts of climate change and exogenic pressures on the focal marine ecosystems could offer additional unforeseen impacts that the framework may not be equipped to tackle due to the lack of external variable considered through direction of the approach.

Sustainable Livelihood Approach (SLA).

This framework looks to identify and analyse a combination of livelihood assets, these assets are based upon the recognition that all people have abilities and assets that can be developed to help them improve their lives. It is centred around six key topics: (1) the people-based nature of the framework; (2) the holistic approach; (3) building on strengths; (4) the dynamic nature of applicability to different types of people; (5) using micro and macro links, and (6) sustainability, which is at the centre of the framework (DFID, 2001).

This approach has links with complementary approaches, including:

- Participatory development as it requires skilled individuals to operationalise the approach. These link with the participatory poverty assessments (PPA) that heavily rely upon implementation by skilled people (DFID, 2001).
- Sector wide approaches - there is a large emphasis on understanding structures and processes that affect people’s lives, this requires analysis across sectors.

- Integrated Rural development (IRD) - the SLA approach has been compared to the IRD project which aimed to improve sectors across African rural areas but was not successful. It was considered too complicated and demanding of the small institutions within the rural-based sectors (Cohen, 1987).

Using the vulnerability context, the external factors which affect people within an area, the livelihood assets and transforming structures and process (Figure 17), the SLA aims to help a range of stakeholders to engage and problem solve (Dorward, 2014).

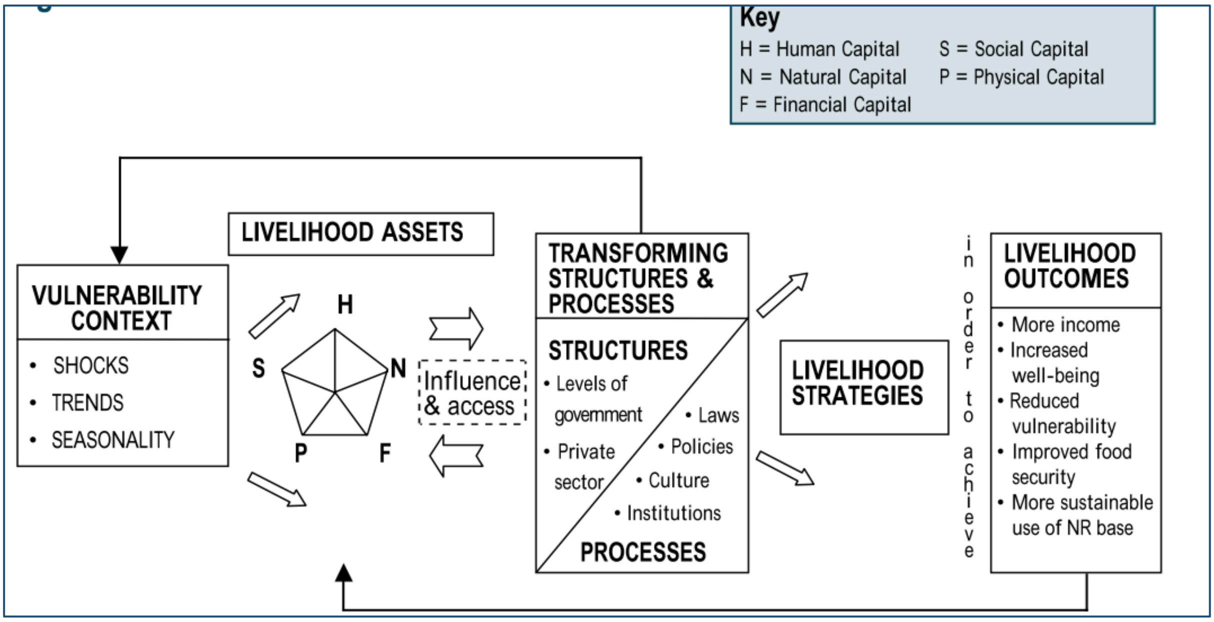


Figure 17: The SLA framework diagram summarising the main components of influences on livelihoods (DFID, 2001).

The vulnerability context:

This aspect of the SLA frames the external environment from where people's lives are centred (Serrat, 2017). The vulnerability context provides 'a bigger picture' of what affects people and their access to livelihood assets. The SLA establishes three main effects:

1) Trends – these are within the population, resources, economy, governance, and technology (Serrat, 2017). By establishing trends within different contexts, this allows management to recognise influences on rates of return of chosen measures.
2) Shocks – these are on human health, nature, economy, crop/livestock health and from conflict (Serrat, 2017). Shocks can affect assets directly and indirectly through circumstances such as extreme weather, economic strain, and pandemics.
3) Seasonality – in relation to prices, production, health, and employment (Serrat, 2017). The seasonal shifts in the cost of living, health issues and employment are an important factor to consider when managing people's exposure to vulnerability.

Once vulnerability factors are mapped, this may allow for prevention and mitigation measures to be tailored accordingly and to aid the preparedness of people to encourage resilience (DFID, 2001). This context is required to be considered alongside the livelihood assets.

Livelihood assets:

The SLA defines five core asset groups on which livelihoods are built. The framework emphasises that links between the assets can show trends and links to solutions. These links can be in the form of sequencing, where particular assets contributing to issues are identified and targeted solution to the assets can be applied. The other link is substitution, which is assessed if one asset can be substituted for another, if the substitution can resolve the problem. Furthermore, DFID (2001) argues that understanding can be helped by identifying such links between assets and other components of the approach as:

- Assets and Vulnerability
- Assets and Transforming processes and structures.
- Assets and livelihood strategies
- Assets and livelihood outcomes

The five assets:

These assets are at the core of the SLA within the vulnerability context, the aim being to gather information on the assets and to present this visually to illustrate (Figure 18) the importance of inter-relationships between assets (DFID, 2001).

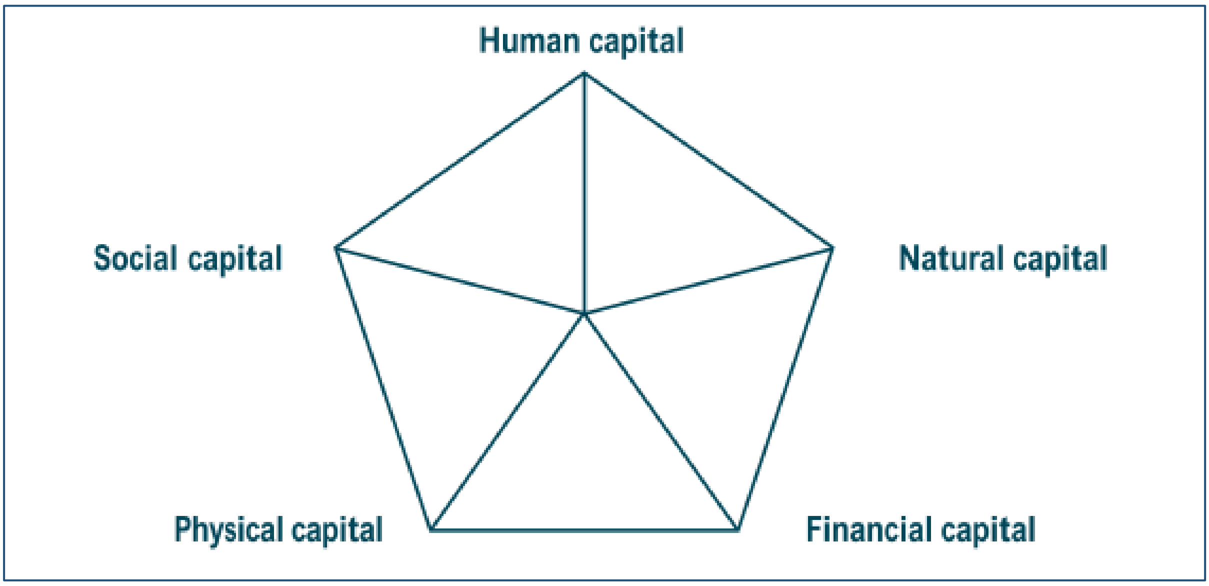


Figure 18: The asset pentagon that can be used to schematically illustrate the variation in stakeholder assets (DFID, 2001). By analysing the different abundance of various assets relating to an individual can highlight unevenly distributed assets and guide management of these areas.

1) Human capital – this is the access and ability to health, labour, education, skills, and knowledge (DFID, 2001).
2) Social capital – this entails the social resources that people use in pursuit of their livelihood objectives. It is developed through formalised groups with rules, norms, and sanctions, alongside, relationships of trust and networks and connectedness (Serrat, 2017).

3) Natural capital – the natural resources that provides society goods and benefits, described as the stock from which resource flows and services are derived to be used for livelihood (Serrat, 2017).
4) Physical capital – this is described as the infrastructure and producer goods that are required to support livelihoods; infrastructure is a change to the physical environment that allows people to meet their basic needs. Producer goods are the tools and equipment that people use to function more productively (Serrat, 2017).
5) Financial capital – the financial resources that people use to achieve their livelihood objectives (Shen et al., 2008). Two main sources are the available stocks and the regular inflows of money (DFID, 2001).

Transforming structures and processes:

These are the institutions, organisations, policies, and legislation that shape livelihoods. They determine the access to resources; the terms of exchange and the returns individuals and organisations will receive (Shen et al., 2008). Analysis of institutions and linked policy in a cost-effective way is described to be underdeveloped, but this framework suggests mapping roles, responsibilities, relations, and rights is the first step to understanding the structures and processes that effect livelihoods.

Caveat:

The Sustainable Livelihoods Approach promotes creative problem-solving. This approach guides professionals to expand the analysis from conventional methods such as plan-execute thinking and invites them to consider contexts and connections to make management measures more process-oriented (Serrat, 2017). However, this approach is a singular way of organising complex issues and is tailored to poverty as a central issue, amendments would be necessary to address priorities in the marine environment.

SWOT analysis of SLA:

Strengths:

- The Sustainable Livelihoods Approach recognises the multiple factors that affect people's livelihoods, and the importance of considering economic, social, political, and some environmental factors.
- It emphasises the need for an integrated and holistic approach to development, and the importance of involving all stakeholders in decision-making (Knutsson, 2006).
- It supports the diversification and improvement of people's livelihoods, and the building of resilience to shocks and stresses, in addition to seeking to understand changing combinations of modes of livelihood in a dynamic and historical context.
- It calls for investigation of the relationships between different activities that constitute livelihoods and draws attention to social relations and acknowledges the need to move beyond narrow sectoral perspectives and emphasises seeing the linkages between sectors (DFID, 2001).
- It acknowledges ‘smaller voices’ in stakeholders (Serrat, 2017).

- It can support interdisciplinary research and collaboration between the natural and social sciences (von Wehrden et al., 2018).
- It can help to inform policies and decision-making at local, national, and global levels (Seddon et al., 2016).

Weaknesses:

- The Sustainable Livelihoods Approach is a complex and abstract concept, which can make it difficult to apply in practice. As it does not provide clear guidance on how to address specific development challenges, it may require additional frameworks or tools to support implementation (Serrat, 2017).
- It may not adequately account for the political and cultural dimensions of development and may not adequately address issues of social justice and inequality. Hence, a substantial weakness is the lack of attention to inequalities of power (Serrat, 2017).
- This approach underplays the fact that enhancing the livelihoods of one group can undermine those of another, which can further undermine different assets (Serrat, 2017).
    - The lack of attention to the services ecological elements provide within the approach i.e. the acknowledgement of solely final ecosystems goods and services, excluding marine processes and functioning, and is extremely likely to produce a result biased towards anthropogenic elements and outcomes.

Opportunities:

- The Sustainable Livelihoods Approach can provide a valuable framework for addressing poverty issues and vulnerability in developing countries.
- It can support interdisciplinary research and collaboration between the natural and social sciences.
- It can help to inform policies and decision-making at local, national, and global levels (Seddon et al., 2016).

Threats:

- The Sustainable Livelihoods Approach may not be widely adopted or recognized by policymakers and other decision-makers, which could limit its impact and usefulness. Particularly due to the main focus of the framework being poverty alleviation, hence its application to marine management will require many alterations (Serrat, 2017).
- As it is guided heavily by social systems, there is a potential threat of resistance from stakeholders who have vested interests in maintaining the status quo, or who may see the approach as a threat to their interests.
- It may be vulnerable to changing political and economic conditions, which could impact funding and support for research and implementation (Bull et al., 2016).

Systems Assessment Framework (SAF)

The SAF was first developed in the Science and Policy Integration for Coastal System Assessment project (SPICOSA) (McFadden et al., 2010) and revisited in the Systems Approach Framework for Coastal Research and Management in the Baltic project (BONUS Balt Coast) (Støttrup et al., 2017). The SAF guides coastal managers to consider ecological, social and economic issues to find an accepted balance of measures regarding the resource conservation and recovery, as well as societal use, and the resulting goods and benefits (Støttrup et al., 2017). Including six key steps, the SAF modified the existing framework presented by Hopkins (2011) with the steps comprising: issue identification, system design, system formulation, system assessment, implementation, and monitoring and evaluation (Figure 19).

Issue identification:

This is the initial step intended to identify the base conditions and collect data for assessment (Hopkins et al., 2011). The SAF directs users to complete a checklist of actions to gather the data, as shown in the left column of Table 4. This step emphasises the actions do not need to be conducted in a particular order, barring actions such as mapping stakeholder preferences, needed to ensure the relevant and appropriate stakeholders are involved in the process (Støttrup et al., 2019). The actions within this step of the SAF are aligned with recommended tools to gather the information required, as shown is the right column of Table 4.

Table 4: SAF recommended tools for issue identification (Støttrup et al., 2017).

Action	Recommended tools
Identifying potential and existing issues	• DPSIR (problem structuring method) • Customers Actors-Transformational Process-Worldview-Owners Environmental constraints (CATWOE) Technique (a technique that provides a framework for defining and analysing business stakeholder perspectives) • Marine Ecosystem Services Assessment Tool (where a list of the relevant ES is drawn, and the actual provision of services assessed). • Stakeholder Preference and Planning Tool (to deal with issues such as stakeholders defending their own interests rather than what is sustainable) • Public Participation tool (which guides a stepwise decision process (Inform – Consult – Involve - Partner) on how to engage with stakeholders).
Mapping stakeholders	
Mapping institutions	
Listing human activities	
Mapping ecosystem services	
Mapping stakeholder preferences through consultation	
Prioritising and defining Policy Issue(s)	
Identifying relevant environmental, social, economic elements	

System design:

This step of the SAF guides users to develop a conceptual model of the system state by mapping the way in which the social and ecological sub-systems interact and their relevance to previously identified policy issues. It prescribes actions of modelling and the identification of system linkages and scope (as listed in Table 5).

Table 5: SAF recommended tools for system design (Støttrup et al., 2017).

Action	Recommended tools
Develop conceptual model	• InSAT ○ Designed to measure sustainable development in coastal areas and to evaluate the success of different ICZM 'best-practice' examples applied throughout Europe. ○ A spreadsheet-based tool, created from previous projects (DEDUCE, SUSTAIN and Quality Coast) ○ Includes sets of well-established 45 indicators that are grouped into 4 categories: ▪ Environmental Quality (13 indicators) ▪ Economics (9 indicators) ▪ Social well-being (9 indicators) ▪ Governance (14 indicators)
Identify Ecological-Social-Economic (ESE) linkages	
Assess data availability, resources, and modelling methods	
Define boundaries, both administrative and system boundaries	
Identify external hazards	
Create and define a success criterion and the relevant indicators	
Assess system state	
Ensure all relevant stakeholders and institutions are represented	

System formulation:

This next step guides users to use transdisciplinary mathematical modelling to integrate both stakeholder and scientific knowledge (Hopkins et al., 2011). Tools were not listed for these actions (Table 6), as the SAF leaves freedom for the scientific team to choose the appropriate modelling approach and statistical methods, as well as methods to integrate qualitative information (Støttrup et al., 2017; Støttrup et al., 2019).

Table 6: SAF recommended actions for system formulation (Støttrup et al., 2017).

Action
Assemble data inputs and variables
Formulate, document, hindcast/calibrate and validate each of the individual ESE model components and auxiliary models
Discuss model components with stakeholders
Link ESE model components into a complete ESE model
Test sensitivity
Run scenario simulations
Validate system model

System assessment:

During this step of the SAF, the results are discussed with stakeholders and there is an opportunity to revisit stakeholder preferences to assess whether the determined success criteria (created in step 2 of system design) are still relevant. Alternatively, stakeholder preferences could have changed, hence, the revised success criteria could then be used to evaluate the suitability of different management scenarios/options to fulfil the new stakeholder preferences (Støttrup et al., 2019). Multiple actions and tools are introduced and reintroduced at this stage (Table 7).

Table 7: SAF recommended tools for system assessment (Støttrup et al., 2017).

Action	Recommended tools
Prepare scenario results for communication to stakeholders	• InSAT ○ designed to measure sustainable development in coastal areas and to evaluate the success of different ICZM 'best-practice' examples applied throughout Europe. ○ A spreadsheet-based tool, created from previous projects (DEDUCE, SUSTAIN and Quality Coast) ○ Includes sets of well-established 45 indicators that are grouped into 4 categories: ▪ Environmental Quality (13 indicators) ▪ Economics (9 indicators) ▪ Social well-being (9 indicators) ▪ Governance (14 indicators) • Marine Ecosystem Services Assessment Tool (where a list of the relevant ES is drawn, and the actual provision of services assessed). • Stakeholder Preference and Planning Tool (to deal with issues such as stakeholders defending their own interests rather than what is sustainable)
Visualize consequences of different results of ESE model scenario simulations	
Conduct stakeholder meetings to discuss scenario simulation results and consequences of potential management options	

Implementation:

Within the SAF the penultimate step is the implementation of agreed decisions. This stage of the framework prepares for application the decisions made in the assessment with stakeholders and measures their success. As illustrated in the previous steps, the SAF prescribes actions to this stage of the framework (Table 8).

Table 8: SAF recommended actions for implementation (Støttrup et al., 2017).

Action
Specify regulatory and financial requirements
Obtain legal permits

Identify mitigation measures to reduce, offset or eliminate negative impacts
Ensure pro-active public information/consultation
Validation

Monitoring and evaluation:

The final step in the SAF is to monitor and evaluate the process. Monitoring is necessary to indicate the status for the system and allows evaluation of implementing management decisions (Støttrup et al., 2019). Monitoring aims to answer the question: "Has the implementation of the decision had the expected outcomes relative to the success criteria defined in the beginning steps of the SAF?" (Støttrup et al., 2019). Table 9 gives the recommended actions and tools for monitoring and evaluation.

Table 9: SAF recommended actions and tools for monitoring and evaluation (Støttrup et al., 2017).

Action	Recommended tools
Ensure the required mitigation measures are implemented	• InSAT ○ designed to measure sustainable development in coastal areas and to evaluate the success of different ICZM 'best-practice' examples applied throughout Europe. ○ A spreadsheet-based tool, created from previous projects (DEDUCE, SUSTAIN and Quality Coast) ○ Includes sets of well-established 45 indicators that are grouped into 4 categories: ▪ Environmental Quality (13 indicators) ▪ Economics (9 indicators) ▪ Social well-being (9 indicators) ▪ Governance (14 indicators) • Marine Ecosystem Services Assessment Tool (where a list of the relevant ES is drawn, and the actual provision of services assessed). • Citizen science
Agree on the indicators to be used and the appropriate monitoring in place to evaluate the indicators.	
Evaluate need for additional data requirements	
Evaluate whether mitigation measures are effective	
Ensure communication with stakeholders on progress	
Evaluate the need to re-iterate the SAF	

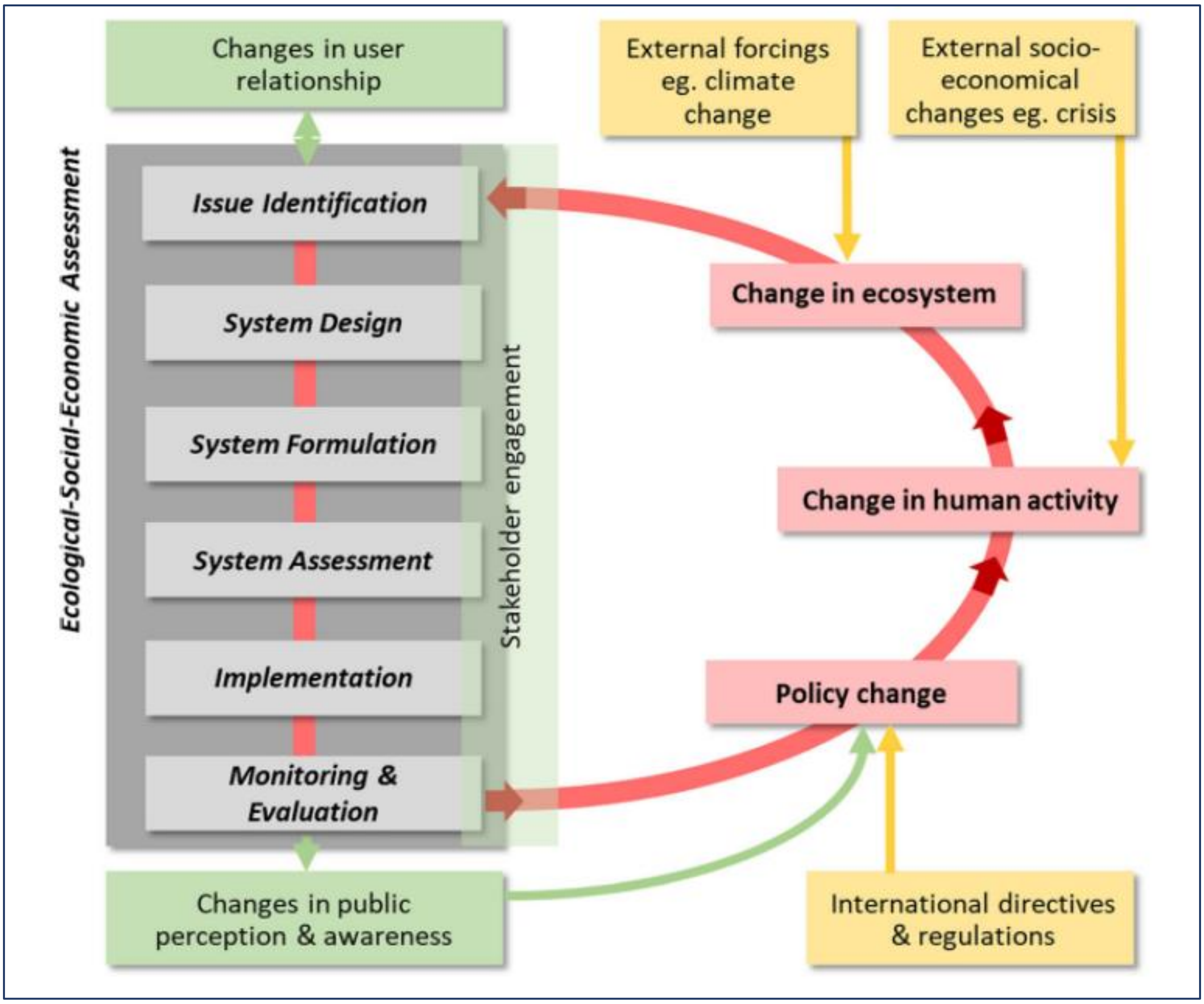


Figure 19: SAF framework process, taken from Støttrup et al., (2019).

SWOT analysis of SAF:

Strengths:

- The framework focuses on the interconnections between varied factors in marine ecosystems and can provide a comprehensive view of marine systems (Støttrup et al., 2017).
- The SAF provides tools as well as actions to guide users and transdisciplinary approaches are incorporated throughout to aid communication and inclusion (Støttrup et al., 2017).
    - Including stakeholder involvement tools to enhance cooperation, inclusion, and incorporation of stakeholders to the process (Inácio & Umgiesser, 2019). Alongside recent works improving upon the use of stakeholders in collaborative decision making (Gillgren et al., 2019).
- The freedom the SAF provides in the system formulation step allows for flexible application to different testing areas. This may increase the applicability and adaptive nature of the framework dependent on area specific factors, such as funding or data type (McFadden et al., 2010).
- It can support interdisciplinary research and collaboration between the natural and social sciences (von Wehrden et al., 2018).

- It can help to inform policies and decision-making at local, national, and global levels (Seddon et al., 2016).

Weaknesses:

- The success of the framework is heavily reliant on data and information, which may not always be available or accurate.
- A lack of supporting tools regarding stakeholder engagement and the development of indicators hinder the application of the SAF in practice, as comparability may may not occur substantially between areas (Hopkins et al., 2011).
- Whilst some aspects promote simplicity of application (e.g., the prescriptive tools), the SAF has been criticised for the complex terminology used in the approach and for lacking guidance both on the inclusion of all parties, and on the implementation and monitoring steps in the context of policy and decision making (Inácio & Umgiesser, 2019).
- As an open methodological framework, a weakness of the approach is the requirement of experts to implement the steps. The most technical aspects of the methodology, such as stakeholder interaction and construction of the model and scenarios, are not rigidly defined and so further interpretation is required to implement these elements; without experts to aid implementation, the model may not work as effectively as designed (Tomlinson et al., 2011).

Opportunities:

- The growing recognition of the importance of sustainable management of marine resources is amplified in the SAF approach. Furthermore, the development of new technologies and tools for studying marine social-economic-ecological systems may advance in tandem with the appraoch.
- By implementing this approach, the opportunity exists to improve the availability of data and information on marine ecosystems for future use.

Threats

- It may face resistance from stakeholders who have vested interests in maintaining the status quo, or who may see the framework as a threat to their interests (Schlüter et al., 2014). This threatens the effectiveness of the framework and competing interests and priorities among stakeholders could lead to lowest common denominator effects.
- Political and economic pressures may pose threats to the implementation and upscaling of this framework.

The Turner et al. (2003a) Vulnerability Framework (VF)

This framework was designed to analyse a system at a location facing multiple changes and hazards. Turner (2003) defined vulnerability as “the degree to which a system or system component is likely to experience harm due to exposure to a hazard”. This analysis of vulnerability integrates previous models; it considers human and environmental conditions within a Risk-Hazards model (RH), and Pressure And Release (PAR) model to identify and map the sensitivity and resilience of a system. RH models focus on the analysis of understanding the effects a natural hazard will have upon an exposed system (a system vulnerable to stress or shock). The RH model was described as insufficient as it did not address the distinctions among components, nor how the system can use different tools (attenuation and amplification) to tackle impacts or hazards, and it lacks consideration for the social structures and institutions in shaping the system and the relevant hazards (Turner et al., 2003). PAR models were created in response to criticism of the RH model, this directed attention of vulnerability not being an outcome but a factor which contributed to a disaster as a result of socio-economic pressures (Blaikie et al., 2004). On review, the PAR model, whilst primarily used to address social groups in relation to disaster preparation and rebuilding, does not address the coupled human-environment system in considering biophysical subsystems (Turner et al., 2003a). Both of these approaches have frequently come under scrutiny for their "ad hoc" approach to representing appropriate variables and processes. This is a result of post-disaster analysis and management particularly with respect to modelling changes in human behaviour when looking to create anticipatory management measures (Feola & Binder, 2010). To overcome these deficiencies, the vulnerability framework addresses the three main concepts embedded in the RH and PAR models, these being entitlement, diversity, and resilience (Figure 20), as well as accounting for the human-environment system and its different scales (Turner et al., 2003).

The vulnerability framework, as a whole, aims to bring direct focus to the coupled human-environment systems and how the affected processes operate at different spatial-temporal scales (Brugère & De Young, 2016). In Figure 20, the differing scales refer to the place of study (depicted in blue), its region (depicted in yellow) and the wider global area (depicted in green) (Turner et al., 2003).

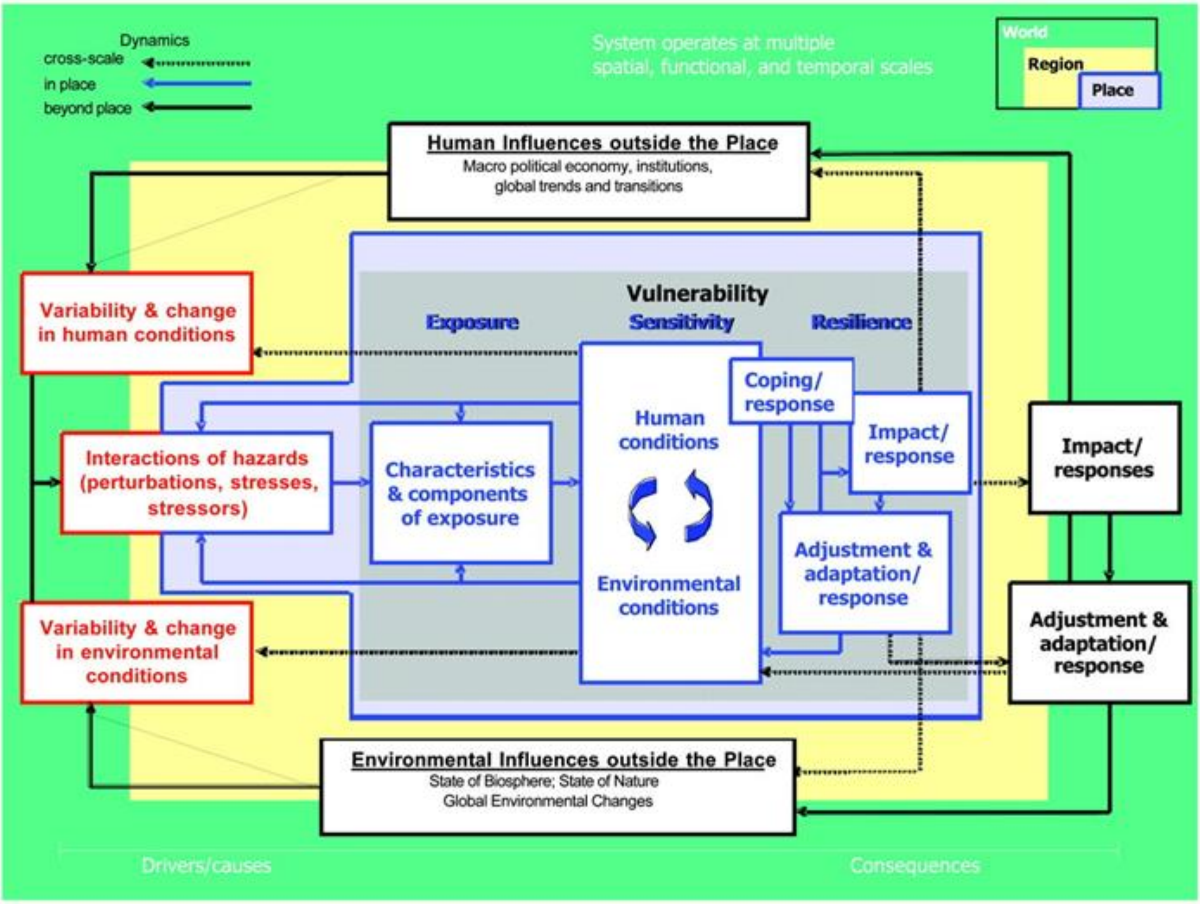


Figure 20: The Turner Vulnerability Framework illustrating the nested systems within the scope of influence, these being blue-place, yellow-region and green-world (Taken from Turner et al., 2003).

The central focus of the framework is where vulnerability is situated, the vulnerability context, denoted by the internal grey section in Figure 20. This vulnerability context consists of the basic components of the vulnerability analysis and includes the linkages to broader human and biophysical conditions of the system, the perturbations and stressors that emerge from the system conditions, and the coupled human-environment system incorporating vulnerability. The three components within the vulnerability context of the framework identify its exposure, sensitivity, and resilience (resilience being referred to as the system capacity to adapt (Turner et al., 2003a)) (see also Figure 21). Exposure is argued to be an external characteristic of a system and relates to effects of impacts outside the system. Sensitivity is considered to be an internal characteristic of the system, as it is the degree to which the system is affected by the exposure to risks. In contrast, resilience/ adaptive capacity is the ability to cope and recover/ adapt following the impacts of stressors.

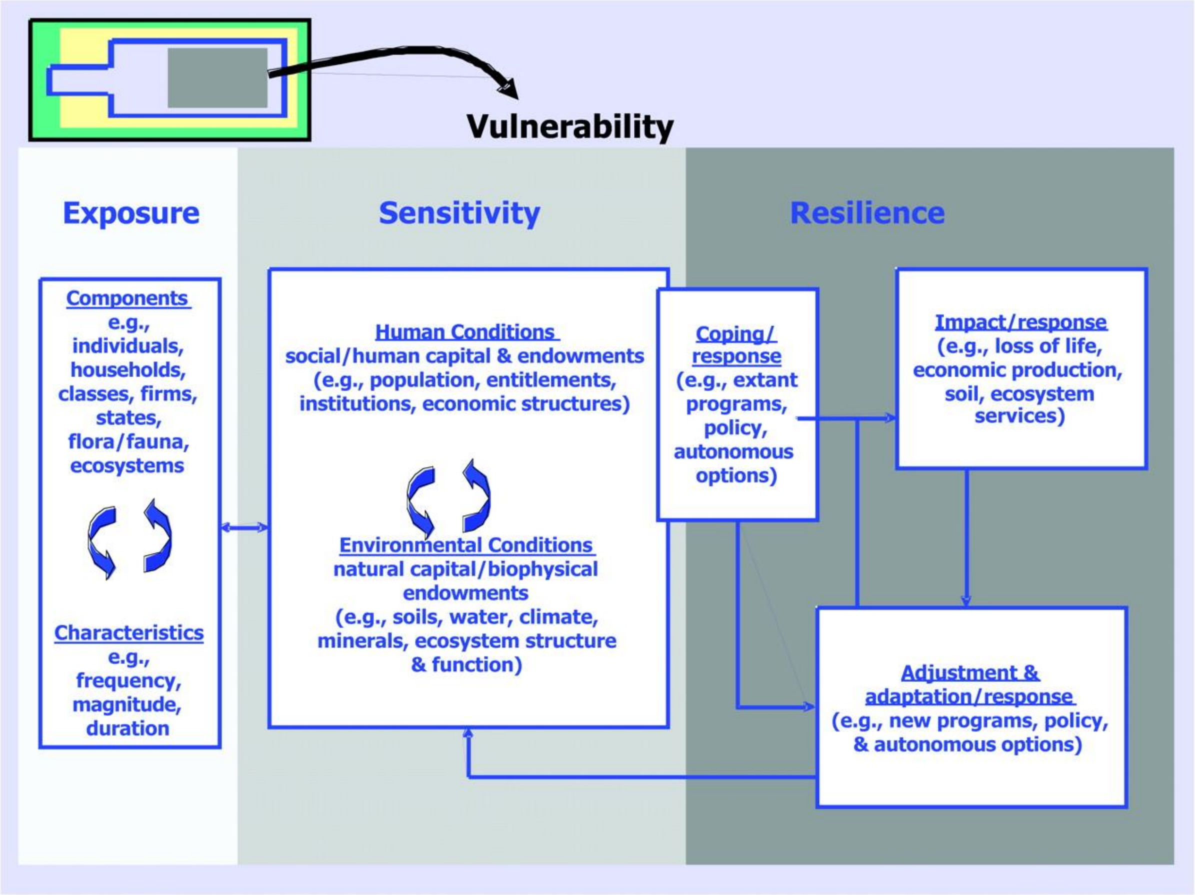


Figure 21: Details of the exposure, sensitivity, and resilience components of the vulnerability framework. Figure at the top left refers to the full framework (Taken from Turner et al., 2003.

Overall, this framework sets out what information is necessary to assess a coupled human-environment system and to map the effects of processes relating to vulnerability; however, there is no prescribed method of application.

SWOT analysis of the VF

Strengths:

- It can support interdisciplinary research and collaboration between the natural and human systems (von Wehrden et al., 2018).
- It can help to inform policies and decision-making at local, national, and global levels in strengthening systems adaptive capacities (Seddon et al., 2016).
- It presents many features relating to resilience and adaption, although this is solely in the context of vulnerability.

Weaknesses:

- It is a conceptual framework with no prescriptive method of application, so much development would be necessary to align with the goals of Marine SABRES, which may prove a barrier when applying to the demonstration areas.

- It may be difficult to quantify and measure the various components of the framework (e.g., exposure, sensitivity, adaptive capacity) in a precise and objective way; this will also hinder comparability between systems.
- The outcome information relating to the vulnerability context may not provide achievable strategies for reducing risk due to the conceptual nature of the framework (Turner et al., 2003b). Hence there may be a misalignment with the Marine SABRES project goals.

Opportunities:

- The various temporal and geographical scales could assist the prioritisation of interventions and issues.
    - This could potentially provide opportunities at a policy level to support policy-making related to risk management and climate change adaption in relation to vulnerable communities, such as coastal areas, hence, enhancing sustainable ecosystems.

Threats:

- The impacts of climate change on marine ecosystems could offer additional unforeseen impacts that the framework may not be equipped to tackle, for example, cumulative effects.
- A lack of prescriptive methods may result in differing applications and reporting of the framework when used and further upscaled throughout Europe (Turner et al., 2003b).

Evaluation summary

All the frameworks have been scored according to set criteria which allows direct comparison between them (Table xx?). All frameworks were found to recognise the interconnectedness of human and natural systems and promote opportunities to develop the marine environment sustainably but this was expected given the criteria by which they were chosen. The frameworks presented qualities that were resilient and adaptive in nature, an example being the use of feedback loops to cope with change and introduce new information to the system. The consistency of these characteristics emerging within the various SESs highlights their importance.

Table 10: Criteria Comparison table of all the analysed SES frameworks.

Criteria	EF	ESF	IEA	ISA	SESF	SEAS	SLA	SAF	VF
Simple in application									
Resilient and adaptive features	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
Unbiased in outcomes	**X**	**X**	**X**	**X**	**X**	**X**		**X**	
Ability to consider scales (temporal and functional)	**X**			**X**	**X**	**X**			**X**
Holistic	**X**	**X**	**X**	**X**	**X**	**X**		**X**	
Balances consistent application and restriction of actions.	**X**	**X**	**X**	**X**			**X**	**X**	**X**
Adequate inclusion of stakeholders and sectors		**X**	**X**	**X**	**X**		**X**	**X**	
Previously applied to the marine environment.	**X**	**X**	**X**	**X**	**X**	**X**		**X**	**X**
Total Score	**6/8**	**6/8**	**6/8**	**7/8**	**6/8**	**5/8**	**3/8**	**6/8**	**4/8**

PART C: Identification and discussion of the SES framework(s) most fit for the purposes of the Marine SABRES project

This section addresses the various frameworks that offer desired characteristics and beneficial approaches to designing the Simple SES. The interrogation of the various frameworks, explored in the above (Part B) SWOT analysis and criterion comparison (Appendix V), leads to the recommendation of the Integrated Systems Approach (ISA) (Elliott et al., 2020b). This approach should be coupled with components of the SAF framework, especially concerning prescriptive methods and the evolution of stakeholder involvement (Støttrup., et al. 2017). Additionally, the systems concepts associated with scales (Panarchy) from the EF and the need to accommodate variability are recommended for incorporation to enhance the ISA's alignment with Marine SABRES objectives, and to ensure the resilient application of marine EBM approaches.

Both the ISA and the SAF frameworks emphasise the pivotal role of stakeholders with the ISA endorsing their consistent participation and integrating the ten-tenets for achieving meaningful outcomes of successful and sustainable marine management (Elliott et al., 2020b). Similarly, the SAF includes a Stakeholder Preference and Planning Tool, which enhances the collaboration and inclusion of stakeholders (Støttrup et al., 2019; Inácio & Umgiesser, 2019). Furthermore, the SAF has beneficial recent advances of the importance of including all stakeholders, particularly citizens, to refine system dynamics in SES creation (Gillgren et al., 2019). The SAF, while prescribing tools and actions, has been criticised for its complex terminology and certain ambiguities regarding stakeholder inclusion (Inácio & Umgiesser, 2019). In contrast, the ISA, particularly if it incorporates a Process and Information Management System, to encompass the subsystems relating to data provenance, evaluation, governance, and management processes of part a, b , and c; it will expand the capacity to address these gaps, focusing on policy, communication, and administrative aspects (Elliott et al., 2020b).

Whilst the ISA has the capacity to account for transboundary scales, attributes from the EF and VF consider scales, both temporal and spatial, which are key desired characteristics of the Simple SES. An EF core concept is Panarchy, which as previously described, informs how systems function across various scales, with a capacity to consider temporal, spatial, and institutional scales with govern the SES. Within the EF, the life cycle of a system goes through exploitation, conservation, creative destruction, and renewal (Holling, 1994). The process of the life cycle can be then compared to processes on differing levels in hierarchies in the specific SES, to identify leverage points of action and change to create desirable outcomes when designing response measures. When response measures are implemented without consideration of scale, adverse management outcomes may ensue. A well-documented example is that of coral reefs, where the impact of nearby terrestrial ecosystems on coral reef systems is often not accounted for in management measures (Norstrom et al. 2016). Moreover, as a sustainability-based framework, the underpinning adaption and resilience theory offers the possible application of the process to different scales, and the linkages between these scales. The Panarchy framework explains how system resilience can ensure adaptation and change over time, emphasising how changes in a system at one level are affected by the larger-scale systems within which they are embedded, and the smaller-scale systems embedded within them (Garmestani et al., 2009). Incorporation of the EF's inherent acceptance of systemic decline permits management to engineer strategic response measures to strengthen the SES variability (Holling, 1994).

Although the ISA incorporates endogenic and exogenic pressures, further application is required to address different ecosystem scales. This gap can be mitigated using insights from EF and Turner's Vulnerability Framework (VF). While the VF considers vulnerability across system, regional, and global scales (Turner et al., 2003), the EF, rooted in sustainability, acknowledges scales through nested hierarchies encompassing various stages of a system life cycle. This perspective is enhanced when viewed through the Panarchy lens, which interconnects hierarchies of adaptive cycles and emphasises the interdependence of systems of different scales (Garmestani et al., 2009). This lens of Panarchy acknowledging both endogenic and exogenic pressures will enable the ISA to deal with various environmental variety, for example the potential to address cumulative effects and climate change impacts.

A key attribute of the ISA applicability is in its consistent terminology, aiding in stakeholder consultations and data comparisons. Enhancing this strength would require incorporating the SAF prescriptive actions and tools. However, it is of note that the inherent data-intensive nature of the ISA demands extensive information for effective implementation (Jorge-Romero et al., 2022). Despite this, the data-centric nature of ISA has the potential to integrate local knowledge and facilitate data sharing when upscaled, promoting efficient predictive and mitigation strategies (Elliott et al., 2017b).

Considering uptake potential, established frameworks such as the SESF, SAF, and ISA hold prominence. While SESF (initiated by Ostrom, 2007) has been a trusted choice for analysing complex adaptive systems, both the ISA and SAF have demonstrated efficacy in marine contexts (Støttrup et al., 2017; Lovecraft & Meek, 2019; Støttrup et al., 2019; Mahrad et al., 2020). The ISA provides a holistic marine environmental view, with its underpinning DAPSI(W)R(M) framework highlighting interactions of different marine SES facets through a cause-consequence-response method. While certain literature criticises its anthropocentric inclination (Binder et al., 2013), the ISA focus on environmental relationships supports biodiversity conservation measures, thereby aligning with Marine SABRES and EBM goals.

PART D: Review of relevant concepts, theories and associated methodologies from the systems discipline to enhance SES theory and practice.

12 Principles of the Ecosystem Approach

The Convention on Biological Diversity (CBD) is a multi-lateral treaty created at the Earth Summit in Rio De Janeiro in 1992 (STOCK, 1992). It is a key document regarding sustainable development with the aspiration of three goals: the conservation of biological diversity; the sustainable use of its components, and the fair and equitable sharing of benefits arising from genetic resources (CBD, 1992). The Ecosystem Approach is considered by parties to the CBD as the primary framework for achieving sustainable development, this being the starting point for the practical implementation of EBM. The CBD includes 12 key principles that are to be considered holistically to ensure all relevant factors are accounted for. These 12 principles are:

Principle 1: *Management objectives are a matter of societal choice (CBD,1992).*

Principle 2: *Management should be decentralised to the lowest appropriate level (CBD,1992).*

Principle 3*: Ecosystem managers should consider the effects of their activities on adjacent and other ecosystems (CBD,1992).*

Principle 4: *Recognizing potential gains from management there is a need to understand the ecosystem in an economic context, considering e.g. mitigating market distortions, aligning incentives to promote sustainable use, and internalising costs and benefits (CBD,1992).*

Principle 5: *A key feature of the ecosystem approach includes the conservation of ecosystem structure and functioning (CBD,1992).*

Principle 6: *Ecosystems must be managed within the limits of their functioning (CBD,1992).*

Principle 7: *The ecosystem approach should be undertaken at an appropriate scale (CBD,1992).*

Principle 8*: Recognising the varying temporal scales and lag effects which characterize ecosystem processes, objectives for ecosystem management should be set for the long term (CBD,1992).*

Principle 9*: Management must recognise that change is inevitable (CBD,1992).*

Principle 10: *The ecosystem approach should seek the appropriate balance between conservation and the use of biodiversity (CBD,1992).*

Principle 11: *The ecosystem approach should consider all forms of relevant information, including scientific and indigenous and local knowledge, innovations and practices (CBD,1992).*

Principle 12: *The ecosystem approach should involve all relevant sectors of society and scientific disciplines (CBD,1992).*

The proposed framework, including additional elements from other frameworks, together with the use of systems concepts to bridge the gap between theory and implementation, aligns with these key principles in various ways. The use of the DAPSI(W)R(M) framework as an underlying structured problem identification and solution method resonates with principles 1, 4, 9, 11, and 12. The DAPSI(W)R(M) promotes societal choice (Principle 1) in a transparent way by considering social, economic (Principle 4) and ecological elements, with the use of stakeholders (Principle 12) throughout the framework to optimise evidence from multiple informants (Principle 11). Furthermore, the inclusion of principles such as the ten-tenets (Elliott, 2013) supports the ISA in achieving fulfilling principles 11 and 12. The circularity of the DAPSI(W)R(M) framework includes the use of feedback mechanisms to re-start the cycle to help manage change and benefit from lessons learned (Principle 9). The inclusion of Panarchy aids with the successful integration of principles 2, 3, 7, and 8. As previously explored, Panarchy considers different scales of the system, coupled with the systems thinking of nested hierarchies of systems; this allows for the assessment of adjacent effects (principle 3) at different hierarchical scales of the system to allow for delegation of decisions to the suitable level (Principle 2). This operation across multiple sectors and scales (Principle 7) can provide opportunities for appropriate goal setting on a short-term basis, as well as factoring in long-term approaches (Principle 8) for a sustainable flow of ecosystem services. Hence, this aligns with EMB principles to support biodiversity resilience and a sustainable blue economy.

Systems concepts, theories and methodologies

Systems thinking not only originated in multidisciplinary dialogues, but it is inherently multidisciplinary as all living and social systems share the same set of principles of organisation and properties (Capra & Luisi, 2014). There is much debate within the systems community in defining a system, however the application here follows Reynolds and Holwell (2020) who describe ‘systems’ as being constructs for engaging with and improving situations of real-world complexity”, hence, essentially systems thinking can refer to any approach that adopts a holistic approach to analysis. Here we discuss the relevant systems concepts and methodologies identified intended to complement the Simple SES approach for the purposes of the Marine SABRES project.

Holism

Holism suggests that systems and their properties should be viewed as interconnected entities, not merely as a collection of individual parts (Capra, 1996). This key philosophy within systems thinking challenges the traditional reductionist approach, which seeks to understand systems by deconstructing them into their constituent components. Instead, holism emphasises that the entirety of a system is greater than the mere sum of its parts, and that its full nature can only be understood by looking at it in its entirety, accounting for all interactions and relationships within (Bertalanffy, 1968).

In the context of the Simple SES, this holistic perspective is important given the need to understand and address SESs in their entirety, recognising that the variety of components within an SES – ecological, social, economic, or cultural – are deeply interlinked and interdependent (Ostrom, 2009). Any intervention or management strategy proposed without this holistic view risks ignoring key factors which may exasperate the issue which is intended to be fixed (Meadows et al., 1972; Holling, 1973). Another indication of holism for the Simple SES is its contribution to the approach for stakeholder engagement. Recognising that local communities, policymakers, industries, and other stakeholders are integral components of the system, the ISA seeks to integrate their insights, concerns, and aspirations into its analysis (Ostrom, 2009). This not only enriches the depth and breadth of the understanding but also fosters collaborative and inclusive decision-making for co-creating an SES.

In summary, holism, as an intrinsic element of systems thinking and a complementary concept of the Simple SES, viewing SESs as interconnected entities can account for the multi-faceted nature of the challenges and opportunities within these systems. This, in turn, enables solutions that are holistic, sustainable, and aligned with EMB and Marine SABRES goals.

Complexity

Complexity refers to the intricate interconnections and interdependencies among the system components, which lead to emergent behaviours and non-linear outcomes that are often unpredictable (Kauffman, 1993; Lovelock, 2007). Addressing such a complexity necessitates a holistic approach, acknowledging the multifaceted interactions and feedback loops within the system rather than isolating individual elements. Complex adaptive systems (CAS) can be characterised by many components interacting in multiple ways, with each other and their environment, for example the marine environment (Schneider & Somers, 2006). Mainly emerging from self-organisation rather than external design, CAS present emergent outcomes (e.g., the depletion of fish stock in an area from overfishing) as a result of interactions between components (Zimmerman et al., 1998).

Complexity theory is valuable when applying an EBM approach through the use of SES frameworks in understanding the system complexity in order to make appropriately informed decisions for the management of the system. Complexity emphasises the existence of interactions between elements within a system, and the accompanying feedback loops which change the systems constantly (Schneider & Somers, 2006). CAS is relevant to creating the Simple SES, as the reduced understanding of an intricate system could undermine the capacity to effectively deal with important combinations of marine Activities and Pressures. In addition, the existence of multiple stakeholders with varying levels of understanding of the systems of concern, and different claims and concerns, means that there is no singular accepted SES framework or model that is widely recognised or applied. Accounting for the intricacies of different interacting elements of a system will improve understanding, hence, considering complexity theory when reviewing potential Simple SES frameworks and framework elements.

Variety Engineering

Variety is a measure of complexity, and variety engineering refers to the understanding and use of systems interactions to ensure a balance is met to promote the viability of the system (Flood & Carson, 1993). Hence, a system which includes prevention measures or mitigation resources encompasses responses to tackle different challenges which arise, and so the system will continue to exist and operate with its usual function; this is regarded as functioning within Ashby's Law of Requisite Variety (LORV) (Ashby, 1991). This concept is applicable to the CAS of the marine environment and provides practical considerations when designing an adaptive Simple SES. An example of requisite variety in practice is the cybernetics-based Viable Systems Model (VSM) which operationalises LORV (Ashby, 1991).

The Viable Systems Model (VSM).

Developed by Beer (1984), this model was created by applying management cybernetics to human organisations (Beer, 1984) and is used to identify organisational problems and shortcomings to create an autonomous and adaptable system. The term cybernetics relates to the circular communication structures within a system (Lowe et al., 2020), whereas recursion refers to the vertical movement within the nested hierarchies of the VSM. Consisting of five systems (1-5), the model considers both internal and external factors relating to actors within the system, it further shows how the different systems will communicate internally in the subsystems but also within the big-picture of the overall system.

Within this framework, System 1 encompasses the primary undertakings and actions (Beer, 1984) which, in a marine-oriented setting, could be synonymous with the foundational operations of a fishery. For example, various fishing methodologies, e.g. trawling, dredging, or gill netting, can be perceived as diverse, yet occasionally overlapping sectors that constitute this primary activity. System two then connects the primary operations carried out in System 1. Its principal role is to produce a flow of information, coupled with the necessary regulatory oversight (Beer, 1984). This intricate web of connections facilitates the System 3 role in monitoring and administering the internal processes of the system (Beer, 1984). In the extensive marine SES, System 3 may mirror the regulatory and administrative bodies ensuring that fishing practices are both sustainable and effective, for example the English Marine Management Organisation (MMO). Furthermore, this system acts as an agent, interacting with the more external-oriented Systems 4 and 5.

System 4 stands as the system's external sentinel, with its primary orientation being the broader external changes and dynamics (Beer, 1984). In practical terms, this could translate to a continuous assessment of the marine ecosystem health, and the impending threats from external factors such as pollution or climate-induced changes, and recalibrating operations in response. Concluding the suite is System 5: Policy, positioned at the top of management, this system in the marine realm and elsewhere is the overarching policy imperative. It synthesises inputs from its subordinate systems, mediating and harmonising demands, and in the process, crafts the overarching directives for the organisation (Beer, 1984). In the context of Marine SABRES, it ensures that the objectives of the marine SES are harmonised with broader goals such as sustainability, conserving biodiversity, and balancing diverse stakeholder interests.

Underpinning the VSM is its holistic approach, by leveraging cybernetics, it ensures varied levels of communication and response to both internal and external events. For a marine SES, the integration of VSM provides a robust framework ensuring that the SES model is responsive to environmental shifts and internal variances. It ensures the SES has qualities to promote resilience to adapt, fostering its long-term viability and alignment with its EBM goals. Such an all-encompassing perspective ensures that the SES remains prepared in relation to its dynamic marine environment, making necessary adjustments to fortify its overall coherence and sustainability in an approach.

Systems modelling techniques

Causal Loop Diagrams (CLDs) are but one facet of a broader suite of systems approaches to modelling. For instance, System Dynamics (SD) modelling expands on the foundational concepts of CLDs by introducing Stocks and Flows diagrams (e.g. Forrester, 1961). Stocks represent accumulations or reservoirs of resources, be they tangible such as water in a reservoir, or intangible such as reputation in a community. Flows, on the other hand, represent the rates at which these stocks change over time, driven by various factors (Sterman, 2000). These Stocks and Flows diagrams are quantified versions of CLDs, allowing for detailed simulations of system behaviour over time (Sterman, 2000). In the ecological context in Marine SABRES, the stocks and flows are analogous to ecological structure and functioning respectively in that structure refers to a situation at one time whereas functioning refers to rate processes (Gray and Elliott, 2009). Another essential tool within this discipline is provided by differential equations, which give a greater quantitative understanding of system dynamics. Integrating these various systems modelling techniques enables researchers and decision-makers to achieve a richer and more nuanced understanding of complex systems. Whether in forecasting environmental impacts in marine systems or understanding socio-economic shifts, these tools, grounded in systems thinking, offer a robust framework for analysing, predicting, and managing intricate systems dynamics.

CLDs are rooted in systems thinking and are designed to visually represent the intricate interrelations between system variables (Senge, 1990). CLDs are complementary to the ISA approach, as they offer a visual tool to understand the numerous connections within a system in a simpler approach compared to Systems Dynamics and stocks, and flow modelling which would require expert input. Hence providing insight to the behaviour and intricacies within a system but in a more simple to understand approach compared to stocks and flows and systems dynamics models. These CLD diagrams illustrate the complexities of systems by identifying both reinforcing and balancing feedback loops. They enable unravelling the causal relationships and cyclical patterns that characterise the behaviour of systems (Richardson, 1991). By doing so, they pinpoint potential leverage points for intervention, especially in fields such as marine and water management where ecological and socio-economic variables are closely intertwined (Ostrom, 2009).

Leverage points refer to those places within a complex system where a small shift can produce significant impacts on the system as a whole. Identifying and acting upon these points can lead to effective and sometimes transformational change (Meadows, 1999). The idea was popularised by Meadows (1999) in her influential work, where she argued that systems could be transformed by identifying and adjusting these critical points. Hence, by dissecting the structural underpinnings of SESs, CLDs have the capacity to empower decision-makers to devise strategies that account for the system's inherent complexities and behaviours.

Behaviour Over Time (BOT)

BOT graphs, informed by systems thinking principles, provide a visual framework for understanding the temporal dynamics of specific system variables and are analogous to time-series graphs and their analysis in field and experimental sciences. These graphs capture historical patterns, trends, and potential future trajectories, offering stakeholders an intuitive indication of how particular phenomena have evolved over time and give insight into the behaviour of an element within the system (Kopainsky et al., 2015). Within the SES approach, BOT graphs can serve as instruments, grounding understanding in empirical data and projected patterns, for a data-driven approach.

Boundaries of systems and boundary critique

Boundary critique, a concept cultivated by Ulrich (1983) within the realm of systems thinking, serves as a pivotal element when intertwined with the discourse of SESs. Boundary critique is fundamental to achieving inclusivity and holism in the context of SES, and by methodically interrogating what does and does not lie within the system's boundaries, the SES can embrace a comprehensive approach. This guarantees that an array of stakeholders, ranging from local fishermen, to environmental NGOs, to governmental bodies, are adequately represented, and their perspectives incorporated, in co-creating and implementing the SES. Furthermore, this systems tool assumes an ethical dimension in the act of discerning who has the authority to characterise the system, and who might be influenced by such definitions (Ulrich 1983). The SES approach can pave the way for decisions that are rooted in ethical considerations for those with interests relevant to the SES. For the SES, this could manifest as amplifying the voices of marginalised groups, thereby allowing them to exert greater influence in dialogues that bear implications for them.

In essence, by weaving boundary critique into its approach to stakeholders, the ISA approach can more accurately, ethically, and comprehensively navigate the intricacies of SESs. This ensures that all relevant voices are heard, and potentialities are considered when building a vision of the SES and making decisions based upon this information.

Ostrom’s Work

As a foundational author in SES research, Ostrom's research (1990, 2007, 2009) explores the complexities of SES interactions, warning of the inherent danger in oversimplifying these systems. Examining the commonly held notion of the "tragedy of the commons," Ostrom (1990) revealed how local communities often exhibit a remarkable capacity for collective self-governance, enabling them to manage shared resources sustainably. The risk of portraying these intricate dynamics simplistically is that it can lead to crucial misunderstandings. Hence, oversimplification between understanding of policy-making or interventions might be founded on partial insights, potentially rendering them ineffective or even counterproductive.

Drawing from Ostrom's insights, the Simple SES approach recognises the pivotal role that local communities play, endowed with rich, contextual knowledge of their ecosystems. To grasp these intricacies, ISA prioritises engagement with local stakeholders. Moreover, acknowledging the complexities of local governance, as highlighted by Ostrom (2007), necessitates that the ISA should continually revisit and adjust its assessments, ensuring alignment with the changing realities of the system. In valuing and integrating local insight, the ISA will aim to avoid oversimplification, ensuring a balanced approach that captures the depth and breadth of these complex systems while preventing any misinterpretations and being a salient and usable approach for actors within marine EBM.

PART E: The Simple SES Approach.

Given the comments and analysis throughout this review, the recommended framework for use in the Marine SABRES project is the Integrated Systems Analysis (adapted from Elliott et al., 2020b) (Figure 23). However, acknowledging the underpinning SES theory (Berkes and Folke) and the SESF approach (Ostrom et al., 2009) was necessary for selecting the chosen framework. Complementing systems theories, concepts, and methodologies discussed in the previous section have found roots in the ISA operationalisation, to be further referenced and explored in the Simples SES guidance document (Marine SABRES Deliverable 3.2).

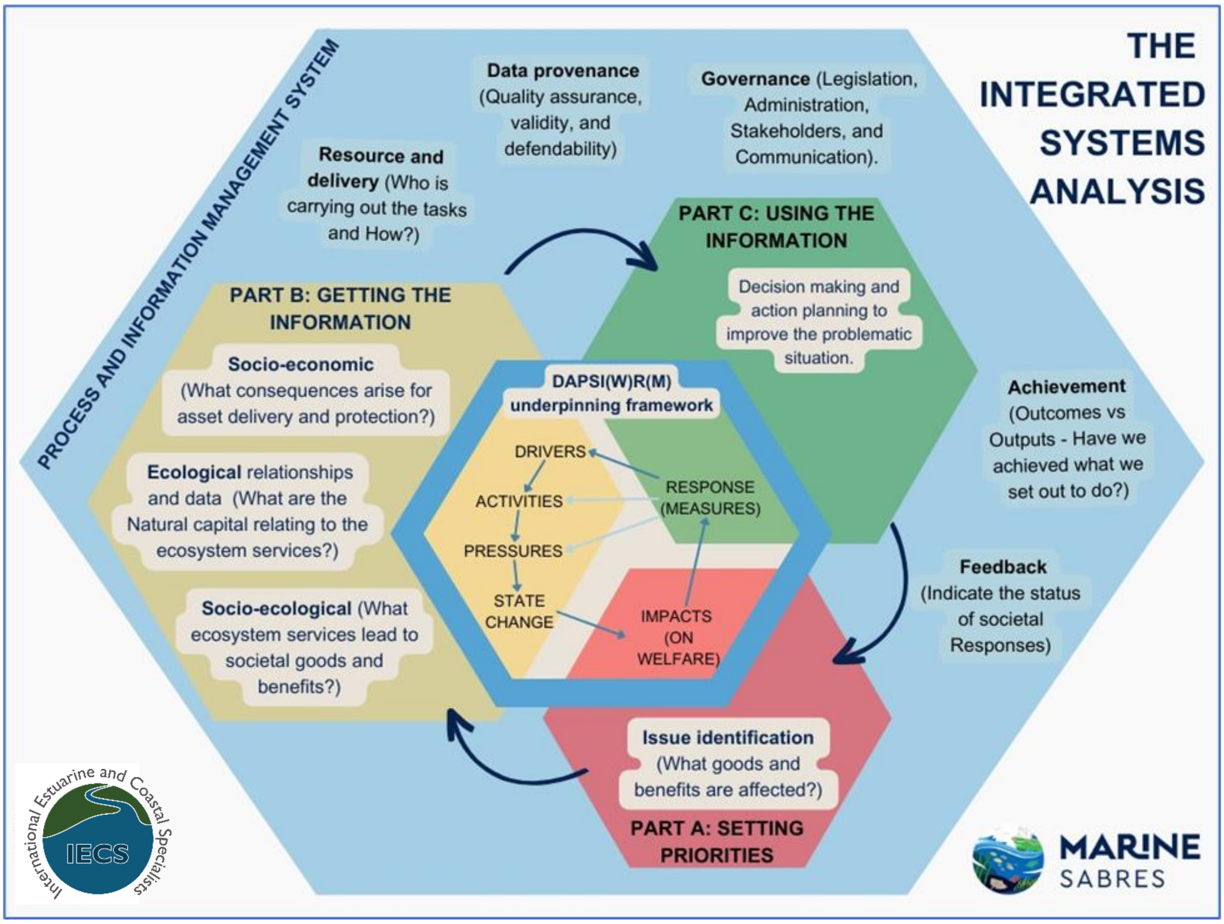


Figure 22: The integrated systems analysis expanded, adapted and redrawn from Elliott, et al., (2020).

As indicated above, the ISA employs three phases and 14 sub-systems to address different elements of an SES (Elliott et al., 2020b). At the heart of operationalising the framework, the ISA functions in a nested operational system, with the DAPSI(W)R(M) framework (pronounced *dap-see-worm*, Elliott et al., 2017a) being pivotal to its application. This framework is surrounded by the three stages of the ISA: setting priorities, gathering information, and using the information. The essence of this framework is to define the Drivers, which are fundamental human needs, and the Activities through which these drivers are achieved. These Activities then give rise to Pressures, as the mechanisms of change, which subsequently result in State Changes to the natural system and the Impacts on human Welfare. The Drivers, Activities, and Pressures necessitate Responses, implemented through management

Measures, to avert such alterations to the natural and social systems (see also Figure 2 in Elliott, 2023).

The sub-system arrangement (Figure 23) differs from the original approach (Elliott, 2020), as the intertwined nature of data provenance, governance, and resource and delivery are not separate sub-systems. Instead, they serve roles within the overall management system, hence the amended diagram in Figure 1. The ISA offers a comprehensive perspective of the marine environment, accounting for numerous factors and interactions. Identifying principal determinants of change and understanding their repercussions on the ecosystem will pave the way for more efficient and sustainable management strategies.

The operationalisation of the ISA method requires a hierarchical structure aimed at comprehending various facets of the Socio-Ecological System (SES) (Figure 24). The initial phase of the three ISA stages as portrayed in Figure 23, which focuses on prioritising marine management initiatives, necessitates the recognition of human welfare impacts. This encompasses effectively identifying and communicating with stakeholders, establishing priorities, and formulating the criteria for successful intervention. To make these elements operational, it is necessary to incorporate the Process and Information Management System (PIMS). These foundational elements involve holistic process management, encompassing areas such as data management strategies, logistics, stakeholder identification and communication, and goal-setting, together with evaluation.

When determining priorities, there's an imperative to substantiate the rationale behind any management Response Measure. Any Response Measures must derive from a human agency, hence, any Impacts on Welfare become the imperative for intervention. Phase B is characterised by the accumulation of data. Here, the objective is to understand and interrogate the dynamics between social-economic elements and ecosystem services in the context of the influences from State Changes, Pressures, Activities, and Drivers. This produces a logical causal structure associating the Welfare Impacts to the ramifications on societal goods and benefits (Elliott, 2023). Such information is to be accompanied through tools of Excel spreadsheets, facilitating the evaluation of the Behaviour Over Time (BOT) graphs of elements and their integration into Causal Loop Diagrams (CLD), which serve as a qualitative tool to understand how elements act within the SES. The third and concluding phase is characterised by data-driven decision-making, targeting stakeholders, policy architects and implementers, and other influential entities. Analysing the system pertinent to the existing issue is imperative; Causal Loop Diagrams (CLDs) offer invaluable insights for this analysis and aid in the strategic formulation of responsive actions. In addition to comprehension provided by BOT, graphs further clarify the system data-driven characteristics.

By executing these three phases, the justification for intervention is constructed by probing the problem context and indicating the suitable means for intervention via Response Measures. This methodology is encouraging of further iterations, hence meaningful insights are able to be re-incorporated post-intervention, the ensuing decisions and actions provide a precedent for future improved decision-making, culminating in a feedback-driven learning cycle centred on this intrinsic problem-analysis mechanism.

The iterative learning cycle that orbits the core system operates in an anti-clockwise direction, grounded in the DAPSI(W)R(M) Framework (as visualised in Figure 24). Therefore, in addressing the DAPSI(W)R(M) stages systematically culminating in the problem situation, we are enhancing stakeholder comprehension and fostering a holistic system perspective. The DAPSI(W)R(M) framework and its embedded learning cycle are nestled within the broader management framework, the PIMS, which integrates governance, administrative procedures, project management, stakeholder communication and engagement, and data provenance. These processes are not linked to singular DAPSI(W)R(M) stages but rather oversee and modulate the ISA's continual execution process. In essence, this overarching PIM system consistently appraises resource utilisation, stakeholder involvement, data provenance, governance and goal evaluation throughout the ISA process.

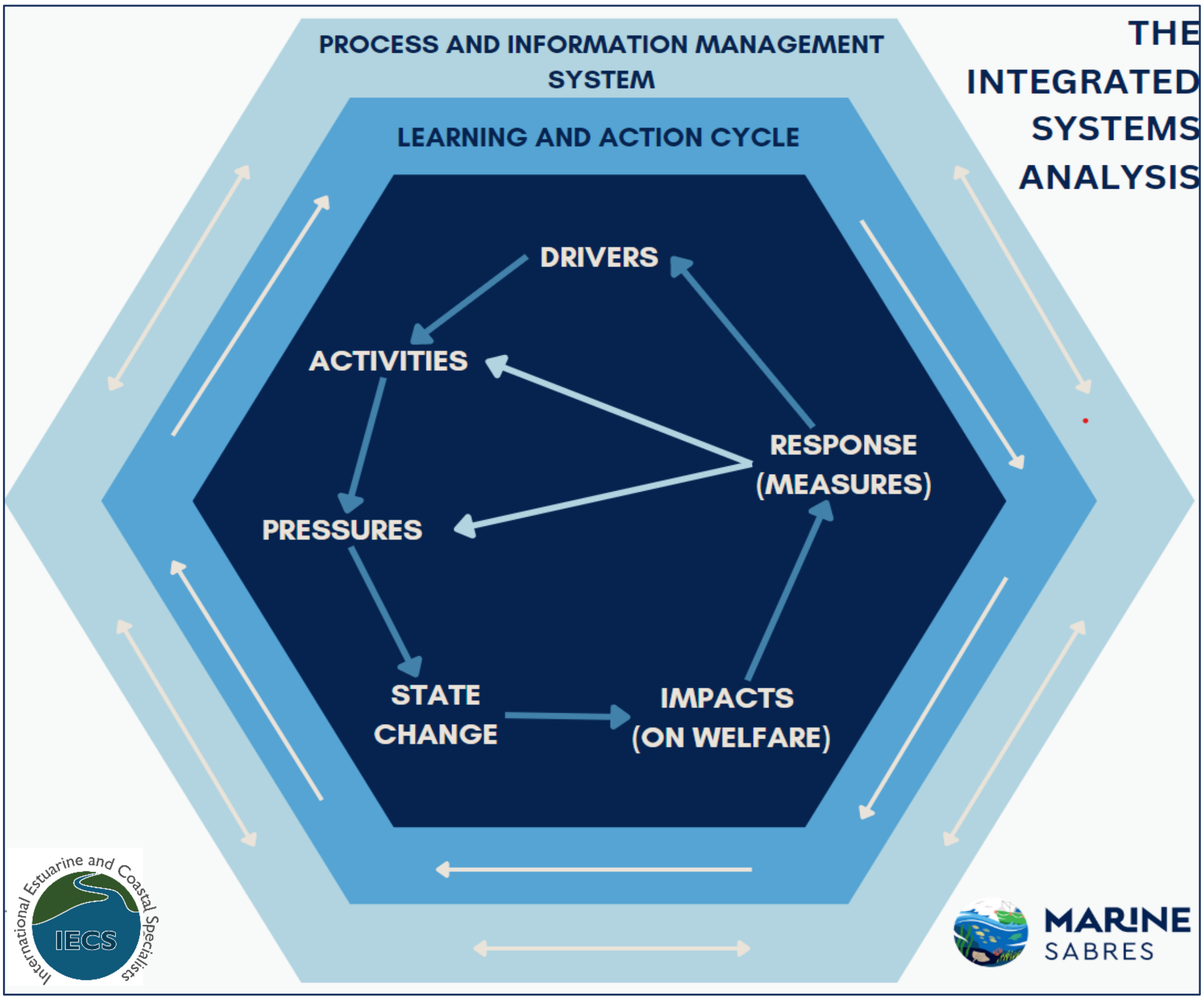


Figure 23: The operationalised ISA systems model (unpublished Gregory and Aitkins, 2023).

Altogether, this holistic approach, as presented in Figure 24, is the ISA and the Marine SABRES project Simple SES. The further development of operationalising the Simple SES approach and use within the project is to be detailed throughout the guidance in the project Task 3.2 and then followed by testing within the Demonstration Areas under WP4. In turn, this will be followed by a refinement of the approach under Deliverable 3.3.

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Appendix I

Overview of Marine SABRES.

Marine Biodiversity loss is continuing to decline despite current conservation efforts. Reversing the decline in biodiversity requires rapid roll out of effective conservation measures that can also enable a sustainable and resilient blue economy. Social-ecological systems-thinking and Ecosystem-Based Management are globally recognized tools to enable balanced marine development and conservation. Marine SABRES will co-design as Simple Social Ecological Systems approach (the Simple SES) to rapidly enable and upscale EBM across Europe and abroad. Marine SABRES will set European marine management on a course to reverse biodiversity decline, it will conserve and protect biodiversity by integrating sustainable ecosystems and a resilient blue economy; enable managers to make sustainable decisions; empower citizens to engage with marine biodiversity conservation; promote sustainable development and in coastal and marine sectors. Marine SABRES is comprised of an interdisciplinary consortium including world leaders in the field of EBM and Social Ecological System distributed across Europe and focusing demonstration of practical management efforts in three Demonstration Areas (Tuscan Archipelago, the Arctic North-East Atlantic and Macaronesia) before upscaling throughout Europe and beyond.

Overview of WP3.

Taking the priority components developed by stakeholders (in WP2), WP3 will combine established and emerging frameworks for systems analysis, and bring together the essential theoretical and practical components of systems analysis to design the Simple SES. It will focus on the simplest possible combinations of social, technological, economic, environmental, political, legal and ethical factors that confront decision makers and sectoral actors (e.g., fisheries, aquaculture, tourism and recreation.). The Simple SES will be designed to effectively address a representative subset of Drivers, Activities and Pressures affecting Ecosystems) and the Impacts on human Welfare (as ES and Societal Goods and Benefits). This Simple SES will focus on the minimum level of data and detail required to address individual natural resource management and environmental issues. We focus on creating methodological approaches with the minimum level of complexity required to make decisions using selected activities in the DAs. Taking the Marine SABRES Concept as a starting point, and in co-design with stakeholders, it will use best practice from other empirical and theoretical research to create a new, pragmatic, understandable framework. The Simple SES and supporting guidance will be rolled out to the DAs for application. Task 3.1. SES Development. (Lead: IECS, Participants: CEFAS, NIOZ, UCC, WU.). Based on the stakeholder generated System Descriptions of priority components and requirements (see D2.1), WP3 will generate a specification to ensure that the Simple SES is robust and sufficiently flexible to incorporate the social and ecological components of each DA and includes the functionality to provide useful and usable for all end users. A rigorous SWOT analysis of existing SES model, literature and past project output will supplement the stakeholder system-descriptions and design briefs to contribute to the development of the Simple SES (D3.1) for application in the DAs.

Appendix II

The relevant goals taken from the Marine SABRES project outline are to:

- Enable and upscale ecosystem-based management across Europe and abroad through integrating data and knowledge to understand the direct drivers of biodiversity decline and their interrelations.
- Reverse biodiversity decline: conserve and protect biodiversity by integrating sustainable ecosystems and a resilient blue economy
- Enable managers to make sustainable decisions.
- Empower citizens to engage in marine biodiversity conservation.
- Promote sustainable development in the coastal and marine sectors.
- Merge different systems used across sectors (science, policy, socio-economic) to reach holistic management solutions.
- Understand complex systems and identify the main drivers of biodiversity loss in areas with various levels of complexity.
- Develop and implement marine conservation interventions and policies.
- Set conservation management objectives and goals, identifying barriers, and developing holistic solutions.

Further goals to build on previous projects as stated in Annex 2 of the Marine SABRES projects include:

- Explicitly focus on the nested nature of marine social-ecological systems. This is essential to meet the emerging challenges of global climate change caused by pressures that are
    - (a) exogenous to a management area, i.e., where the causes of change originate outside the management area but the consequences are manifest within it (enabling the Simple SES to be applied to processes such as ocean warming).
    - (b) endogenic activities and pressures in which the causes and consequences originate inside a management domain.
- Directly address flows of supply and demand for ES at scales, balancing the requirement of human use and benefits of healthy ecosystems.
- Emphasise how social processes and subsystems can drive human behaviours to provide a more realistic picture of the social system dynamics.
- Provide an analysis tool and a source of solutions for systemic and emerging problems by identifying pathways for transformation to sustainable ecosystems and the Blue Economy.

Appendix III: Past project outputs

CERES Climate Change and European Aquatic Resources

AQUACROSS Knowledge assessment and management for Aquatic Biodiversity and Ecosystem services across EU policies.

RAGES (DG Environment)

DEVOTES

KNOWSEAS Knowledge-based Sustainable Management for Europe Seas

VECTORS of Change in Oceans and Seas Marine Life, Impact on Economic Sectors addressed.

TIDE (INTERREG North Sea Region Programme)

MAREFRAME Co-creating Ecosystem-based Fisheries Management Solutions

TAPAS Tools for Assessment and Planning of Aquaculture Sustainability

PANDORA-Paradigm for Novel Dynamic Oceanic Resource Assessments

JUSTNORTH- Toward just, ethical and sustainable arctic economies environments and societies

Appendix IV Literature Review papers resulting from the title and abstract screening.

KEY	
SESF	EF
SE-AS	IEA
ISA	ESA
VF	SAF
SLA	Comparative papers

Year	Title	Reference
2022	Integrating spatial and social characteristics in the DPSIR framework for the sustainable management of river basins: case study of the Katari River Basin, Bolivia	Afnan Agramont, Nora van Cauwenbergh, Ann van Griesven & Marc Craps (2022) Integrating spatial and social characteristics in the DPSIR framework for the sustainable management of river basins: case study of the Katari River Basin, Bolivia, Water International, 47:1, 8-29, DOI: 10.1080/02508060.2021.1997021
2020	DPSIR-ESA VULNERABILITY ASSESSMENT (DEVA) FRAMEWORK: SYNTHESIS, FOUNDATIONAL OVERVIEW, AND EXPERT CASE STUDIES	Anandhi, Aavudai & Mankin, Kyle & Srivastava, Puneet & Aiken, Robert & Senay, Gabriel & Leung, L. & Chaubey, Indrajeet. (2020). DPSIR-ESA Vulnerability Assessment (DEVA) Framework: Synthesis, Foundational Overview, and Expert Case Studies. Transactions of the ASABE. 63. 741-752. 10.13031/trans.13516.
2010	Institutional learning and adaptation to global environmental change: A review of current practice from institutional, socio-ecological, and complexity approaches	Espinosa, Angela & Andrade, German & Wills, Eduardo. (2007). Learning and adaptation to global environmental change: A review of current practice from institutional, socio-ecological, and complexity approaches.
2016	Advancing Empirical Approaches to the Concept of Resilience: A Critical Examination of Panarchy, Ecological Information, and Statistical Evidence	Kharrazi, Ali & Fath, Brian & Katzmair, Harald. (2016). Advancing Empirical Approaches to the Concept of Resilience: A Critical Examination of Panarchy, Ecological Information, and Statistical Evidence. Sustainability. 8. 10.3390/su8090935.
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