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Research, part of a Special Feature on A Framework for Analyzing, Comparing, and Diagnosing Social-Ecological Systems

Comparison of Frameworks for Analyzing Social-ecological Systems

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ABSTRACT. In this paper we compare 10 established frameworks for analyzing social-ecological systems. We limited ourselves to frameworks that were explicitly designed to be used by a wider community of researchers and practitioners. Although all these frameworks seem to have emerged from the need for concepts that permit structured, interdisciplinary reasoning about complex problems in social-ecological systems, they differ significantly with respect to contextual and structural criteria, such as conceptualization of the ecological and social systems and their interrelation. It appears that three main criteria suffice to produce a classification of frameworks that may be used as a decision tree when choosing a framework for analysis. These criteria are (i) whether a framework conceptualizes the relationship between the social and ecological systems as being uni- or bidirectional; (ii) whether it takes an anthropocentric or an ecocentric perspective on the ecological system; and (iii) whether it is an action-oriented or an analysis-oriented framework.

Key Words: *anthropocentric; conceptualization; decision tree; dynamics; ecocentric; ecological system; framework; human-environment systems; social-ecological systems; social system;*

INTRODUCTION

Complex environmental problems, such as climate change, biodiversity loss, resource scarcity, and resource degradation, e.g., water, energy, minerals (e.g., Vitousek et al. 1997) have been constantly increasing in relevance in both the scientific and policy communities. The experiences of various scholars have led to the insight that these complex problems cannot be analyzed with disciplinary approaches alone. They have to be dealt with in an integrative, interdisciplinary way that considers the interaction between social and ecological systems (Newell et al. 2005, Folke 2006, Young et al. 2006, Ostrom 2007, 2009).

Within the last decade, significant progress has been made with respect to interdisciplinary investigation and modeling of coupled social-ecological systems (SES). Various research approaches have been developed and applied to different studies in which the interaction between the social system and the ecological system has been explicitly considered (Young et al. 2006, Binder 2007, Liu et al. 2007). These approaches include:

- combining material or energy flows and economic flows (Duchin and Steenge 1999, Bouman et al. 2000, Kytzia et al. 2004; for a review see Binder 2007);
- modeling human behavior and drivers that specifically impact on an ecosystem or an ecosystem service (Redman 1999, Antle and Stoorvogel 2006);
- identifying and modeling specific goods that are relevant for the human system as well as for the ecological system (Liu et al. 2007);
- studying the resilience and adaptive management of social-ecological systems (Folke et al. 2002, Holling and Allen 2002, Walker et al. 2002).

Concomitantly, frameworks have been developed to set a common language, to structure research on SES, and to provide guidance toward a more sustainable development of SES (Redman 1999, Gallopín et al. 2001, Holling and Allen 2002, Newell et al. 2005, Ostrom 2007, 2009, Pahl-Wostl 2009, Scholz 2011). These frameworks differ significantly in their goal, their disciplinary background, their applicability, the temporal, social, and spatial scale addressed, and their conceptualization of the social and ecological systems as well as their interaction. This is mirrored in a high diversity of valuable results on different scales, which, unfortunately, impedes comparison of the results obtained via the different frameworks, and makes it difficult for scholars entering the field of research to obtain an overview of the frameworks available and to choose the appropriate framework to answer the research question addressed.

Hence, even though numerous interdisciplinary and integrative case studies, and the methods and frameworks developed therein, have significantly improved our understanding of the complexity of SES, various authors have raised the following issues for improving research endeavors on SES and enhancing the outreach to praxis of the research conducted: (1) It should become clear to what extent frameworks treat the human and the ecological dimension in equal depth and include their codevelopment. It would be particularly interesting if frameworks treated both subsystems in equal depth (Folke 2006, Sylvester and Redman 2008, Scholz 2011); (2) A portfolio of approaches and frameworks

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should be elaborated that supports international networks for integrative and interdisciplinary research (Turner and Carpenter 1999, Liu et al. 2007).

To this we add the need for a characterization and typology of frameworks that will allow researchers to choose the framework(s) that is/are most relevant to the issues they wish to address. A similar action was taken in the multidisciplinary field of information systems (IS). About 15 years after its emergence at the interface of computer science, decision science, management science, and organizational psychology, the IS community felt a need for structure and overview, and this led to reviews of paradigms and methodological frameworks for research (Galliers and Land 1987) and design (Olle et al. 1983).

We aim to contribute to these research challenges by providing a review of prominent frameworks in the research area of social-ecological systems. In so doing, we address four questions that relate to key issues raised by scholars when designing integrative or interdisciplinary studies (see also Turner and Carpenter 1999, Folke 2007, Scholz 2011):

- How are the social and the ecological systems and their dynamics conceptualized?
- How are the interaction and the dynamics between the social and the ecological systems conceptualized?
- To what extent are the social and the ecological systems treated equally with respect to analytical depth?
- How can we select the appropriate framework for a specific research issue studied?

This review results in a classification of frameworks, which can be used as a decision tree to support researchers in their choice of a specific framework depending on the issue studied.

TERMINOLOGY

For the sake of clarity, we begin by providing definitions for some terms that we will use throughout this article.

- Framework: A framework provides a set of assumptions, concepts, values and practices that constitute the way of viewing the specific reality (J. Hinkel, P. Bots, and M. Schlüter, *unpublished manuscript*).
- Social-ecological systems (SES): SES are nested, multilevel systems that provide essential services to society such as supply of food, fiber, energy, and drinking water (Berkes and Folke 1998). Other terms used to denote such systems are “socio-ecological system” (Gallopín 1991) or “human-environment system” (Turner et al. 2003*a*, Scholz 2011).
- Ecological system: We use this term even if the term used in the analyzed framework to refer to this concept is “environmental system.”
- Social system: We use this term even if the term used in the analyzed framework to refer to this concept is “human system.”
- Dynamics: By dynamics in SES we understand the way in which SES change over time, e.g., how and to what extent social structures change, how and to what extent learning in the social system plays a role, or what patterns of growth or change occur within the ecological system (http://www.businessdictionary.com/definition/dynamics.html#ixzz1jcWLXMGl; http://www.thefreedictionary.com/dynamic). Thus, we consider a framework to support dynamic analysis only if it provides a conceptual basis for understanding the feedbacks within and between the social and the ecological systems and their change over time. Furthermore, we differentiate between informal (natural language) and formal (mathematical language) descriptions of dynamics.

METHOD

Criteria used for selecting the frameworks

The primary criterion for deciding which frameworks to include in our comparison was that they should provide concepts for conceptualizing SES. We only selected frameworks that included the social and the ecosystems, as well as the interaction between them. Furthermore, the frameworks had to be general in the sense that they were explicitly designed for use by a community of researchers larger than its developers.

A further criterion for selecting frameworks was that they should be primarily conceptual in the sense that they provided concepts; this means that we disregarded frameworks that are primarily “procedural” in the sense that they provide sequences of steps, or a set of planning guidelines. Examples of such procedural frameworks are Integrated Coastal Zone Management (ICZM), Integrated Water Resources Management (IWRM), and Strategic Environmental Impact Assessment (SEIA). However, if such a procedural framework suggested using a particular way of viewing the system of interest, we either included the framework as such in our selection, e.g., The Natural Step, or we included only the suggested systems view, e.g., the DPSIR framework.

We first selected 16 potential frameworks basing ourselves on a general literature review of peer-reviewed journal publications and books that provided reference to, or report applications of, the frameworks. The literature review was combined with the snowball principle. The number of frameworks was then reduced to 10 using the criteria mentioned above.

Framework comparison

We compared the frameworks in two steps. First, we provided an overview of the frameworks, and discussed them on the

Table 1. Contextual criteria used to analyze the main characteristics of the selected frameworks.

Criterion	Question
Used for general description	
Name/acronym used	How is the framework referred to in the scientific literature?
Disciplinary origin	Which discipline does the framework depart from? In which discipline does it have its foundations?
Theoretical origin	On which theories does the framework base itself (implicitly/explicitly)?
Application fields	In which research fields can and has the framework been applied? What kind of research questions can be or have been addressed with the framework?
Used for analysis	
Purpose	For what purpose do the authors claim was the framework developed?
Temporal scale	What are the temporal scales at which the framework can be applied best (month, year, decades, etc.)?
Guidance/operationalization	Which type of guidance does the framework provide to operationalize its concepts and make it applicable to a real case study?

basis of contextual criteria; we then provided an in-depth comparison based on structural criteria.

Contextual criteria used in the framework comparison

Our contextual criteria related to the context in which a SES is studied (Table 1). In particular, they described where the frameworks came from, i.e., disciplinary origin and theoretical background, the purpose for which they were developed, the scales at which they operated on, the extent to which they provided a clear guideline for operationalization of their main concepts, and the fields in which they have been applied. Our characterization of the frameworks in terms of these criteria was based on our reading of only the primary sources.

Structural criteria used in the framework comparison

Our structural criteria (Table 2) followed from the key issues we listed at the close of the Introduction section. These criteria are defined as follows:

Conceptualization of the social system and its dynamics

To characterize how frameworks conceptualize the social system, we first studied the hierarchical levels (social scales) of the social system that were included in the framework, for example, individual, group, organization, society (Miller 1978, Scholz 2011). Second, we analyzed whether and how these different levels interact, and to what extent the frameworks consider interactions among different hierarchical levels. We distinguished the following categories:

Macro: depicts the social system only at the macro level, i.e. society, not including the level of the individual
Macro → Micro: provides concepts in which the macro level, i.e., societal or governance system, influences the micro level, e.g., individual users, consumers, etc.
Micro → Macro: sets the focus on the micro level, i.e., individual decision making and learning, and how this impacts the macro level, e.g., group, society
Micro: considers only the micro level, e.g., individual decision making, without considering the upper levels
Macro ↔ Micro: considers the duality between the macro level, i.e., social structure, and the micro level, agency (Giddens 1984), that is, social structure influences individual behavior, and individual behavior perpetuates or changes the social structure. Whereas the first is synchronic, the second is diachronic, that is, delayed, in time (see also methodological individualism / individual collectivism).

Third, we analyzed how dynamics within the social system are conceptualized, i.e., whether the frameworks explicitly conceptualize feedbacks within and between the social levels, in natural or formal language.

Conceptualization of the ecological system and its dynamics

To characterize how frameworks conceptualize the ecological system, we first considered two main views: (1) conceptualization from an anthropocentric perspective, which defines the ecological system based on its utility for humans; (2) conceptualization from an ecocentric perspective, which defines the ecological system based on its internal functioning. Second, we analyzed the extent to which hierarchies in scale and space are included. Third, we looked at how the dynamics of the ecological system are conceptualized. Here we considered whether the frameworks only describe the dynamics occurring (in natural language), or whether they specify the dynamics in formal language, e.g., using difference or differential equations.

Conceptualization of the interaction between the social and ecological systems and its dynamics

To characterize how frameworks conceptualize the interaction between the social system (S), and the ecological system (E), we followed the classification used by Scholz and Binder (2003) and Scholz (2011) who identify the following three forms of interaction:

E → S: the ecological system influences the social system
S → E: human activities affect the ecological system or ecosystem services

Table 2. Structural criteria used to analyze the selected frameworks.

Criterion	Question
Social system	
Name of the social system	By which term is the social system referred in the framework?
Scale of social system	Which social scales does the framework include, e.g., individual, group, organization, society?
Conceptualization of social system and its dynamics	How is the social system conceptualized? How are the dynamics within and the interactions between the levels of the social system considered?
Ecological system	
Name of the ecological system	By which term is the ecological system referred in the framework?
Scale of ecological system Spatial scale	At which spatial scales has the framework been applied and can it be applied, e.g., local, regional, global?
Conceptualization of ecological system and its dynamics	How is the ecological system conceptualized? Are different hierarchical levels considered? How are the dynamics within the ecological system considered?
Social-ecological system	
Conceptualization of the interactions within SES and their dynamics	How is the interaction between the social and the ecological systems conceptualized? How are dynamics within the social and the ecological systems conceptualized?
Degree in which the social and the ecological systems are treated in equal depth	Are the social and ecological systems treated in equal depth?
Analysis-oriented versus action-oriented framework	Is the framework analysis or action oriented?

S ↔ E: the reciprocity between the social system and the ecological system is considered, including feedback loops and learning processes in the social system in response to changes in the ecological system.

Second, we looked at how the dynamics between the social and ecological systems are conceptualized. Here we considered whether the frameworks explicitly conceptualize feedback loops between the social and ecological systems in natural or formal language.

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

To analyze to the extent to which both the social and the ecological system are treated in equal depth, we synthesized the analyses of the social and ecological systems and their dynamics and interactions.

To these four criteria we added:

Orientation: analysis-oriented frameworks versus action-oriented frameworks

We distinguish between analysis-oriented frameworks that have been developed with the goal of providing a general language that can be used for formulating and approaching different research questions, and action-oriented frameworks that have been developed with the goal of acting upon or intervening in the SES to, for example, reduce the vulnerability of local communities (J. Hinkel and A. Bisaro, *unpublished manuscript*).

Note that while characterizing the frameworks in terms of our structural criteria, we considered only the main concepts used within the frameworks and stated in the referenced literature. This implies that if additional relationships were mentioned but not thoroughly conceptualized, these have not been included in our analysis.

RESULTS

Applying the criteria, we selected the following frameworks out of the 16 frameworks originally considered:

1. The Driver, Pressure, State, Impact, Response (DPSIR) framework (Eurostat 1999).
2. The Ecosystem Services (ES) framework (Boumans et al. 2002, Limburg et al. 2002, de Groot et al. 2002).
3. The Earth Systems Analysis (ESA; Schellnhuber 1998, 1999, Schellnhuber et al. 2005).
4. The Human-Environment System (HES) framework (Scholz and Binder 2003, 2004, Scholz et al. 2011*a*,*b*).
5. The Material and Energy Flow Analysis (MEFA/MFA) framework (Ayres 1978, Baccini and Bader 1996, Haberl et al. 2004, Brunner and Rechberger 2005).
6. The Management and Transition Framework (MTF; Pahl-Wostl 2009, Pahl-Wostl and Kranz 2010, Pahl-Wostl et al. 2010).

7. The SES framework (SESF), pivotal in this Special Feature of *Ecology and Society*, (Ostrom 2007, 2009; M. McGinnis and E. Ostrom, *unpublished manuscript*).
8. The Sustainable Livelihood Approach (SLA; Scoones 1998, Ashley and Carney 1999).
9. The Natural Step (TNS) framework (Burns 1999); and
10. The Turner et al. (2003) Vulnerability framework (TVUL; Turner et al. 2003*a*).

FRAMEWORK DESCRIPTION BASED ON THE CONTEXTUAL CRITERIA

The Driver, Pressure, State, Impact, Response (DPSIR) framework is an extension of the PSIR framework for developing an improved understanding of, indicators for, and appropriate responses to impacts of human activities on the environment along the causal chain: drivers-pressure-state-impact-responses (Eurostat 1999). It originated from integrated environmental assessment (natural sciences) and bases itself on systems science. DPSIR is policy oriented and provides a framework for categorizing a problem domain. All variables that fall under one of the categories (D-P-S-I-R) have to be included. Details depend on the specific problem domain under consideration. It has been applied very broadly in Integrated Environmental Assessment such as coastal zones, water, transport, or pollution control. More recently it has been applied to issues of sustainable development (Table 3).

The Ecosystem Services (ES) framework focuses on the integral, dynamic, and complex interactions of biotic and abiotic components providing the services that support life on Earth (Boumans et al. 2002, Limburg et al. 2002). It has its origins in biology and botanic science (natural sciences), and ecological-economics (social sciences) and is based on systems science. ES was developed to ensure a sustainable and continued availability of ecosystem functions by translating the basic ecological structures and processes into value-laden entities (de Groot et al. 2002). It has been mostly applied in the field of integrated management of the linkages between environment and human well-being, e.g., the Convention on Biological Diversity (United Nations 1992) and the Millennium Ecosystem Assessment (MA).

Earth Systems Analysis (ESA) is a framework for understanding the global dynamics of the earth system (Schellnhuber 1998, 1999, Schellnhuber et al. 2005). These dynamics are analyzed in terms of a set of linked global biogeophysical subsystems such as the atmosphere, the biosphere, the cryosphere, the hydrosphere, etc., and the human system. The linkages between these subsystems are represented as flows of matter and energy. ESA emerged from physics (natural sciences) and is based on systems sciences and control theory. It has been applied in the International Geosphere Biosphere Programme.

The Human-Environment System framework (HES) has been developed as a heuristic tool for structuring the investigation of human-environment interactions (Scholz and Binder 2003, 2004, Scholz et al. 2011*a,b*). It provides a set of operative concepts for an organized exploration of environmental problems related to human activities, as well as a methodological guide for investigating human-environmental structures and processes. It originated from environmental decision making and psychology (social sciences) and has its theoretical origins in systems science, decision theory, game theory, and sustainability science. It can be applied to any research area in which human-environmental interactions play a role: e.g., energy, water, waste. HES is applicable on any scale. However, it makes sense to have a complex system in which different social and ecological hierarchical levels are involved.

The Material and Energy Flow Analysis framework (MEFA/MFA) considers the biophysical aspects of society on different scales (region, nation). It serves to quantify the relevant processes involved in the material and energy flows, and to identify steering possibilities for minimizing the impact of society on nature (Ayres 1978, Baccini and Bader 1996, Haberl et al. 2004, Brunner and Rechberger 2005). Depending on the selected scale, these analyses can be combined with different socioeconomic modeling approaches (Binder 2007). MEFA has its origins in engineering (natural sciences). It is based on systems science. The application fields are all problem fields that have to deal with the analysis of human impact on the ecological system and can be related to material and energy flows, such as resource management, pollution control, etc.

The Management and Transition Framework (MTF) was developed with the intention of capturing the most important variables and processes for the research field of integrated and adaptive water governance and management, with emphasis on transition processes toward new regimes (Pahl-Wostl 2009, Pahl-Wostl et al. 2010). What is included at which level of detail in a specific application of the MTF depends on the specific research question addressed. Its goal is to support the understanding of water systems and management regimes, as well as transition processes toward more adaptive management; to enable comparative analyses of a wide range of diverse case studies; and to facilitate the development of simulation models based on empirical evidence (Pahl-Wostl et al. 2010). It has no specific disciplinary origin, but it can be attributed to complex systems science. It is based on common pool resource theory, the Institutional Analysis and Development framework, and social psychology (social sciences). MTF was designed for application to water systems but has also been applied for risk governance and integrated

Table 3. Purposes of the different frameworks as stated by the authors.

Framework	Purpose	References (selection)
Driver, Pressure, State, Impact, Response (DPSIR)	Develop an improved understanding of, indicators for, and appropriate responses to impacts of human activities on the environment along the causal chain-drivers-pressure-state-impact-responses.	Eurostat 1999, Carr et al. 2007, Svarstad et al. 2008
Earth Systems Analysis (ESA)	Understand the global interactions in and dynamics of the earth system as well as its sustainable evolutions.	Schellnhuber 1998, 1999, Schellnhuber et al. 2005
Ecosystem Services (ES)	Analyze the integral, dynamic, and complex interactions of biotic and abiotic components of an ecosystem in relation to the supply of services this system provides to support life on Earth.	Costanza et al. 1997, Daily 1997, de Groot et al. 2002, Limburg et al. 2002
Human Environment Systems Framework (HES)	Provide a methodological guide or template for analyzing the structure of social-ecological systems and understanding the processes and dynamics between the social and ecological systems as well as within different scales of the social system.	Scholz and Binder 2004, Scholz et al. 2011*a*
Material and Energy Flow Analysis (MEFA)	Analyze the metabolic profiles of societies. Analyze the material and energy flows as representing the metabolism of a society, region, or nation.	Ayres 1978, Baccini and Bader 1996, Haberl et al. 2004, Brunner and Rechberger 2005
Management and Transition Framework (MTF)	Support the understanding of water systems, management regimes, and transition processes toward more adaptive management; enable comparative analyses of a wide range of diverse case studies; and facilitate the development of simulation models based on empirical evidence.	Pahl-Wostl 2009, Knieper et al. 2010, Pahl-Wostl and Kranz 2010
Social-Ecological Systems Framework (SESF)	Provide a common language for case comparison for organizing the many variables relevant in the analysis of SES into a multitier hierarchy that can be unfolded when needed, and for facilitating the selection of variables in a case study.	Ostrom 2007, 2009
Sustainable Livelihood Approach (SLA)	Analyze which combination of livelihood assets enable the following of what combination of livelihood strategies with sustainable outcomes.	Ashley and Carney 1999, Scoones 1998
The Natural Step (TNS)	Provide a framework for planning toward sustainability based on: constitutional principles (how the system is constituted); outcome (principles for sustainability); and process to reach this outcome (principles for sustainable development).	Burns and Katz 1997, Robèrt 2000, Upham 2000, Missimer et al. 2010
Vulnerability Framework (TVUL)	Analyzes who and what are vulnerable to multiple environmental and human changes, and what can be done to reduce these vulnerabilities.	Turner et al. 2003*a,b*

landscape management and could be tailored to other domains of application.

The Social-Ecological Systems framework (SESF), pivotal in this Special Feature of *Ecology and Society*, is an extensive multitier hierarchy of variables that have proven to be relevant for explaining sustainable outcomes in the management of forestry, fishery, and water resources (Ostrom 2007, 2009; M. McGinnis and E. Ostrom, *unpublished manuscript*). On the first tier, it distinguishes between resource system, resource units, governance system, actors, interactions, and outcomes. Lower tiers, i.e., second, third, fourth, etc., decompose higher tier concepts and variables into more fine-grained variables. The disciplinary origin of SESF is in political science (social science). It is based on theories such as collective choice, common-pool resources, and natural resource management. SESF has been developed and applied mainly in the area of management of forests, pastures, fisheries, and water.

The Sustainable Livelihood Approach (SLA) analyzes at a community level which combination of livelihood resources, i.e., natural, economic, human, physical, and social capital, permits which combination of sustainable livelihood strategies, e.g., agricultural intensification/extensification, livelihood diversification, and migration (Scoones 1998, Ashley and Carney 1999). SLA has its origins in social science based development studies and is based on the capability/entitlement approach (Schumacher 1973, Sen 1981). The framework is widely applied within development research as well as in development assistance.

The Natural Step (TNS) provides a framework for planning toward sustainability. It includes constitutional principles (how the system is constituted), outcome principles (for sustainability) and process principles (on how to reach the desired outcome.). "... [T]he natural step framework is a strategic planning tool that helps an organization identify the risks and opportunities associated with the sustainability challenge. TNS provides a clear vision of sustainability and a scientifically rigorous definition of the term, and the compass that helps a company move in that direction" (Burns 1999:3; Burns and Katz 1997, Robèrt 2000). TNS is based on economics (social science) and relies on systems science and management theories (Upham 2000). It has been widely applied in businesses and regions (Nattrass and Altomare 1999, James and Lahti 2004).

The Turner et al. (2003*a*) vulnerability framework (TVUL) is a prominent framework for analyzing a location facing multiple environmental and human changes and hazards situated in a regional and global context. It considers a wide range of human conditions (social/ human capital and endowments) and environmental conditions (natural capital/ biophysical endowments such as soils, water, climate, minerals, ecosystems). TVUL has its disciplinary origins in social and natural science, namely human geography and natural hazards. It uses theoretical concepts from risk-hazard (RH) and pressure-and-release (PAR) models, climate impact research, and resilience research. TVUL has been widely applied (Turner at al. 2003*b*).

Guidance for applying the framework

The type of guidance provided varies significantly across the different frameworks. When focusing on the guidance for the selection of variables provided, the DPSIR, MTF, and SESF provide the clearest guidance. They thus ensure an appropriate and consistent representation of the case studied. However, guidance for tailoring the frameworks to a specific research question, i.e., what variables or kinds of representations should be chosen, is scant. In the other frameworks, the variables are derived from the case studied and the research question posed, and hardly any guidance is provided.

Regarding guidance for the analysis, DPSIR, MEFA, and TNS provide a more or less standardized procedure, i.e., they have clear steps to be followed to obtain a sound analysis. ES, HES, MTF, and SESF provide basic guidance and methodologies to be applied, i.e., they provide a structure for the analysis and mention a pool of methods that would allow a sound application of the framework. These frameworks furthermore provide a range of examples that support the understanding of the framework and its applications. ESA, SLA, and TVUL provide no guidance at all.

ANALYSIS OF THE FRAMEWORKS BASED ON THE STRUCTURAL CRITERIA

Conceptualization of the social system and its dynamics

DPSIR, ES, ESA, and MEFA conceptualize the social system only at a macro level, disregarding interactions with the micro level (Table 4). The social system is viewed as the aggregate of socioeconomic processes or as the hybrid of culture, meaning, and communication about the natural world. Dynamics within the social system are not explicitly considered (Table 5).

SLA, TNS, and TVUL conceptualize the social system by considering the macro → micro relationship. They emphasize social principles, governance structures, and politics (Table 5). SLA, TVUL, and TNS study either communities or firms. The social system is conceptualized as situated in a context of external factors; a set of livelihood resources, i.e., natural, economic, human, physical, and social capital; and a set of institutional processes that influence how the resources can be used to realize different livelihood strategies, such as agricultural intensification/extensification, livelihood diversification, and migration). The outcomes of these processes are evaluated on the basis of various criteria, such as whether working days are created, poverty is reduced or the natural resource base is sustained. Social dynamics per se are not conceptualized.

HES, MTF, and SESF include in their conceptualization of the social system both the micro level and the macro level, and also the interaction and feedback loops between them. HES and MTF are largely based on decision theory and social learning processes. Feedbacks between the individual and the governance system are called either single, double, or triple loop learning (MTF), or short-term and long-term feedbacks (HES). In SESF, the social and governance structures affect the way in which the actors behave, and actors might be part of the governance system and shape it. HES, MTF, and SESF are the only three frameworks to explicitly include dynamics in the social system. In HES and MTF dynamics are driven through changes in environmental awareness at different hierarchical levels of the social system, the learning processes, and the different types of feedbacks. SESF includes variables, containing natural language descriptions, that refer to dynamic processes such as "information sharing," "deliberation processes," and "self-organization activities" grouped under the label "interaction" (Table 5).

Conceptualization of the ecological system and its dynamics

DPSIR, HES, MTF, SESF, SLA and TVUL conceptualize the ecological system from an anthropocentric perspective: the ecological system is seen as a provider of services that increase human well-being. In addition, MTF explicitly considers environmental hazards that constitute a threat to human well-being. Within the frameworks, the ecological system is for the most part represented in less detail than the social system, SESF being the exception. DPSIR includes a set of aggregated ecological variables categorized in state and impact. HES considers the ecological system as the system coupled to the social system, whereby the framework suggests starting research by understanding or acquiring a state of the art model of the environmental problem. The scaling of the ecological system is then related to the corresponding social system. MTF and SESF include variables that are considered relevant for

Table 4. Conceptualization of the social system. General concept (naming of the social system in parentheses).

Framework	Conceptualization of the social system
DPSIR Driver, Pressure, State, Impact, Response	The social system is conceptualized as the aggregated socioeconomic processes/ variables in particular drivers and responses.
ESA Earth Systems Analysis	The social system (human system/anthroposphere) is the aggregate of all individual human lives, actions, and products and the global subject comprises the emerging institutions for global governance.
ES Ecosystem Services	The social system is conceptualized as humans being the users of the ecological system and acting as valuing agents. They translate the basic ecological structures and processes into value-laden entities.
HES Human Environment Systems Framework	The social system (human system) is conceptualized based on decision making theory to analyze human actions and learning and feedback processes at and between different hierarchical levels of the social system. The decision making process includes: goal formation, strategy formation, and strategy selection, all of which are based on preferences and different degrees of environmental awareness.
MEFA Material and Energy Flow Analysis	The social system (society) is conceptualized as a hybrid of the realm of culture, of meaning, of communication, and of the natural world. The social system consists of a cultural system, as a system of recurrent self-referential communication, and of material components, namely, a certain human population as well as a physical infrastructure such as buildings, machines, artefacts in use, and animal livestock, which in their entirety can be denoted as “biophysical structures of society.”
MTF Management and Transition Framework	The social system is conceptualized in a combination of rational choice (IAD framework) and social constructivism, leading to social learning approaches. Context of learning and decision making processes is of importance.
SESF Social-Ecological Systems Framework	The social system is composed of resource users (actors) and the governance system that influences the actions of the users by defining rules as well as monitoring and sanctions mechanisms.
SLA Sustainable Livelihood Approach	The social system (human system) is conceptualized as situated in a context of external factors, a set of livelihood resources (natural, economic, human, social, and other capital), a set of institutional processes that influence how the resources can be used to realize different livelihood strategies, such as agricultural intensification or extensification, livelihood diversification and migration. The outcomes of this process are evaluated based on various criteria such as creation of working days, poverty reduced, natural resource base sustained.
TNS The Natural Step	The social system is conceptualized through social principles (relevant stake, laws, norms, etc.).
TVUL Turners Vulnerability Framework	The social system is conceptualized as “human conditions” (social/human capital and endowments) and various types of responses to the hazard and unfavorable internal human or environmental conditions.

resource governance and resource management. Whereas MTF focuses on the watershed level, SESF has been applied to different types of resource systems, such as fisheries, forests, and meadows, and allows for analyzing nested systems, thus supporting analyses on different scales. In SLA and TVUL the ecological system is both part of the contextual factors influencing the livelihood of farmers, and of natural capital influencing the farmers’ decisions regarding their livelihood. TVUL includes, in addition, the aspect of factor endowments in the analysis (Table 6).

None of the anthropocentric frameworks considers the dynamics of the ecological system very explicitly let alone formally (mathematically). Rather, DPSIR, HES, MTF, and SESF conceptualize the dynamics within the ecological system from an anthropocentric perspective, i.e., changes that can be relevant for the social system, and using very general concepts. For example, DPSIR measures the state of the environment over time; HES states that the understanding of the ecological system comes first and feedbacks within the ecological system can be analyzed in the form of stocks and flows; SESF includes variables that depict the dynamics of the ecological system that are relevant to humans, such as growth rate, equilibrium properties, and productivity. MTF includes as a subjective knowledge category the perceived state of the water system, which may change over time (Table 7).

ES, ESA, MEFA, and TNS conceptualize the ecological system from an “ecocentric” perspective: the system and its processes are analyzed irrespective of its utility for humans.

Table 5. Conceptualization of the social system and its dynamics.

Framework	Social Scale	Interaction type	Dynamics
DPSIR Driver, Pressure, State, Impact, Response	Decision makers	Macro	Social dynamics are not conceptualized
ESA Earth Systems Analysis	Society	Macro	Social dynamics are not conceptualized
ES Ecosystem Services	Society	Macro	Social dynamics are not conceptualized
HES Human Environment Systems Framework	Includes all hierarchical levels	Macro ↔ Micro	Learning processes and interferences between and within different levels of the social system are the drivers of the dynamics
MEFA Material and Energy Flow Analysis	Society	Macro	Social dynamics are not conceptualized
MTF Management and Transition Framework	Includes all hierarchical levels	Macro ↔ Micro	Decision making and learning processes within an action situation context but also multilevel and multiloop processes of learning, negotiation, and policy development
SESF Social-Ecological Systems Framework	Includes all hierarchical levels	Macro ↔ Micro	Conceptualized textually by a number of variables such as “information sharing,” “deliberation processes,” and “self-organization activities” grouped under the label “interaction”
SLA Sustainable Livelihood Approach	Local stakeholders	Macro → Micro	Social dynamics are not conceptualized
TNS The Natural Step	Businesses or regions	Macro → Micro	Social dynamics are induced through a scenario/ visioning and backward planning process
TVUL Turners Vulnerability Framework	Local communities	Macro → Micro	Social dynamics are not conceptualized

ES uses the concept of ecosystem function; MEFA and TNS base themselves on the concept of stocks and flows, and look mostly at regional/national and business scale. ESA takes a different view of the ecological system by looking at the interaction between environmental subsystems on a global scale. Although ESA and MEFA do not include interaction between different scales, TNS does, to some extent, include the scaling issue, as the impact of business behavior on the ecological system in general (Table 7).

In MFA and ESA the dynamics of the ecological system are considered as changes of stocks and flows, in MEFA with differential equations, and in ESA by considering feedbacks in the material or energy flows between subsystems of the ecosphere. TNS does not explicitly formulate the dynamic considerations. ES does not consider dynamics at all.

Conceptualization of the interaction between the social and the ecological systems

DPSIR, ES, ESA, MEFA, and TNS conceptualize the interaction between the social and the ecological systems as how human actions and resource needs affect the ecological system (S → E). ESA, MEFA, TNS do so by looking at the flow of matter, e.g., emissions, land use change, yields, energy, resources, CO_2, that originates in the social system, and its impact on the ecological system. ES conceptualizes the interaction between the social and ecological systems as the activities within the social system reducing the services the ecological system can provide. DPSIR conceptualizes the interaction and dynamics of a social-ecological system through the causal chain. Human activities generate pressures on the environment. These pressures change the state of the environment, which leads to negative impacts (Tables 8, 9). SLA and TVUL focus on the influences of the ecological system on the social system (E → S), through either having a limited supply of resources, or environmental hazards affecting the social system.

Only HES, MTF, and SESF explicitly address the reciprocity between the social and the ecological systems (S ↔ E). The HES framework conceptualizes this reciprocity in three ways. First, it explicitly looks at the complementarities between these systems as early as when a study is designed: the scale of the ecological system to be studied is chosen to fit with the problem perception in the social system. Second, the feedback loops considered in the analysis explicitly include both the

Table 6. Conceptualization of the ecological system: General concept (naming of the ecological system in parentheses).

Framework	Conceptualization of ecological system
DPSIR Driver, Pressure, State, Impact, Response	Conceptualizes the ecological system (environment) from an anthropocentric perspective. It considers aggregated ecological processes and variables and differentiates into state and impact variables.
ESA Earth Systems Analysis	The ecological system (ecosphere) is conceptualized from an ecocentric perspective as linked global subsystems such as the atmosphere, the biosphere, the cryosphere, the hydrosphere, etc. The linkages between these subsystems are represented as flows of mass and energy.
ES Ecosystem Services	The ecological system (ecosystem) is conceptualized from an ecocentric perspective focusing on ecosystem functions. To ensure the continued availability of ecosystem functions, the use of the associated goods and services should be limited to sustainable use levels.
HES Human Environment Systems Framework	The ecological system (environment) is conceptualized from an anthropocentric perspective as the coupled system to the social system. An HES analysis is problem oriented and typically departs from the ecological system. Tools such as MEFA can be used for conceptualizing the ecological system.
MEFA Material and Energy Flow Analysis	The ecological system (nature) is conceptualized from an ecocentric perspective. It is based on stocks and flows.
MTF Management and Transition Framework	The ecological system is conceptualized from an anthropocentric perspective. It includes variables that are considered to be important for resource governance and management. Less elaborate than the social system.
SESF Social-Ecological Systems Framework	The ecological system is conceptualized from an anthropocentric perspective as resource system, e.g., water, forest, and corresponding resource units, e.g., water quantity, tree.
SLA Sustainable Livelihood Approach	The ecological system (natural system/natural capital) is conceptualized from an anthropocentric perspective. It appears in two different parts of the framework. First as part of the context that comprises all social (political) and natural system factors that influence the livelihood. Second, as natural capital, one of the livelihood resources available for pursuing livelihood strategies.
TNS The Natural Step	The ecological system (resources, biodiversity) is conceptualized from an ecocentric, stocks and flows perspective, thermodynamics, (natural laws, natural resources, biodiversity, etc.).
TVUL Turners Vulnerability Framework	The ecological system is conceptualized from an anthropocentric perspective as “environmental conditions” (natural capital/biophysical endowments such as soils, water, climate, minerals, and ecosystems).

short-term and the long-term impact of human actions on the ecological system, and also their links back to the decision making process (primary and secondary feedback loops). Finally, environmental awareness, which is considered in each step of the decision making process, allows for considering the degree to which changes in the ecological system affect goal setting, strategy development, and strategy selection. These various feedbacks drive the dynamic interaction between the social and ecological systems.

In the MTF framework, environmental services and environmental hazards are used to characterize the interface between the social and the ecological systems. These bridging concepts have meaning from both a social and an ecological systems perspective. The environmental services capture the function of an ecological system as the provider of different kinds of services and benefits for human activities. The environmental hazards are the threats that an ecological system poses to a societal system. The impact of human activities on ecological systems is mainly addressed in the broad category of “operational outcomes” which can refer to physical interventions in the environment. Over time, changes in and impacts of human-environment interactions are captured by the “perception of the system state,” which may characterize the dominant framing of a social decision making context and/or the framing by specific actor groups. This perception includes normative judgments on the state of, e.g., the water system regarding sustainability and system properties such as adaptive capacity (Pahl-Wostl 2009).

The SESF addresses the S $\leftrightarrow$ E interaction by defining the first tier level variable “interactions.” This generic category then provides second tier level variables that allow further detailing, such as “harvesting rate” to represent how actors impact on the ecological system by using resources (S $\rightarrow$ E), and “sharing of information” to represent how actors assess

Table 7. Conceptualization of the ecological system and its dynamics.

Framework	Spatial scale	Interaction type	Dynamics
DPSIR Driver, Pressure, State, Impact, Response	Can be applied at any scale	It does not consider the interaction between the spatial scales	The dynamics are addressed implicitly through measurement of the state of the environment over time.
ESA Earth Systems Analysis	Global scale	Interaction occurs between different subsystems but not across spatial scales	Ecological dynamics are represented as feedbacks in the flow of energy or matter between the subsystems of the ecosphere.
ES Ecosystem Services	Can be applied at any scale; favors regional, national scale	No interaction between scales is considered	Dynamics are not considered.
HES Human Environment Systems Framework	Can be applied at any scale; favors regional, national scale	Interaction between scales might be included, but not explicitly foreseen	Dynamics of the ecological system are not explicitly mentioned, but the understanding of the ecological system stands out front in this framework; feedbacks within ecological system can be analyzed in form of stocks and flows.
MEFA Material and Energy Flow Analysis	Can be applied at any scale, favors regional, national scale	MEFA does not consider interaction across scales.	Dynamics are analyzed as changes in stock and flows.
MTF Management and Transition Framework	Can be applied at any scale; favors regional, national scale	MTF considers the interaction among the spatial scales	Dynamics are not addressed in detail. Only trends are captured that show the state of the ecological system but no feedbacks within the ecological system are addressed.
SESF Social-Ecological Systems Framework	Local and regional scale	The ecological system could potentially be studied at any scale. Interactions between scales are named but not further conceptualized.	The dynamics are considered by a number of variables (natural language descriptions) of the resource system and resource units such as growth rate, equilibrium properties, and productivity.
SLA Sustainable Livelihood Approach	Local and regional scale	Interactions within spatial scales are not considered.	Dynamics of the ecological system are not conceptualized.
TNS The Natural Step	Businesses and regions	Interactions between businesses and other scaled systems are partly considered.	Dynamics of the ecological system are not conceptualized.
TVUL Turners Vulnerability Framework	Local scale	Interactions within spatial scales are not explicitly considered.	Dynamics of the ecological system are not conceptualized.

the condition of the resource (E $\rightarrow$ S). The SESF has been applied in case studies to study under what conditions the users of the resource develop rules for a sustainable management of the resource. As Ostrom (2009:421) puts it: “If the initial set of rules established by the users, or by a government, are not congruent with local *resource* [emphasis added] conditions, long-term sustainability may not be achieved. Studies ... suggest that long-term sustainability depends on rules matching the attributes of the resource system, resource units, and users.”

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

Even though authors have claimed that frameworks should represent both the social and the ecological systems equally well and in equal depth (Turner and Carpenter 1999, Folke 2007), most of the frameworks do not do so. The frameworks with an ecocentric perspective (ES, ESA, MEFA, TNS) conceptualize the ecological system much more in depth than they do the social system. Their origin also lies in natural sciences. Most of the frameworks with an anthropocentric perspective (DPSIR, HES, MTF, SLA, TVUL) conceptualize the social system more in depth. The only framework that, despite its origin in the social sciences, provides the option to treat the social and ecological systems in almost equal depth is the SESF. Given the definition of four subsystems, resource system, resource unit, governance system, and actors, it provides a structure in which data from different aggregation levels can be used and an analysis of the SES could be performed that considers both systems in almost equal depth

Table 8. Conceptualization of the interaction between the social and the ecological systems: General concept.

Framework	Conceptualization of the interaction between the social and ecological systems
DPSIR Driver, Pressure, State, Impact, Response	Human activities generate pressures on the environment. These pressures change the state of the ecological system, which leads to negative impacts on humans. These negative impacts (should) lead to a response of the social system.
ESA Earth Systems Analysis	Human activities, such as CO_2 emissions, land use, crop harvested, etc., lead to a flow of matter that changes the ecosystem.
ES Ecosystem Services	The social system changes the services that can be provided by the ecological system.
HES Human Environment Systems Framework	Human activities affect the ecological system through actions in an intended or unintended way and in the short and long run. Feedback through environmental awareness and environmental changes to human actions is conceptualized in the short and long run. Concept of sustainability learning.
MEFA Material and Energy Flow Analysis	Human activities require resources and affect the ecological system through energy and material demand and emissions.
MTF Management and Transition Framework	The ecological system influences the social system via (i) environmental services and, (ii) environmental hazards are the threats that an ecological system poses to a societal system. The social system influences the ecological system by interventions related to using services and preventing hazards. Feedbacks are addressed by changes in the perception of the SES state that may characterize the dominant framing of a social decision making context and/or the framing by specific actor groups.
SESF Social-Ecological Systems Framework	The actors use resources impacting on the ecological system and may cause externalities in related SES. These externalities feedback to the social system in that the productivity of the system changes affecting the harvesting rates.
SLA Sustainable Livelihood Approach	Options of humans are affected by external boundary conditions among those are environmental assets.
TNS The Natural Step	Human demand on resources and emissions to the ecological system affects the quality and carrying capacity of the ecological system.
TVUL Turners Vulnerability Framework	The social system is influenced by the ecological system through environmental hazards.

(Table 10). The elaboration of the SESF by Brock and Carpenter (2007) illustrates this.

Orientation: analysis-oriented frameworks versus action-oriented frameworks

Analysis-oriented frameworks, even if developed for a specific case, provide a general structure to analyze SES. They are rather flexible and offer either a structure for organizing data in SES or a methodological approach for improving system understanding. Frameworks that offer a methodological approach are ESA, ES, HES, MEFA, and MTF. They also provide either clear instructions on how to perform the analysis or examples of how to apply the framework. Among these general frameworks, only SESF offers a generic data organizing structure. It is the most general framework, and the data collected within its structure could potentially be used in any of the other frameworks analyzed (Table 10).

The action-oriented frameworks have an action perspective, that is, they provide information for improving a particular situation. As such, they aim at, e.g., improving the livelihood of poor communities in developing countries (SLA), developing a backward planning process for obtaining more sustainable companies or regions (TNS), reducing the environmental impact of human activities (DPSIR), or reducing the vulnerability of communities in developing countries (TVUL).

DISCUSSION

Having characterized 10 frameworks for analyzing social-ecological systems with respect to contextual and structural criteria, we find that these frameworks vary significantly regarding their theoretical and disciplinary origin, their purpose, and the way in which they conceptualize the social and the ecological systems, their interaction and dynamics. In the following we propose a categorization of the frameworks and a heuristic on how to choose the appropriate framework for a specific SES.

Categorization of the frameworks

We found that three criteria were sufficient to classify the frameworks into four different groups. The criteria were: (i) the way in which the conceptualization and the interaction within and between the social and the ecological systems occurs; (ii) the perspective from which the ecological system is conceptualized; and (iii) whether it is an analysis-oriented

Table 9. Conceptualization of the interaction and the dynamics between the social and the ecological systems. S: Social system; E: Ecological system.

Framework	Interaction type	Dynamics
DPSIR Driver, Pressure, State, Impact, Response	S → E	Not conceptualized
ESA Earth Systems Analysis	S → E	Not conceptualized
ES Ecosystem Services	S → E	Not conceptualized
HES Human Environment Systems Framework	S ↔ E	Primary and secondary (short- and long-term) feedback loops between the social and the ecological systems
MEFA Material and Energy Flow Analysis	S → E	Not conceptualized
MTF Management and Transition Framework	S ↔ E	Single, double, and triple loop learning of the social system as a reaction to changes in the ecological system. Formalized representation of action situations without using mathematical descriptions.
SESF Social-Ecological Systems Framework	S ↔ E	Feedback between the resource conditions and the rules determining the harvesting rates of the resource
SLA Sustainable Livelihood Approach	E → S	Not conceptualized
TNS The Natural Step	S → E	Not conceptualized
TVUL Turners Vulnerability Framework	E → S	Not conceptualized

or an action-oriented framework. Thereby, four types of frameworks are derived.

Ecocentric frameworks

The first group of frameworks conceptualizes the relationship between the social and the ecological systems to be an S → E relationship, that is, human activities affect the ecological system, whereas direct feedbacks from the ecological to the social system are not considered. It conceptualizes the social system at an aggregate level, mostly the level of society (macro). It follows an ecocentric perspective, that is, the ecological system is conceptualized in terms of its internal functioning. With the exception of ES, it uses the notion of stocks and flows to analyze the ecological system and its dynamics. The frameworks belonging to this group are: ES, ESA, and MEFA. All these frameworks are analysis oriented.

Regarding dynamics, only ESA and MEFA consider the dynamics of the ecological system. They also have a basis for modeling the ecological system in depth. Even though the analysis provides some information about the impact of humans on the ecological system, it cannot be directly used as a management tool. ES provides insight into how human activities affect ecosystem services.

These frameworks should be considered if the research aims at elucidating the impact of human behavior on the ecological system. Typical research questions would be: How have the societal transitions or structural changes in human societies, e.g., from agricultural to industrial society, affected the magnitude of material and energy flows (metabolism) of different social-ecological systems?

Integrative frameworks

The second group of frameworks considers the reciprocity between the social and the ecological systems S ↔ E, and includes different types of feedbacks within the social system and between the social and ecological systems in different time and social scales, named single, double, or triple loop learning or primary and secondary feedback loops. Within the social system the frameworks in this group also consider the duality between social structure and agency. They view the ecological system from an anthropocentric perspective, that is, they look at the ecological system from the point of view of its utility to humans. The frameworks belonging to this group are: HES, MTF, and SES. All three frameworks are analysis oriented.

These frameworks do not explicitly consider the dynamics within the ecological system, even though the social system perceives the changes in the ecological system over time. HES provides an understanding of the decision making processes and also supports the development of dynamic models for the selected questions posed. From a management perspective, the interference analysis in HES supports the ex-ante identification of potential conflicts and need for consensus

Table 10. Degree to which the social and the ecological systems are represented in equal depth; orientation of the frameworks. S: Social system; E: Ecological system.

Framework	Degree of equal representation of S and E	Orientation
DPSIR Driver, Pressure, State, Impact, Response	Antropocentric S > E	Action oriented
ESA Earth Systems Analysis	Ecocentric E > S	Analysis oriented
ES Ecosystem Services	Ecocentric E > S	Analysis oriented
HES Human Environment Systems Framework	Antropocentric S > E	Analysis oriented
MEFA Material and Energy Flow Analysis	Ecocentric E > S	Analysis oriented
MTF Management and Transition Framework	Antropocentric S > E	Analysis oriented
SESF Social-Ecological Systems Framework	Antropocentric S ≈ E	Analysis oriented
SLA Sustainable Livelihood Approach	Antropocentric S > E	Action oriented
TNS The Natural Step	Ecocentric E > S	Action oriented
TVUL Turners Vulnerability Framework	Antropocentric S > E	Action oriented

building processes to solve the ecological problem tackled. MTF provides to some extent management relevant information. It allows analyzing and improving structural deficits, e.g., cross-level coordination, and procedural aspects, e.g., social learning. It can also be used to support scenario development and identify transition pathways toward more sustainable management approaches. SESF provides a framework for selecting the variables necessary to describe the dynamics in the social and ecological systems and the interaction between them and suggests variables for analyzing the potential sustainable development of a social-ecological system.

These frameworks should be applied when a complex social-ecological issue is to be studied that involves a dynamic perspective on the social as well as on its interaction with the ecological system. Research questions could be: What are the characteristics of rural communities of forest users in the Himalayas that are able to sustainably use their forests? What are the barriers and drivers for a transition toward sustainable water management in a catchment area?

Policy frameworks

The third group of frameworks conceptualizes the interaction between the social and the ecological systems as being S → E, that is, human action affects the ecological system. They do not explicitly consider feedbacks between the social and ecological systems, but changes in the ecological system are seen to potentially affect the social system. These frameworks conceptualize the social system as a macro → micro relationship. Like the second, and in contrast to the first group, they define the ecological system from an anthropocentric perspective. The frameworks belonging to this group are: DPSIR and TNS. Both frameworks are action oriented.

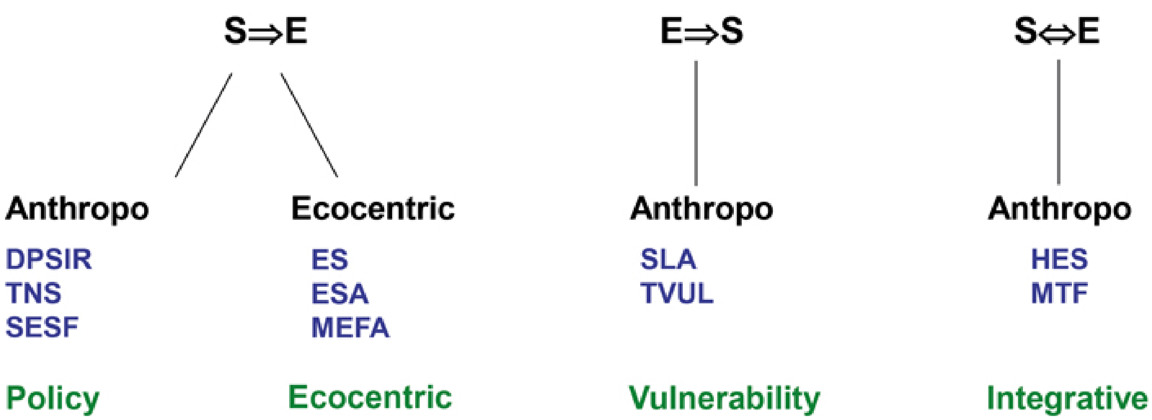
Regarding dynamics, these frameworks do include it in textual form, that is, changes in the interaction between the social and the ecological systems are captured by indicators, which can be measured at the different time steps. Neither of the policy frameworks explicitly includes model building, but all of them aim at providing policy relevant information, either on pressures and responses on different scales (DPSIR) or on improving the management of resources at business level (TNS) respectively, by delivering a particular protocol that supports businesses, regions, and communities in the management of their ecological system.

These frameworks are appropriate for developing action-oriented strategies for reducing the impact of humans on the ecological system. Research questions could be: How might different pressures develop in the future, what could be their impact on aquatic ecosystems, and what would be appropriate policy programs or management measures that have to be implemented to avoid undesirable impacts?

Vulnerability frameworks

The fourth group of frameworks conceptualizes the interaction between the social and the ecological systems as being E → S, that is, the ecological system affects the social system. Even

Fig. 1. Guide for selecting the adequate framework.



though the social system might affect the ecological system, this is not specifically included in the analysis. These frameworks (SLA and TVUL) conceptualize the social system as a macro → micro relationship. They define the ecological system from an anthropocentric perspective.

These frameworks do not explicitly consider the dynamics within the ecological system, even though some variables describe the dynamics in natural language. However, they see that the micro level is not only influenced by the macro level, but also by the ecological system (resource availability in SLA; hazards in TVUL). Both frameworks do not consider dynamics and are not appropriate for quantitative modeling. However, both of them are action frameworks providing information for policy makers and extensionists on how to improve the livelihood of poor communities (SLA), or how to reduce their vulnerability (TVUL).

These frameworks are likely to be useful if they are applied to studying problems in which humans are vulnerable or are exposed to changes in their environment and are not able to influence these external forces themselves. Typical research areas would be climate change adaptation of vulnerable societies: e.g., what factors determine the vulnerability of the marginal groups living in the urban fringe of megacities to climate change?

Choosing the appropriate framework

From our analysis it becomes clear that there is no single framework that can be used to address all research issues in SES. Through our analysis we provide support for selecting the right framework based on the problem to be studied and the way in which the social-ecological system is conceptualized (Fig. 1). Guiding questions for the selection of the framework could be:

- Do you study the effect of the social system on the ecological system, the effect of the ecological system on the social system, or are you interested in understanding the reciprocity of both systems?
- How do you conceptualize the environmental system? Do you conceptualize it from the perspective of its utility for humans? Or do you want to understand it by itself?
- Does the research question require an analysis or an action framework?

FURTHER RESEARCH: STEPS TO MAKE THE RESULTS COMPARABLE

Our analysis has shown that frameworks used to analyze social-ecological systems vary significantly as to their theoretical and disciplinary origin, their purpose, and the way they conceptualize the social and the ecological systems, their interaction and dynamics. This variety is important because it also reflects the diversity of research questions and purposes addressed by the different frameworks. As shown in Figure 1 there is no one framework that would serve all purposes of research and be applicable for all cases studied.

Given that we need a variety of frameworks, we consider two issues to be particularly relevant for future research. The first relates to the comparability of results if the same social-ecological system is studied with several frameworks. Here an interesting research question would be to what extent the theories underlying the frameworks would lead to similar conclusions or would contribute significantly to biasing the results obtained.

The second issue relates to the question whether we would be able to extract from the frameworks a set of variables common to all frameworks and whether then the results obtained with the different frameworks would become comparable. A subsequent question would be to what extent it could be possible to develop an ontology and database for SES as suggested by J. Hinkel, P. Bots, and M. Schlüter (*unpublished* *manuscript*) that allows for collecting and sharing relevant data on the social and ecological systems that might be usable for applying in any framework. The database should be composed of a minimal set of variables to be elicited for all cases. If the database were expandable, it would allow for deeper analyses by including variables that might be suggested by different frameworks.

Probably best suited for providing a first step in this direction is the SESF because it (i) is the only framework that treats the social and ecological systems in almost equal depth; and (ii) provides a frame for developing different degrees of specificity in differentiating different tiers. Ongoing research is already looking into making the criteria with which to organize concepts and variables into tiers more valid (J. Hinkel, P. Bots, and M. Schlüter, *unpublished manuscript*). Further research may build on this and explore the development of a formal ontology as a basis for developing a database from which the different frameworks could be applied. The utility of such a database becomes obvious if one considers that different research questions could be answered with different frameworks using comparable and consistent data sets. Also, similar research questions could be addressed with different frameworks to test the robustness and validity of the results obtained by using one frame of reference.

Responses to this article can be read online at:
http://www.ecologyandsociety.org/issues/responses.php/5551

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