Coordinating the study of sustainability: towards a shared language for the social-ecological system framework

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Abstract:

This paper represents a first attempt to move towards a shared language for the study of sustainability with the social-ecological systems (SESs) framework. It begins by situating knowledge generation using the interdisciplinary SES framework as a coordination problem that depends upon alignment around a core set of operational definitions to build a new science of sustainability. A related challenge is that the literature on the commons that provides much of the theoretical background for the framework lacks clear definitions for the vast majority of its key terms. Thus, definitions are presented in this paper for each of the tier one components and tier two attributes of the SES framework. It is hoped that these definitions will serve as a starting point for the development of a shared language that maximizes the accessibility and diagnostic capacity of the SES framework as we seek to understand sustainability in the anthropocene. The paper concludes by briefly discussing issues concerning the social, ecological, evaluative and macro-level components of the framework, respectively.

Keywords: Social-ecological systems; frameworks; definitions; coordinating inquiry

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1.0 INTRODUCTION

The social-ecological system (SES) framework (Ostrom 2007, 2009) is an outgrowth of the institutional analysis and development (IAD) framework (Ostrom 2005) designed explicitly to organize inquiry and integrate knowledge in the emergent field of sustainability science. The core orienting hypothesis of the framework is that successful governance, broadly speaking, is a function of the fit between institutions and the diverse context of SESs. Given that somewhere between thirty and fifty variables and their potential interactions are presumed to define this context (Agrawal 2003; Ostrom 2007), the analytical challenge to develop a theory of sustainable governance is immense. The SES framework offers an architectural solution to this problem that seeks to integrate knowledge from a long-term, interdisciplinary, multi-method, and polycentric research program by adopting a nested partially decomposable structure. However, the viability of this decentralized, but integrative program of research also depends upon the existence of a shared language or definitions of the core concepts and phenomena under study such that insights from one study using a particular method can be linked to other studies across discipline and method.

This paper aims to contribute to this goal as part of a larger program of study at the Vincent and Elinor Ostrom Workshop in Political Theory and Policy Analysis to develop and refine the SES framework for the study of sustainability. More specifically we propose definitions for each of the tier one and tier two components of the SES framework in an attempt to provide a starting point for a larger collaborative discourse concerning knowledge accumulation in the study of sustainability. The ultimate goal of which is to organize and integrate theoretical statements towards a more general theory of sustainability; while minimizing the costs of learning and using a shared language that may at the outset undermine adoption and use of this potentially valuable research tool. The remainder of this paper is structured in the following way. Section one continues with a brief elaboration of the SES framework, its structure and then situates the discussion of SES definitions as a coordination problem. Section two discusses the methods that were used to develop and refine the definitions presented in section three. The paper concludes with a discussion concerning issues that emerged as we attempted to develop clear, concise, broadly acceptable definitions for this shared framework.

1.1 Building knowledge through coordination with the SES Framework

The SES framework (Table 1) is built on the premise that SESs are partially decomposable systems wherein the social and ecological components of these systems interact to produce a variety of relevant social and ecological outcomes. Decomposability refers to a system in which the components are arranged in levels such that lower level components are subdivisions of higher-level components (Simon 2000). This can be understood as a general increase in specificity regarding an element of that system as one moves down the levels of the framework and has clear parallels to the organization of inquiry in the biological sciences and the Linnaean system of classification. This decomposability is, however, partial in that one must first define the core elements of a system (tier one components) and then identify the fundamental characteristics or attributes (tier 2 components) that collectively define those elements.

The framework identifies four core, or tier one, components; the resource system (RS) such as a lake, forest or rangeland ecosystem where resource units (RU), the focal unit of analysis such as fish, water, and trees are found which are harvested, managed or in some way influenced by actors (A) such as fishers, irrigators or herders whose choices depend upon the formal and informal governance systems (GS) that define the institutionally mediated incentive structure of their choices. These core components are joined by two additional tier one components: related ecosystems (ECO) that describes macro-level climate patterns and the exchange of matter and energy between the focal system and other system(s), and the social, economic and political setting (S) that describe macro-level economic, demographic, and political features at higher levels of aggregation such as the national or international level.

Table 1: Tier one and tier two components of the SES framework. Adapted from Ostrom (2009)

Social, Economic, and Political Settings (S) S1– Economic development. S2– Demographic trends. S3– Political stability. S4– Government resource policies. S5– Market incentives. S6 – Media organizations.	
Resource Systems (RS)	**Governance Systems (GS)**
RS1– Sector (e.g., water, forests, pasture, fish) RS2– Clarity of system boundaries RS3– Size of resource system RS4– Human-constructed facilities RS5– Productivity of system RS6– Equilibrium properties RS7– Predictability of system dynamics RS8– Storage characteristics RS9– Location	GS1– Government organizations GS2– Nongovernment organizations GS3– Network structure GS4– Property-rights systems GS5– Operational-choice rules GS6– Collective-choice rules GS7– Constitutional-choice rules GS8– Monitoring and sanctioning rules
Resource Units (RU)	**Actors (A)**
RU1– Resource unit mobility RU2– Growth or replacement rate RU3– Interaction among resource units RU4– Economic value RU5– Number of units RU6– Distinctive characteristics RU7– Spatial distribution RU8 – Temporal distribution* RU9 – Equilibrium properties* RU10 – Predictability of resource dynamics*	A1– Number of relevant actors A2– Socioeconomic attributes A3– History or past experiences A4– Location A5– Leadership/entrepreneurship A6– Norms (trust-reciprocity)/social capital A7– Knowledge of SES/mental models A8– Importance of resource (dependence) A9– Technologies available
Action Situations: Interactions (I) ⟶ Outcomes (O)	
Activities and Processes:	**Outcome Criteria:**
I1– Harvesting I2– Information sharing I3– Deliberation processes I4– Conflicts I5– Investment activities I6– Lobbying activities I7– Self-organizing activities I8– Networking activities I9– Monitoring activities I10– Evaluative activities	O1– Social performance measures (e.g., efficiency, equity, accountability, sustainability) O2– Ecological performance measures (e.g., overharvested, resilience, biodiversity, sustainability) O3– Externalities to other SESs
Related Ecosystems (ECO) ECO1– Climate patterns. ECO2– Pollution patterns. ECO3– Flows into and out of focal SES.	

* Indicates modification proposed in this paper.

The first tier components of the framework serve mostly to define the units of analysis or alternatively define the scope within which findings are expected to apply. For instance Basurto and Ostrom (2009) begin their analysis of self-organization by identifying the resource system as an inshore fishery, the resource units as benthic mollusks, relevant actors as the local communities that harvest the benthic mollusks, and the governance system as the combination of formal government policies and informal local activities. They also situate the analysis of cases within the social, economic and political context of Northwestern Mexico coastal communities. After identifying the relevant units for analysis they can begin identifying potentially relevant variables on the basis of a theory and/or features of the case that are either of interest, or controlled for via study design. In this case, they outline a general deductive theory to predict when groups will successfully self-organize and then use this model to select from amongst the second tier components of the framework.

The second tier components of the framework identify potentially relevant attributes of each tier one component that may influence interactions in the set of relevant action situations that lead to social and environmental outcomes; or alternatively have a direct effect on those same outcomes. The second tier, as presented in table 1 identifies sixty separate variables, each of which may be decomposed further to increase the level of specificity and analyze the effects of variables in particular states and combinations thereof. The sheer number of tier two variables contained within the SES framework is often seen as overly complex, which is only magnified as one begins decomposing those variables. As an example of decomposition Ostrom and Cox (2010) show how equilibrium properties (RS6), can be decomposed into sub-attributes that classify cases according to their recharge dynamics (RS6a), recharge rate (RS6b), number of equilibria (RS6c), and feedbacks (RS6d) which are further broken down into those that demonstrate positive feedback processes (RS6d(i)) and those with negative feedback processes (RS6d(ii)). However, the number of relevant tier two components (and in particular the number of relevant sub-attributes) is dependent on the research question at hand. For example, Ostrom (2007) focuses on ten variables to analyze Hardin's (1968) tragedy of the commons. Nevertheless, the choices concerning how variables are decomposed remains somewhat of a mystery even to those that regularly apply the framework, but the analytical concept of decomposability remains a central feature of any diagnostic approach and diagnosis would undoubtedly benefit from additional work to develop the nested conceptual map.

Interdisciplinary studies of sustainability, much like their objects of study are mired in a set of collective action problems. First of all, the incentives that scholars interested in sustainability face is often structured around narrow questions as defined by disciplinary, methodological or professional conceits (Poteete et al. 2010). The Perestroika movement in political science (Kasza 2001; Schram 2003) and the "dialog of the deaf" between natural and social scientists (Agrawal and Ostrom 2006) attest to the challenges that exist when the organization of the academy is as much about defining and defending terrain as it is about the production of knowledge. An important part of this terrain is the language that disciplines or specializations develop to aid their investigation of particular phenomena and coordinate findings which serves to facilitate the development of knowledge within a group; but presents significant barriers to entry and integration with other groups. Over time mastery of the language of a group may become synonymous with a profession and become valued in and of itself because of this association. The natural sciences have clearly devoted more attention to the development of a scientific language and have benefited at times. However, when seen in terms of a clearly inter-disciplinary endeavor, such as the production of knowledge concerning the sustainability of SESs, the problem of definitions begins to resemble a coordination problem with multiple possible solutions (or more formally equilibria). Akin to battle of the sexes, each discipline would prefer to have scholars coordinate on "their" definitions of concepts as this expands the influence of their discipline and reduces the barriers to entry for scholars associated with that discipline. Nevertheless, every discipline prefers to coordinate on another discipline's definitions to avoid talking past one another. Unfortunately, this lack of coordination is, in part, what we find in our effort to compile SES definitions.

2.0 METHODS

The methods employed in this research gradually evolved from an attempt to sample the literature to compare and contrast definitions for each tier one component and tier two attribute in the SES framework to a less rigorous, but more practical approach that simply seeks to offer tentative definitions that capture the ways in which variables have been used or operationalized in empirical research. The shift reflects the general absence of definitions in relevant literatures, which apart from quantitative studies focus mostly of the importance of variables while neglecting to explicitly define what they mean by the variable in question. The quantitative literature was clearly helpful in this regard in that the variables used in models are clearly identified. But the difference between a broad definition of a concept and its operationalization in a model means that the latter captures only a portion, or a particular interpretation, of the former.

3.0 DEFINITIONS

3.1 External components

3.1.1 Social, economic and political settings(S): "The broader context within which the governance system per se is located, including the effects of market dynamics and cultural change" (McGinnis 2011).

3.1.1.1 Economic development (S1): The state of macroeconomic and human development conditions as it relates to income, employment, trade, health care, education, infrastructure, etc., or the rate of change thereof (Gutierrez et al. 2011).

3.1.1.2 Demographic trends (S2): Changes in the size and composition of human populations (Agrawal 2001, 2007).

3.1.1.3 Political stability (S3): The predictability of the political system – Generally, a reliance on the rule of law rather than individuals in shaping what actions are permissible (Shepherd, 2010). This allows actors to be more easily estimate the costs and benefits of actions, which in turn aids planning.

3.1.1.4 Government resource policies (S4): The prevailing set of processes or institutions [and organizations] that shape resource policies

3.1.1.5 Market incentives (S5): Macroeconomic incentives such as supply, demand, prices, availability of credit, and the stability thereof that (Berkes et al. 2006; Pagdee et al. 2006; Baland and Platteau 1999).

3.1.1.6 Media organizations (S6): Organizations or groups that communicate information to large audiences such as newspapers, radio, television and the internet, and their characteristics in terms of quantity, quality and availability thereof.

3.1.2 Related ecosystems (ECO): "The broader ecological context within which the focal resource system is located, including the determinants of many potential exogenous influences" (McGinnis 2011).

3.1.2.1 Climate patterns (ECO1): "Climate in a narrow sense is usually defined as the "average weather", or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period is 30 years, as defined by the World Meteorological Organization (WMO). These quantities are most often surface variables such as temperature, precipitation, and wind" (Watson and Albritton 2001).

3.1.2.2 Pollution patterns (ECO2): The movement of deleterious substances across and between social-ecological systems.

3.1.2.3 Flows into and out of focal SES (ECO3): The movement of energy, biotic, and abiotic materials across and between social-ecological systems.

3.2 Social components

3.2.1 Governance system (GS): "The prevailing set of processes or institutions [and organizations] through which the rules shaping the behavior of the [actors] are set and revised" (McGinnis 2011).

3.2.1.1 Government organizations (GS1): An organization within government that is charged with the monitoring and administration of government policy with regards to a particular issue areas or locations relevant to the SES in question.

3.2.1.2 Nongovernment organizations (GS2): "Independent voluntary association[s] of people acting together on a continuous basis, for some common purpose, other than achieving government office, making money or illegal activities" (UNESCO Encyclopedia) that are part of or have significant impact on the *governance system* surrounding the SES in question.

3.2.1.3 Network structure (GS3): "…the connections among the rule-making organizations and the population subject to these rules" (McGinnis and Ostrom, forthcoming). For example, whether the system is constructed so as to be monocentric or polycentric (see V. Ostrom, 1999).

3.2.1.4 Property-rights structure (GS4): The bundle of formal or informal rights held by actors with respect to a specified good or service. (McGinnis 2011). General components include access, withdrawal, management, exclusion and alienation (Schlager and Ostrom 1992); but is often generalized to distinguish between open access and private, public or common property (Acheson 2006)

3.2.1.5 Operational rules (GS5): "Operational rules directly affect day-to-day decisions made by the participants in any setting. These can change relatively rapidly – from day to day." (Ostrom 2005)

3.2.1.6 Collective-choice rules (GS6): "Collective-choice rules affect operational activities and results through their effects in determining who is eligible to be a participant and the specific rules to be used in changing operational rules. These change at a much slower pace [than operational rules]." (Ostrom 2005)

3.2.1.7 Constitutional rules (GS7): "Constitutional-choice rules first affect collective-choice activities by determining who is eligible to be a participant and the rules to be used in crafting the set of collective-choice rules that, in turn, affect the set of operational rules. Constitutional-choice rules change at the slowest pace" (Ostrom 2005)

3.2.1.8 Monitoring and sanctioning processes (GS8): Formal and informal rules used to detect and punish noncompliance with property rights, operational, collective-choice and constitutional rules. (Ostrom, 2005)

3.2.2 Actors (A): A group of individuals as defined by some shared attribute(s) that participates in relevant action situations. Actors need not be individuals though. For example, actors could be analyzed at the household level (Agrawal and Chhatre 2006).

3.2.2.1 Number of relevant actors (A1): The absolute or relative number of actors within a type of actor that make decisions with respect to a resource unit/resource system (Ostrom, 2007; Ostrom, 2009).

3.2.2.2 Socioeconomic attributes (A2): Absolute and relative descriptions of cultural, social, and economic attributes within a type of actor, and across actor types

3.2.2.3 History of use (A3) Absolute and relative measures of historical patterns of appropriation, maintenance, and usage in relation to the resource system or resource unit (Wertime et al., 2007)

3.2.2.4 Location (A4): The geographic location of an actor relative to one another, other actor types, the resource (e.g. Pagdee, Kim, and Daugherty 2006), markets (e.g. Agrawal and Chhatre 2006), resource substitutes and other SES.

3.2.2.5 Leadership/entrepreneurship (A5): Individuals or small groups/elites that possess skills, experience, endowments and respect within a type of actors that can provide energy, direction and conflict resolution (and other) within that group and/or across groups. (Ostrom, 2009)

3.2.2.6 Norms/social capital (A6): Presence of "…shared concepts of what must, must not, or may be appropriate actions…in particular types of situations." (Ostrom 2005)

3.2.2.7 Knowledge of SES/mental models (A7): The ways in which information and beliefs about an SES, or variability in an SES is generated, processed, shared, and interpreted within an actor type and across types.

3.2.2.8 Importance of resource (A8): The extent to which actor(s) are dependent on the resource to secure their livelihoods, and to fulfill their needs and/or desires. (Ostrom 2001)

3.2.2.9 Technology used (A9): The type of technology (and changes therein) that are used in appropriation, maintenance and/or management of a resource

3.3 Ecological components

3.3.1 Resource System (RS): A system of interrelated biotic and abiotic components in which dynamic processes support the production, storage, or movement of resource units (McGinnis 2011)

3.3.1.1 Sector (RS1): General characteristics of a resource system that distinguish it from other types of resource systems (eg. fisheries, forests, wildlife, irrigation)

3.3.1.2 Clarity of system boundaries (RS2): The extent to which boundaries of a resource system whether naturally occurring or artificial are identifiable (Gutierrez et al. 2011; Cox et al. 2010).

3.3.1.3 Size of resource system (RS3): Absolute or relative spatial descriptions of a resource system (Pagdee et al. 2006; Basurto and Ostrom 2009; Chhatre and Agrawal 2009; Wertime et al. 2007).

3.3.1.4 Human-constructed facilities (RS4): Anthropogenic changes to a resource system that affects system inputs, withdrawals, storage, or other characteristics of a resource system (Schlager et al. 1994).

3.3.1.5 Productivity of system(RS5): Absolute or relative characterizations of the rate at which a resource system produces energy and/or matter (e.g. primary, secondary, tertiary production) (Basurto and Ostrom 2009; Krebs 2009).

3.3.1.6 Equilibrium properties (RS6): The attractor(s) of one or more resource system property(s).

3.3.1.7 Predictability of system dynamics (RS7): The degree to which actors can predict the effects of social, environmental or institutional changes on a resource system.

3.3.1.8 Storage characteristics (RS8): Storage capacity that enables users to capture and retain unharvested units (Schlager et al. 1994).

3.3.1.9 Location (RS9): The absolute geographic location of a resource system or its position in relation to some other component of the social-ecological system.

3.3.2 Resource units (RU): Resource units can be alternatively understood as stock and flow variables. The latter refers to units that appropriators extract from a resource system, while the former refers to the units that remain in a system for replenishment or future extraction (Ostrom 1990)

3.3.2.1 Resource unit mobility (RU1): "Spatial movement of [resource] units apart from any harvesting activity by resource users" (Schlager et al. 1994)

3.3.2.2 Growth or replacement rate (RU2): Absolute or relative descriptions of the natural rate of change in some property of a resource unit (i.e. individual mass, population size) over time. (Sibly and Hone 2002; Dietz et al. 2002; Lee and Johnson 2005)

3.3.2.3 Interaction among resource units (RU3): "Regular interactions (or co-actions) in the parts of a system" (Lidicker 1979).

3.3.2.4 Economic value (RU4): Total economic value of an environmental resource consists of its, direct and indirect use values as well as its option, bequest, and existence values (Pearce and Moran 1994) and may vary across actor types (Berkes 2004).

3.3.2.5 Number of units (RU5): Absolute or relative measures of the historical number and/or size of resource units that constitute the stock units.

3.3.2.6: Distinctive characteristics (RU6): Markings and/or behavioral patterns of resource units that can be used by actors to specify operational rules.

3.3.2.7 Spatial distribution (RU7): Spatial variation in resource availability.

3.3.2.8 Temporal distribution (RU8):* "Temporal variation in [resource] availability" (Poteete and Welch 2004).

3.3.2.9 Equilibrium properties (RU9)*: The attractor(s) of a given resource unit or resource unit property.

3.3.2.10 Predictability of resource dynamics (RU10):* The degree to which actors can predict the effects of social, environmental or institutional changes on a resource system

3.4 Interactions and outcomes

3.4.1 Interactions

3.4.1.1 Harvesting level of diverse users (I1): The absolute or relative amount of resources harvested/appropriated per specified period of time.

3.4.1.2 Information sharing among users (I2): The ways in which actors interact and share information about the resource system, the resource and the behavior of other actors and organizations (i.e. the way information is diffused across actors involved in an action situation).

3.4.1.3 Deliberation processes (I3): The ways in which actors interact and make decisions about rules and strategies (e.g. careful discussion, consideration and debate, within a group, of possible actions to be taken by the group) (Blomquist and Ostrom 2008)

3.4.1.4 Conflicts among users (I4): The ways in which conflicts (the persistence and possible resolution) between actors in the action situation manifests itself in decision-making processes and institutions.

3.4.1.5 Investment activities (I5) The ways in which investments (in social, human, natural, monetary, etc terms) by actors in action situation affect future productivity or capacity of resources (e.g. resource system, social interaction, etc).

3.4.1.6 Lobbying activities (I6): The ways in which actors in action situations seek to alter decisions of other actors within a focal action situation or across action situations.

3.4.1.7 Self-organizing activities (I7): The ways in which actors in actions situations interact to address shared collective action problems in the absence of external influences.

3.4.1.8 Networking activities (I8): The ways in which actors actively seek to create and maintain social ties within the community.

3.4.1.9 Monitoring activities (I9): The ways in which actors monitor and sanction other actors. (Ostrom 2005)

3.4.1.10 Evaluative activities (I10): The ways in which actors interact to evaluate their own performance.

3.4.2 Outcomes

3.4.2.1 Social performance measures (O1): Indicators that provide qualitative and/or quantitative information to assess progress towards achieving specified social outcomes. Common indicators include measures of efficiency, social welfare, equity, conflict, robustness, and livelihood benefits (Chhatre and Agrawal 2009; Pagdee et al. 2006; Fleischman et al. 2010; Anderies 2006; Ostrom 1990; Gutierrez et al. 2011).

3.4.2.2 Ecological performance measures (O2): Indicators that provide qualitative and/or quantitative information to assess progress towards achieving specified ecological outcomes. Common indicators include ecological sustainability, resource stocks, levels of exploitation and biodiversity (Persha et al. 2011; Coleman et al. 2011; Coleman 2009; Pagdee et al. 2006; Gutierrez et al. 2011)

3.4.2.3 Externalities to other SESs (O3): Unintended impacts (social and ecological, positive and negative) of actions by actors within a focal action situation on other actors and on resources.

4.0 DISCUSSION

This section builds upon the definition of variables that constitute the core of this paper to discuss a variety of issues related to the use of these terms in the literature and implications for an interdisciplinary science of sustainability. This section is loosely organized around themes of macro-level influences (ECO and S), as well as the ecological (RS and RU), social (A and GS), and evaluative (I and O) components of the framework.

4.1 Macro-Variables

The addition of macro-level variables to the SES framework reflects a long-standing critique that institutional studies fail to account for large-scale demographic, economic, and macro-political features that influence the incentives that actors operating at a local scale face when making choices concerning resource appropriation and management (Agrawal 2003; Clement 2010). In what can be safely described as an important precursor to the SES framework; Agrawal (2003) points out that the attention that commons scholars devote to understanding local phenomena neglects the influence of macro-level phenomena such as population growth, and rapid globalization that may overwhelm the ability of local institutions to adapt, or simply crowd-out longstanding normative influences in favor of economic incentives (Frey and Jegen 2001). Clement (2010) continues along the same lines, but adds global environmental discourses that are said to frame debates concerning natural resource management at lower levels around a set of particular policy alternatives. Collectively these critiques highlight the view that the study of phenomena at a local scale is incomplete without considering the broader and potentially more powerful social and political context in which local decisions are made. Therefore the framework seeks to account for these influences by adding variables to account for market incentives (S5), demographics (S2), and government resource policies (S4) with relatively rapid uptake in related applications. For instance, Basurto and Ostrom (2009) used the aggregate tier one component (S) to situate their analysis of benthic fisheries within the context of northwest Mexico, while Fleischmann et al. (2009) identify demographic changes as a local disturbance, and Blanco (2010) finds that successful nature-based tourism is effected by national political stability (S3), as well as the level of competition and other market-related (S5) factors.

Resilience scholars offer a similar critique of commons theory for its failure to recognize dynamic ecological relationships within and across scales. Berkes et al. (2006) provide a compelling illustration of the relevance of such linkages by describing how a decline in predator populations from overfishing in the Gulf of Maine led to rapid proliferation of sea urchins which then became targets of commercial harvests, before declining themselves. The key point which emerges throughout the resilience literature is that outcomes of particular resource or other environmental dilemma cannot be understood in isolation from other ecological features of systems that are fundamentally linked within and across scales (Holling et al. 2002). The SES framework attempts to address this critique by incorporating variables to account for climate (ECO1), pollution (ECO2), and flows across systems (ECO3); while appearing to maintain its focus on a single resource dilemma. Thus the movement of resource units, their genes, related organisms such as prey or competitors, energy and pollution across action situations can be (possibly) accounted for in a focal action situation using these variables. However, unlike the uptake of macro-level social variables; only Blanco (2010) makes use of these macro-level ecological variables to suggest that nature-based tourism suffers when situated in systems that receive or store pollution from other local or external activities.

The addition of both social and ecological macro-level variables to the SES framework is important in that it formally acknowledges a major short-coming in many applications of the IAD related to the effects of variables external to the focal action situation. However, McGinnis (2011b) with his network of linked action situations offers a different perspective wherein the absence of scalar features across time and space, and the interplay of multiple resources are not a function of missing variables, but rather missing related action situations. In this sense national-level policies would be captured by the same sets of variables that capture local-level policies; but vary in terms of the level of aggregation. The outcomes, or more appropriately outputs from local and national level action situations in the forms of rules, information and resources would then theoretically contribute to define the context in which the other operates. The advantage of this approach is that it maintains its clear emphasis on focal action situations that can be explored using a variety of inductive and deductive methods; while the former seems to correspond better to simple correlational research designs that presume exogeneity.

4.2 Social Components of the Framework

There are no unifying definitions concerning such concepts as norms (A6) or leadership (A5). Crawford and Ostrom (1995), for example, classify scholars' definitions of rules, norms, and conventions, finding that scholars refer to very different concepts using the same terms. Part of the purpose of social science is to clarify concepts through contestation. However, this lack of unified meaning complicates the venture to consolidate our knowledge from diverse studies, each using their own definition of a concept. When studies do not use the same variable, we must collapse concepts into meaningful categories. This process in itself is wrought with pitfalls. Let us illustrate this by examining the effect of communication within a common pool resource problem. Ostrom and Walker (1991) demonstrate, experimentally, that when individuals are allowed to communicate with one another groups behave more cooperatively in solving the tragedy of the commons (Hardin, 1968). The "communication effect" has subsequently been the subject of two meta-analyses (Sally, 1995; Balliet, 2010) aiming to synthesize our understanding of behavior in social dilemmas. By definition, meta-analyses seek to consolidate findings from across different studies and, in order to do so, must craft treatment categories that capture the effect being studied. Balliet, for example, contrasts the effects of communication in face-to-face discussions versus computerized chats. However, he does not distinguish between structured and free communication,[2] but free-form communication is much more prevalent in face-to-face discussions. Hence, it is not clear whether the finding that face-to-face communication is more effective than computerized chat in improving cooperation is driven by the communication medium or the restrictions on the communication content. Therefore, although the chosen categories are instrumental in allowing the integration of knowledge, they obfuscate the driving force behind the observed effect.

The selection of meaningful categories in synthesizing knowledge is made more laborious when explicit concept definitions are lacking in original studies. Although authors are conducting their studies with particular interpretations of concepts in mind, these are often implicit. This is one of the main concerns we encountered during the compilation of definitions. In the social components of the framework, where there are no universal definitions, this concern is particularly troubling.

The SES framework may be seen as an elaboration of the IAD framework (Ostrom, 2005) with an aim to integrate ecological processes (Ostrom, 2007). Consequently, the social components of the SES framework have undergone additional rounds of revisions (as part of the IAD framework) and are, in turn, subject to fewer alterations. Nevertheless, the tier one component "actors" (A) has already been changed from "users" (U) to reflect the multitude of ways that individuals may have an impact on the SES in question. In connection with this, we propose the inclusion of the tier two component "actor type" so as to indicate the relationship the actors may have with the resource system. Furthermore, revisions of the governance system (GS) may take place in the near future (McGinnis and Ostrom, forthcoming), which seek to improve the coherence of this category.

4.3 Ecological Components of the Framework

The ecological components of the SES framework, namely resource systems (RS) and resource units (RU) were introduced to take a step towards natural scientists in recognition of the

[2] Structured communication implies that subjects may only exchange preformulated messages or contribution pledges, whilst free form communication means that subjects may express themselves in their own terms.

longstanding “dialog of the deaf” between the social and natural sciences (Agrawal and Ostrom 2006). In fact the decomposable structure of the framework is explicitly situated alongside the organization of the biological sciences which generally ranges from the study of sub-cellular features or processes such as genes and photosynthesis to individuals, populations, communities and the study of global phenomena such as the distribution of biodiversity and nutrient cycles (Krebs 2009). Decomposition with the SES framework, however, is based on a different logic and does not explicitly differentiate for instance between the distribution of an individual resource unit and that of a population of resource units. This lack of correspondence generally suggests that despite attempts to create a general interdisciplinary framework for the study of sustainability; aspects of the dialog of the deaf remain.

At present the organization of the SES framework presents significant transaction costs for those seeking to integrate natural scientific knowledge and may undermine knowledge accumulation in the emergent field of sustainability science. While sustainability science has emerged in response to the inadequacies of individual disciplines to explain and understand linked social and ecological systems; each discipline brings a large body of cumulative knowledge that may advance diagnosis. The action situation, and its general model of institutionally-mediated choice, carries with it knowledge generated from the multi-method commons literature regarding the social aspects of these systems. Unfortunately the same cannot be said for the natural sciences which appear to be operating in somewhat of a knowledge vacuum; although scholars often devise ad-hoc methods to integrate such knowledge (Basurto and Coleman 2010). Nonetheless, the framework would undoubtedly benefit by developing a systematic way to account for biological mechanisms akin to those that are used to model choice (Anderies 2002). For example studies have shown that size-specific fishing gears may bias fisheries populations towards smaller sizes and lower yields over relatively short time intervals (Birkeland and Dayton 2005). So although groups may resolve a core appropriation problem related to the number of units harvested, an externality of size-selective technologies is that they may eventually lead to declining yields. The addition of ecological mechanisms to the SES framework is also consistent with the multiple method agenda of sustainability science (Young 2006; Poteete et al. 2010) and would be particularly conducive for formal and agent-based models.

4.4 Evaluative Components of the Framework

The search for definitions concerning interactions and especially outcomes is unique among sections of the framework as the literature is keenly aware of the diversity of definitions and potential problems this causes for analysis. First of all, as mentioned interactions are rarely an object of analysis outside of experimental environments where researchers can record patterns and content of communication and individual harvesting levels with relative ease (Ostrom et al. 1994; Janssen 2010). Although they often fail to explicitly define terms for interactions, this section of the framework seems the most self-explanatory. Definitions of short-term success, on the other hand, range from short-term estimates of sustainability, aggregate subsistence livelihood benefits, equitable distribution of resource benefits, and enhanced democratic participation of local users (Gutierrez et al. 2011; Pagdee et al. 2006). As the interval of analysis increases from cross-sectional or short-term longitudinal designs the definitions of successful outcomes change to focus on robustness (Carlson and Doyle 2002; Janssen et al. 2007) or resilience (Biggs et al. 2012; Walker et al. 2004) that broadly speak to the long-term maintenance of one or more desirable system properties. More recently several scholars using a cross-sectional design have begun to explore how characteristics of governance systems affect joint social and environmental outcomes such as carbon storage (or species diversity) and livelihood benefits (Persha et al. 2011; Chhatre and Agrawal 2009). However, it still remains somewhat of an open question how the full diversity of social and environmental outcomes fit together to describe a sustainable SES.

5.0 CONCLUSION

The SES framework is very much a work in progress with a wide range of social dilemmas to overcome as it moves towards its stated ambition to provide a general interdisciplinary framework for the study of sustainability (Ostrom 2009). This paper responds to one of these dilemmas by providing definitions as a starting point that can be altered, refined, and changed to maximize knowledge production, while minimizing the costs of initiation. As illustrated by the discussion we find that there are many issues left unresolved regarding the use of the SES framework and the ways in which it links knowledge across method, systems and cases. Nonetheless it appears that if the ultimate test of a framework is its usefulness, applications in small-scale fisheries (Basurto and Ostrom 2009; Basurto and Nenadovic 2012; Cinner et al. 2012), irrigation (Ostrom and Cox 2010), forests (Fleischmann et al. 2010) and nature-based tourism (Blanco 2010) suggest that the framework is well on its way to generating the interest required to overcome these barriers.

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