

Synthesis

A review of the social-ecological systems framework: applications, methods, modifications, and challenges

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ABSTRACT. The social-ecological systems framework (SESF) is arguably the most comprehensive conceptual framework for diagnosing interactions and outcomes in social-ecological systems (SES). This article systematically reviews the literature applying and developing the SESF and discusses methodological challenges for its continued use and development. Six types of research approaches using the SESF are identified, as well as the context of application, types of data used, and commonly associated concepts. The frequency of how each second-tier variable is used across articles is analyzed. A summary list of indicators used to measure each second-tier variable is provided. Articles suggesting modifications to the framework are summarized and linked to the specific variables. The discussion reflects on the results and focuses on methodological challenges for applying the framework. First, how the SESF is historically related to commons and collective action research. This affects its continued development in relation to inclusion criteria for variable modification and discourse in the literature. The framework may evolve into separate modified versions for specific resource use sectors (e.g., forestry, fisheries, food production, etc.), and a general framework would aggregate the generalizable commonalities between them. Methodological challenges for applying the SESF are discussed related to research design, transparency, and cross-case comparison. These are referred to as “methodological gaps” that allow the framework to be malleable to context but create transparency, comparability, and data abstraction issues. These include the variable-definition gap, variable-indicator gap, the indicator-measurement gap, and the data transformation gap. A benefit of the framework has been its ability to be malleable and multipurpose, bringing a welcomed pluralism of methods, data, and associated concepts. However, pluralism creates challenges for synthesis, data comparison, and mutually agreed-upon methods for modifications. Databases are a promising direction forward to help solve this problem. In conclusion, future research is discussed by reflecting on the different ways the SESF may continue to be a useful tool through (1) being a general but adaptable framework, (2) enabling comparison, and (3) as a diagnostic tool for theory building.

Key Words: *collective action; commons; diagnostic research; frameworks; governance; sustainability*

INTRODUCTION

The social-ecological systems framework (SESF) (Ostrom 2007, 2009, Poteete et al. 2010) is a conceptual framework providing a list of variables that may be interacting and affecting outcomes in social-ecological systems (SES). The evolution of the framework is supported by a long history of empirical research on the commons, institutions, and collective action (e.g., Ostrom 1990, Agrawal 2001, Meinzen-Dick et al. 2002, Anderies et al. 2004, Wollenberg et al. 2007, Poteete et al. 2010). However, the SESF is now viewed less as a theoretical framework to advance collective action theory and more as a general tool to diagnose the sustainability of social-ecological systems (Ostrom 2009). This transition has brought wider engagement over the last 10 years, and the framework’s core literature (i.e., Ostrom 2007, 2009, Poteete et al. 2010, McGinnis and Ostrom 2014) has now been cited in combination more than 7,700 times (Google Scholar, as of November 2018). However, critical methodological questions remain regarding how the framework can be applied empirically, operationalized in new contexts, and continue to evolve (Hinkel et al. 2015, Leslie et al. 2015, Partelow et al. 2018b).

This article reviews the SESF literature to help examine how and where it has been applied and discusses methodological challenges for applying the framework to guide those interested in critical discussion about future research. First, by reviewing the trends in the peer-reviewed literature and, second, by providing an extensive discussion of different methods and methodological considerations for applying the framework. This article builds on previous reviews by McGinnis and Ostrom (2014), who provide

substantial contributions to the framework’s conceptual development, and by Thiel et al. (2015) who review 20 articles using the framework for empirical research. This article continues and considerably expands on these two efforts by examining more than 90 articles that engage with the SESF either conceptually, empirically, and/or for metaanalysis. In the discussion, I critically reflect on how the SESF is inherently related to commons and collective action research, and how this warrants reflection on potential inclusion criteria for variable modification, and ultimately, the framework’s continued development. Numerous methodological challenges are discussed for applying the framework for future research. This review and discussion are guided by the following research questions:

- What are the trends in the SESF literature (i.e., sectors, data types, methods used)?
- What are the different ways the SESF is being applied (i.e., types of research)?
- What variable modifications have been suggested to the framework?
- What are the directions forward and potential challenges for the frameworks continued development?

A brief history of the framework

Although countless articles and books have written far more comprehensively about the evolution of Elinor Ostrom’s research on the commons, institutions, and collective action, leading to the SESF, the nature of this article warrants a brief overview. Initiated

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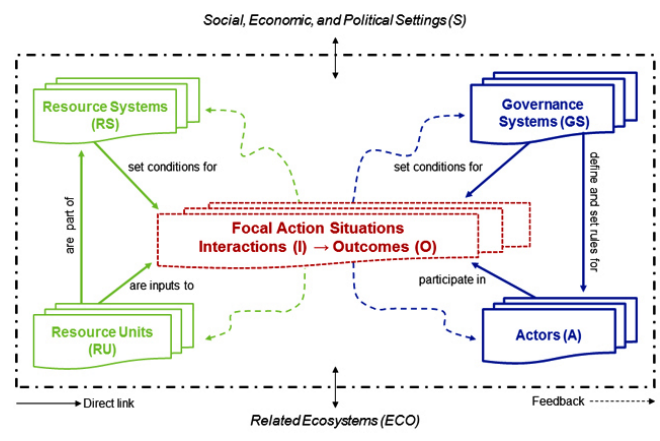
by her book *Governing the Commons* (1990), Ostrom and many colleagues began accumulating empirical evidence on the variables and types of institutional arrangements that were most likely to enable actors to work together and solve social dilemmas in systems with common-pool resources (CPR) and public goods (Olson 1965, Ostrom et al. 1994, Schlager 2004). Her work directly challenged Garrett Hardin's conclusions in the *Tragedy of the Commons* (Hardin 1968), showing that resource users are not helpless in their ability to solve social dilemmas, which are exacerbated by the rivalry and excludability characteristics of CPRs, but they can actually develop self-organized institutions to govern the commons without the need for privatizing common property or imposing state regulation.

Based on the early work of many commons scholars, an empirically supported list of variables began to emerge showing the multitude of influences that affect the development of governance institutions (Agrawal 2003, Anderies et al. 2004, Ostrom 2005). These variables became a comprehensive list of social and ecological variables influencing cooperation and self-organized governance under a theory of collective action (Olson 1965, Ostrom 1990, Poteete et al. 2010). Collective action theory in the commons literature explores a central hypothesis that actors can cooperate and self-organize the development of institutions for natural resource governance. However, the success of this cooperation is likely to vary under different social and ecological conditions. It became evident that the development of successful institutional arrangements for governance was in part dependent on understanding complex and interdependent linkages between these social and ecological variables. It soon became difficult to develop a strong set of theoretical claims that any group of variables will influence sustainability outcomes in predictable and generalizable ways across diverse cases. Instead, a proclaimed "nontheoretical" list of variables was conceptualized as a diagnostic checklist, a list of potentially influential variables that can be used to guide the diagnosis of key variables and interactions influencing outcomes; although the framework is not theory neutral, it is inherently rooted in collective action theory. This shift toward a diagnostic approach has been described metaphorically as similar to medical practitioners who diagnose patients with a standardized checklist of key components and interactions in the human body to find the appropriate treatments and to allow easy comparability between patients (McGinnis and Ostrom 2014). The concept of diagnosis can be applied to environmental problems if a list of key variables and interactive processes can be identified, i.e., variables that are common across a wide variety of systems for examination. The SESF proposes a list of generalizable variables that can be used as a diagnostic tool to help solve challenges with the governance of environmental problems (Ostrom 2007, 2009). However, the challenge with a diagnostic checklist that is proclaimed to not be explicitly linked to collective action theory, despite its clear history and evident theoretical construction under collective action theory (Ostrom 1990, 1998, Ostrom et al. 1994, Poteete et al. 2010), is what the theoretical inclusion criteria for new variables will be for modifying the framework.

The SESF is structured into tiers of nested and related concepts and variables (Fig. 1). The first tiers include the Resource System (RS), Resource Units (RU), Governance System (Gov), Actors (A), Social, Economic and Political Settings (S), Interactions (I),

External Ecosystems (Eco), and Outcomes (O). Second-tier variables are nested within each first-tier variable (Table 1). Beyond its visible structure, the framework emerges from the convergence of political theory and institutional economics (North 1990, Ostrom 1990, Coase 1998, Klein 1999). The epistemology of the framework (e.g., what is worth knowing about reality from the use of the framework) places an institutional and anthropocentric lens on the analysis of natural resource use in the commons through suggesting the need to understand how and why cooperation (via collective action and institutions) influences governance arrangements and their ability to achieve sustainable outcomes. However, it is evident that the framework is useful beyond the scope of commons and collective action research, as it has been proposed as a general tool to diagnose the sustainability of SES more generally (Ostrom 2009) and to develop new theories in SES (Cox et al. 2016).

Fig. 1. Conceptualization of the social-ecological systems framework from McGinnis and Ostrom (2014). First-tier variables are shown with their interactions and outcomes.



Social-ecological systems and sustainability

The SES concept has evolved into a mainstreamed field of research focused on the interdependent linkages between social and environmental change, and how those interdependent linkages influence the achievement of sustainability goals across different systems, levels, and scales (Berkes and Folke 1998, Liu et al. 2007, Fischer et al. 2015). Social-ecological systems research is focused on understanding many dimensions of system functioning, making it an interdisciplinary field, but also on the development and implementation of normative societal goals, such as those related to sustainability (Gibson 2006, Raworth 2012, Abson et al. 2014). What SES scholars would ultimately like to know is how SES can be sustainable for different people and places around the world. However, with these broad and often ambiguous goals, SES scholarship has become diverse and pluralistic (Miller et al. 2008, Binder et al. 2013, Partelow and Winkler 2016). It associates with many different concepts, theories, and methods under two broad conceptual pillars: (1) understanding SES functioning and (2) understanding all aspects related to the development, implementation, and transformation toward normative sustainability goals. A large majority of SES research attempts, in some way, to link these two core pillars,

Table 1. The first- and second-tier variables of the social-ecological systems framework from McGinnis and Ostrom (2014).

Social, Economic, and Political Settings (S)	
S1- Economic development. S2- Demographic trends. S3- Political stability. S4- Other governance systems. S5- Markets. S6- Media organizations. S7- Technology	
Resource Systems (RS)	Governance Systems (GS)
RS1- Sector (e.g., water, forests, pasture)	GS1- Government organizations
RS2- Clarity of system boundaries	GS2- Nongovernmental organizations
RS3- Size of resource system	GS3- Network structure
RS4- Human-constructed facilities	GS4- Property-rights systems
RS5- Productivity of system	GS5- Operational rules
RS6- Equilibrium properties	GS6- Collective choice rules
RS7- Predictability of system dynamics	GS7- Constitutional rules
RS8- Storage characteristics	GS8- Monitoring and sanctioning
RS9- Location	
Resource Units (RU)	Actors (A)
RU1- Resource unit mobility	A1- Number of relevant actors
RU2- Growth or replacement rate	A2- Socioeconomic attributes
RU3- Interaction among resource units	A3- History or past experiences
RU4- Economic value	A4- Location
RU5- Number of units	A5- Leadership/entrepreneurship
RU6- Distinctive characteristics	A6- Norms (trust-reciprocity)/ social capital
RU7- Spatial and temporal distribution	A7- Knowledge of SES/mental models
	A8- Importance of resource (dependence)
	A9- Technologies available
Interactions (I)	Outcomes (O)
I1- Harvesting	O1- Social performance measures
I2- Information sharing	O2- Ecological performance measures
I3- Deliberation processes	O3- Externalities to other SESs
I4- Conflicts	
I5- Investment activities	
I6- Lobbying activities	
I7- Self-organizing activities	
I8- Networking activities	
I9- Monitoring activities	
I10- Evaluative activities	
Related Ecosystems (ECO)	
ECO1- Climate patterns ECO2- Pollution patterns ECO3- Flows into and out of SES	

including the SESF. The SESF provides one of many conceptual frameworks attempting to do this, arguably the most comprehensive framework, but many others exist (Binder et al. 2013, Partelow and Winkler 2016).

METHODS

A systematic review of peer-reviewed literature was conducted from the scholarly databases Scopus and Web of Science. Searches were conducted on both databases (as of January 2018) to find literature directly engaged with the SESF in any context or type of research. Search strings were guided by an extensive list of search terms related to “social-ecological system,” “framework,” and/ or “Ostrom,” resulting in more than 120 articles from both databases. This list was refined manually by reading abstracts, and the full text if necessary, to check for applicability to the scope. Ninety-two articles were included for final review. Each article was read, evaluated, and coded with standardized criteria by two coders, first a research assistant and then the author. Consensus coding was reached on the following categories for each article: source, year of publication, type of research, contextual focus, major discussion points, type of data, type of analysis, variables used, indicators used, and suggested variable modifications.

RESULTS

Trends and gaps in the social-ecological systems framework literature

The SESF is extensively cited and associated with other concepts in the broader SES discourse, including other theories, concepts, and frameworks (Binder et al. 2013, Cox et al. 2016). The most common associations are with ecosystem services (Daily 1997, Partelow and Winkler 2016), resilience (Berkes and Folke 1998), and a variety of other environmental governance theories (Folke et al. 2005, Cox et al. 2016), including multilevel governance, polycentric governance, and adaptive comanagement. The cross-pollination of literature with broader SES research has created a plurality of nested conceptual approaches regarding the contexts in which the framework is applied and the methodologies for its application (Table 2).

The SESF has been applied to a wide variety of empirical contexts (Table 2). Much of the literature remains focused on commons scholarship, with a large focus on community-based systems such as irrigation systems (Meinzen-Dick 2007, Cox 2014a, Hoogesteger 2015, McCord et al. 2016), small-scale fisheries (Basurto et al. 2013, Leslie et al. 2015, Lozano and Heinen 2015,

Table 2. The diversity of methods, contexts, and thematic areas under which the social-ecological systems framework is applied are shown with the relevant literature. The specific sectors in which the framework has been applied are shown. Associated concepts and databases related to the framework are indicated.

Type of engagement with the SESF	Focus	Literature
Meta or large comparative analysis	Quantitative Qualitative Mixed	Gutiérrez et al. 2011, Cinner et al. 2012, Rahimi et al. 2016 Thiel et al. 2015 Kelly et al. 2015
Empirical analysis with single or multiple cases	Quantitative Qualitative Mixed Temporal analysis	MacNeil and Cinner 2013, Leslie et al. 2015 Amblard 2012, Ban et al. 2015, Hoogesteger 2015, Lozano and Heinen 2015, Naiga et al. 2015, Oberlack et al. 2015, London et al. 2017 Ernst et al. 2013, Cox 2014a, Guevara et al. 2016 Epstein et al. 2014a, Ban et al. 2015
Empirical analysis on specific or select variables	Experimental	Aswani et al. 2013, Falk et al. 2016
General development of the framework	Multidimensionality of first-tier variables Application through mixed methods and disciplinary approaches Specifically adding and/or modifying variables. Ontological consistency.	McGinnis and Ostrom 2014 Poteete et al. 2010 Epstein et al. 2013, McGinnis and Ostrom 2014, Frey and Cox 2015, Thiel et al. 2015, Vogt et al. 2015
Sector specific	Small-scale fisheries (general)	Gutiérrez et al. 2011, Cinner et al. 2012, Schlüter and Madrigal 2012, Delgado-Serrano and Andres Ramos 2015, Lozano and Heinen 2015, Partelow 2015, Guevara et al. 2016, Rahimi et al. 2016
Sector specific		
Use in combination with other approaches or concepts	Coral reef fisheries Benthic fisheries Lobster fisheries Large-scale fisheries Recreational fisheries Aquaculture Marine and coastal systems (general) Food production systems Irrigation Forestry Pasture/rangelands Watershed/stormwater management Drinking water management Institutional analysis and development (IAD) framework	Cinner et al. 2012, Stevenson and Tissot 2014 Basurto et al. 2013 Hearn 2008, Ernst et al. 2013, Partelow and Boda 2015 Epstein et al. 2014a Hunt et al. 2013, Arlinghaus et al. 2017, Lanz 2017 Partelow et al. 2018b Schlüter et al. 2013, 2019 Marshall 2015 Meinzen-Dick 2007, Cox 2014a, McCord et al. 2016 Fleischman et al. 2010, Oberlack et al. 2015, Davenport et al. 2016 Cole et al. 2014, Risvoll et al. 2014 Villamayor-Tomas et al. 2014, Bennett and Gosnell 2015, Silva et al. 2015, Flynn and Davidson 2016 Madrigal et al. 2011 Ostrom and Cox 2010, Partelow and Boda 2015, McCord et al. 2016
Use in combination with other approaches or concepts		
Other	Ecosystem services (general) Payment for ecosystem services Sustainability science Resilience Framework as a boundary object	Ban et al. 2015, Partelow and Winkler 2016, Rova and Pranovi 2017 Yin et al. 2013, Addison and Greiner 2015, Bennett and Gosnell 2015, Rodríguez-Robayo and Merino-Perez 2017 Partelow 2016 Risvoll et al. 2014, Arlinghaus et al. 2017 Hertz and Schlüter 2015, Partelow and Winkler 2016
Associated databases	Social-Ecological Systems Meta-Analysis Database (SESMAD) SESGO SES Library CPR Database NIIS Online Database IFRI Database	Cox 2014b https://sesmad.dartmouth.edu/ http://141.48.2.108:8080/ses_db_test/index https://seslibrary.asu.edu/ https://seslibrary.asu.edu/cpr https://ulrichfrey.eu/en/niis/ http://www.ifriresearch.net/resources/data/

Table 3. (A) The main sectors being focused on. The total does not equal 92, because not all papers focus on a specific sector. (B) The types of articles being published. (C) The data sources used for research.

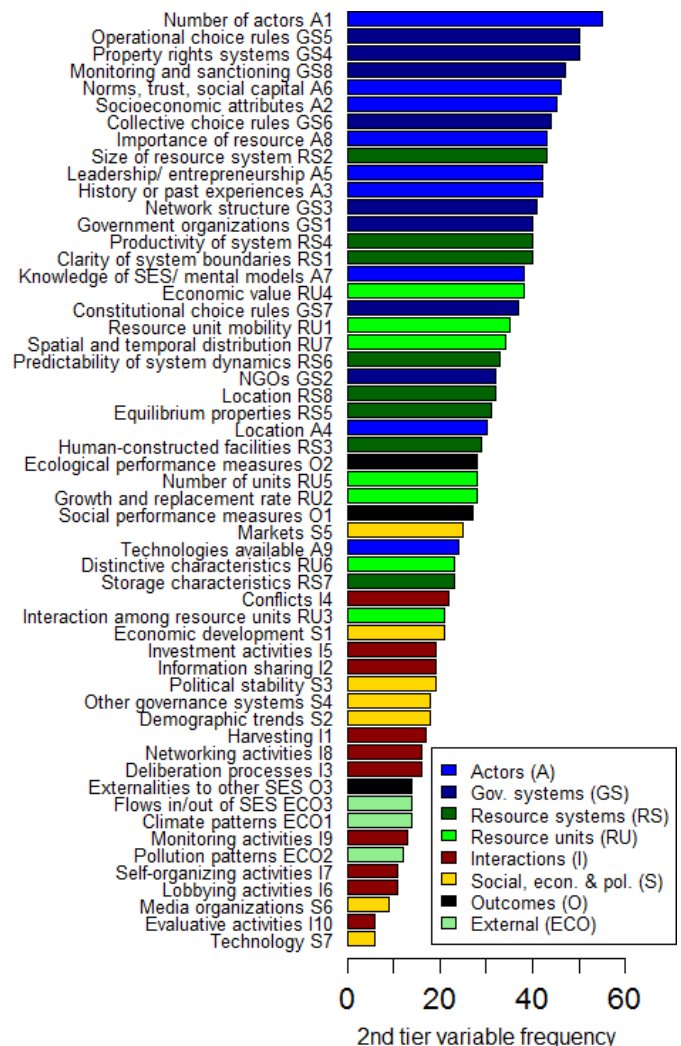
(A) Sectors of focus	No. of articles	(B) Types of articles	No. of articles	(C) Data sources	No. of articles
Fisheries/marine/coastal	39	Empirical - single case	46	Secondary data	52
Forestry	16	Conceptual/method/theoretical	22	Primary and secondary	25
Irrigation/agriculture	10	Empirical - multiple cases	12	Primary	15
Watershed management	2	Metaanalysis/comparative analysis	12		

Partelow 2015, Partelow and Boda 2015, Guevara et al. 2016, Oviedo and Bursztyn 2016, Blythe et al. 2017, London et al. 2017, Nakandakari et al. 2017, Partelow et al. 2018a) and forestry (Fleischman et al. 2010, Oberlack et al. 2015, Davenport et al. 2016). However, use of the framework has expanded beyond those resource-use sectors to general food production systems (Marshall 2015), aquaculture systems (Partelow et al. 2018b), terrestrial conservation and rangeland management (Falk et al. 2012, Risvoll et al. 2014, Baur and Binder 2015, Addison and Greiner 2016, Taggart-Hodge and Schoon 2016, Yandle et al. 2016, Guariguata et al. 2017), watershed management (Madrigal et al. 2011, Mansee et al. 2011, Nagendra and Ostrom 2014, Villamayor-Tomas et al. 2014, Bennett and Gosnell 2015, Naiga et al. 2015, Silva et al. 2015, Falk et al. 2016, Hileman et al. 2016), marine conservation and marine ecosystem management (Cinner et al. 2012, Schlüter et al. 2013, Stevenson and Tissot 2014, Ban et al. 2015, 2017, Williams and Tai 2016), coastal development (Kanwar et al. 2016, Schlüter et al. 2019), energy systems (Ye 2014, Bauwens et al. 2016), and pollution management (Amblard 2012, Epstein et al. 2014b).

Substantial portions of the SESF literature are focused on small-scale CPR systems, dominated by fisheries and marine and coastal systems (Table 3). Still, many articles focus on forestry and irrigation systems, following the history of commons scholarship (Meinzen-Dick et al. 2002, Wollenberg et al. 2007). Single case study research is the most common type of analysis, followed by a considerable number of papers focused on the framework's continued development, either conceptually, methodologically, or for building theory. However, a large majority of research with the SESF relies on secondary data or a mix of primary and secondary data.

The most recent version of the SESF from McGinnis and Ostrom (2014) contains 56 second-tier variables (Table 1); however, not all variables are equally focused on or analyzed in the literature. Figure 2 compares the frequency at which each second-tier variable is explicitly included as part of an analysis or application of the framework across the literature. Social system variables (i.e., Gov. and Actor tiers) are more frequently focused on compared with ecological system variables (i.e., RS and RU tiers). The remaining variables (i.e., S, I, O and ECO tiers) receive considerably less focus comparatively. When this is further divided into focus on different resource-use sectors, the trend remains the same; there is a general disproportionate focus on social system variables (Table 4). The variety of indicators and/or definitions used for all second-tier variables, aggregated from the literature, are provided in Appendix 1.

Fig. 2. The frequency of second-tier variables that have been focused on, either conceptually or empirically, across all relevant articles.



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Table 4. First-tier variable frequency of all articles. “All” shows the sum of second-tier variables at the first tier from Fig. 2. “All” includes all types of articles. The sum total of “All” is then subdivided by those articles that have an empirical focus in major sectors. The total number of articles with an empirical focus is shown, followed by the sum of empirical totals in each of the most relevant sectors.

First-tier variables	Sum frequency of second-tier variables						
	Total all papers	Total empirical only	Fisheries	Forestry	Irrigation	Water management	Other
(A) Actors	365	247	126	35	15	27	44
(GS) Governance	341	216	101	34	14	24	43
(RS) Resource system	271	206	101	33	15	22	35
(RU) Resource units	207	165	77	26	12	23	27
(S) Social, economic, political	116	94	44	13	0	14	23
(I) Interactions	150	130	52	27	12	18	21
(O) Outcomes	69	55	26	9	6	8	6
(ECO) External ecosystems	40	37	17	6	0	6	8

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Suggested modifications to variables in the framework

Ostrom (2007, 2009) iterates that the framework will need to be adapted to context and further developed as new empirical analysis supports the identification of new and/or more refined variables at the second, third, and subsequent tiers. Many articles have since suggested modifications, i.e., the addition, subtraction, or modification of variables. Table 5 presents a synthesis of the literature that has suggested modifications. The degree of generalizability is different between articles, as many may only be relevant to specific contexts (e.g., fisheries or forestry). Furthermore, many articles do not make a distinction between what constitutes a new variable vs. an indicator for measuring a variable. There is a difference between developing indicators to measure second-tier variables vs. developing nested subconcepts of a variable at the third tier (see discussion on methodological gaps). Similarly, not all second-tier variables are defined in the same way across contexts, and often definitions are not explicitly stated. Some second-tier variables represent very broad concepts such as “Socioeconomic attributes (A2),” “Social performance measures (O1),” “Ecological performance measures (O2),” and “Equilibrium properties (RS6).” These variables have more suggested modifications to refine them at the third tier (see Table 5 and Appendix 1). Similarly, some variables combine multiple concepts such as “Norms (trust-reciprocity)/ social capital (A6),” “Knowledge of SES/ Mental models (A7),” “Leadership/ entrepreneurship (A5),” “History or past experiences (A3),” “Monitoring and sanctioning (GS8),” and “Spatial and temporal distribution (RU7).” These variables have also received multiple suggested modifications.

Types of research applying the social-ecological systems framework

The SESF can be used as a tool for different types of research. Table 6 provides an overview of six types of research in which the framework has been applied. These include (1) conducting a mixed-method diagnosis of a single case study, (2) conducting a qualitative diagnosis of a single case study, (3) conducting a quantitative diagnosis of a single case study, (4) conducting a metaanalysis of the literature, (5) comparative analysis diagnosing multiple case studies, or a large N comparative analysis (using either of the first three types), and (6) using the framework as a deliberation tool. The general purpose of each type of research, the benefits of using the SESF, potential challenges, and related literature are provided in Table 6. A few articles have additionally explored modeling approaches linked to the categories in Table 6 (Frey and Rusch 2013; Schlüter et al. 2014).

DISCUSSION

This discussion focuses on the current methodological challenges for applying the SESF and challenges for its continued modification by reflecting on the results above. Current trends in the literature help to spotlight many existing challenges, motivating numerous discussion points on how these trends stem from the framework’s history, indicating the importance of considering how the framework is situated epistemologically. This discussion attempts to guide future research with the SESF by summarizing some of the methodological challenges (which are general in nature, but nonetheless important for applying the framework), and to signpost where to look in the literature for additional insights. To start, the results above are briefly discussed along with reflection into why certain trends may exist. This is followed by discussion of the challenges for modifying the framework. The remainder of the paper focuses on specific methodological gaps for applying the SESF and discusses whether the framework has made progress in helping achieve some of the goals it was claimed to be useful for (Ostrom 2007, 2009). In the conclusion, future research trajectories are discussed.

Social-ecological systems framework research trends and methodological challenges

Social-ecological systems framework research remains largely focused on small-scale CPR systems and public goods, similar to

the majority of research in commons scholarship (Meinzen-Dick et al. 2002, Wollenberg et al. 2007). Similarly, case studies remain focused on the “classic” CPR systems of fisheries, forestry, and irrigation systems. There is certainly room to expand the scope of where the SESF is applied beyond these classic commons and beyond small-scale systems. This review is not an overview of all commons scholarship, just those applying the SESF, but it nonetheless shows the tight link between the two and some current trends. It has long been assumed that knowledge generated on small-scale CPR systems is to a large extent generalizable. This claim can be further tested with more applications of the SESF to diverse cases. A few papers have recently begun to shift the focus to large-scale commons (Cox 2014b, Epstein et al. 2014a, Ban et al. 2015, 2017) and hybrid or overlapping commons like coastal systems (Schlüter et al. 2019) and pond aquaculture (Partelow et al. 2018b).

Perhaps the most interesting trend is the extensive use of secondary data. This may be occurring for numerous reasons. Many authors are simply reanalyzing existing data, using the SESF as a conceptual tool to reframe, restructure, or integrate existing data for new analysis. This also suggests that many scholars are revisiting existing case studies to provide a new conceptual lens. The combination of primary and secondary data is common and is likely a result of the difficulties in collecting sufficient primary data on all the relevant second-tier variables in a case study. If scholars are returning to previous case studies, it is likely that previous data exist. However, very few studies are looking at temporal changes within cases, where there is room for future research. In addition, metaanalysis studies are using secondary data as well as many comparative analysis studies. Nonetheless it is evident that many scholars find it difficult to design empirical research approaches using the SESF from scratch. There are substantial methodological challenges with applying the SESF to a new case study, such as the meaning of a tiered framework, familiarity with collective action literature, understanding diagnostic methodologies, as well as analyzing nested social and ecological systems in an integrated way, as well as how outcome variables relate to other variables in the framework (Hinkel et al. 2014). These likely explain why relatively few articles use primary data. Primary empirical data collection guided by the SESF involves considerable methodological attention to detail, particularly for the design and implementation of empirical data collection. Familiarity with framework’s history and multidisciplinary knowledge on the potential relevance of second-tier variables in a case study are critical. Studies that reanalyze existing data do not have this difficulty to the same extent with data collection, but have many substantial challenges with understanding the data collection methods of previous studies, data formatting, and analysis. A main challenge with secondary data is that it typically involves some sort of data coding procedure (Ratajczyk et al. 2016). This might explain why the framework is a useful conceptual tool but is less applied empirically due to a lack of methodological knowledge or guidance on how to do so.

Modifying the social-ecological systems framework variables

Many have argued for the need to modify variables in the SESF, given new empirical analysis of more diverse cases. For example, numerous articles have suggested modifications to include more biophysical variables (e.g., Epstein et al. 2013, Vogt et al. 2015),

suggesting a bias toward social system variables. This review confirms that this bias exists. This is most likely due to the development and almost exclusive use of the framework by social scientists. However, when suggesting modifications, a key question needs to be asked in relation to epistemological congruence (i.e., what theory is supporting the modification or inclusion of variables and does it align with how variables were included historically?). Below I discuss whether this is important or not. The framework does have a history that justified the inclusion of variables into a theoretical framework because they were shown to influence collective action. However, if variables are being modified for a reason other than their influence on collective action, there is a conflict with congruence in the framework’s development. This is not inherently problematic; it seems likely that the SESF may take numerous developmental trajectories as it becomes useful for different purposes. However, difficulties and confusion in the literature may arise when explicit distinctions are not made between differing goals across the many papers that are applying the framework. For example, are variable modifications being suggested because they have been shown to influence collective action (i.e., building a theoretical framework of collective action for commons governance), or because they help better characterize a case study as a SES (i.e., building a theoretical/ conceptual framework of general SES)?

This issue arises due to a problem in the logic of how the SESF should continue developing (i.e., the organization and addition of variables) without explicit theoretical inclusion criteria for new variables (i.e., all studies should be grounded in collective action theory). It is clear that a large majority of research using the framework engages with collective action theories. However, it is also clear that many studies do not focus on collective action, and that knowledge on collective action theory is not necessary for the SESF to be a useful research tool in the general SES literature. Social-ecological systems framework literature suggests that the framework is useful for characterizing a system as a SES, and for diagnosing general challenges for sustainability. These applications have shown that an analysis with the SESF does not have to be related to the collective action theory roots of the framework. Nonetheless, there are also clear benefits of having a malleable framework, as envisioned by Ostrom. This makes it appealing to a broader research audience and can allow for the development of new theory using the framework’s variables as the building blocks.

From the argument above, it becomes clear that the SESF does not provide a list of all relevant intrinsic variables and interactions in a social or ecological system (i.e., the SESF is not a comprehensive framework characterizing all identifiable variables and interactions in a SES). Certainly there would be more variables if there were no limitations for adding variables based on theoretical inclusion criteria. In contrast, from a social science perspective, it may be argued that all variables likely affect collective action processes in some way, or it would at least be difficult to parse out that a variable is not influential in an observational study (nearly all applications of the SESF), and that the argument for including new variables may be leveraged more on the degree of observable or explicit influence and the degree of empirical support across studies. However, it is also evident in the literature that many variable modifications are not being suggested with explicit justification as to the relevance of

Table 5. Articles suggesting modifications to variables of the social-ecological systems framework. The table is organized by the variables, articles, and context. Many articles suggest modifications, however, this is not an exhaustive list. Most articles focus on many variables, but only suggest modifications to a few. “All” refers to all second-tier variables within the first-tier variable.

First tier	Variables	Article	Context
<i>Social, economic, and political settings (S)</i>	All	Delgado-Serano and Andres Ramos 2015	Water; Forestry; Fisheries
	Economic development	Guevarra et al. 2016	Fisheries
<i>Resource systems (RS)</i>	Political stability		
	All	Vogt et al. 2015	Forestry
	Ecological rules	Epstein et al. 2013	Lake systems;
		Vogt et al. 2015	Forestry
	Clarity of system boundaries	Delgado-Serano and Andres Ramos 2015	Water; Forestry; Fisheries
<i>Resource units (RU)</i>	Equilibrium properties		
	Storage characteristics	Basurto et al. 2013	Benthic fisheries
	Productivity of system	Basurto et al. 2013	Benthic fisheries
	All	Vogt et al. 2015	Forestry
	Resource unit mobility	Partelow and Boda 2015	Fisheries
	Economic value	Bennett and Gosnell 2015, Vogt et al. 2015, Delgado-Serano and Ramos 2015	PES [†] ; Forestry
		Partelow and Boda 2015	Water; Fisheries
	Number of units	Partelow and Boda 2015	Fisheries
	Interactions among resource units	Basurto et al. 2013	Benthic fisheries
	Spatial and temporal distribution	Partelow and Boda 2015; Basurto et al. 2013	
<i>Governance systems (GS)</i>	Distinctive characteristics	Partelow and Boda 2015	Fisheries
		Basurto et al. 2013	Benthic fisheries
	All	McGinnis and Ostrom 2014	General
		Basurto et al. 2013	Benthic fisheries
		Partelow and Boda 2015	Fisheries
	Rules-in-use	Blanco 2011	Tourism
	Governmental organizations	Delgado-Serano and Andres Ramos 2015	Water; Forestry; Fisheries
		Williams and Tai 2016	MPAs [‡]
	Nongovernmental organizations	Williams and Tai 2016	MPAs [‡]
	Network structure	Delgado-Serano and Andres Ramos 2015	Water; Forestry; Fisheries
<i>Actors (A)</i>	Property-rights systems	Delgado-Serano and Ramos 2015	Water; Forestry; Fisheries
	Monitoring and sanctioning	Delgado-Serano and Andres Ramos 2015	Water; Forestry; Fisheries
	All	Partelow and Boda 2015	Fisheries
	Number of relevant actors	Duff 2017	Agriculture
		Delgado-Serano and Andres Ramos 2015	Water; Forestry; Fisheries
	Socioeconomic attributes	Bennett and Gosnell 2015	PES [†]
		Delgado-Serano and Andres Ramos 2015	Water; Forestry; Fisheries
	Technologies	Duff 2017	Agriculture
		Basurto et al. 2013	Benthic fisheries
	History and past experiences	Basurto et al. 2013	Benthic fisheries
<i>Interactions (I)</i>	Norms/social capital	Delgado-Serano and Andres Ramos 2015	Water; Forestry; Fisheries
	Knowledge of SES/mental models	Delgado-Serano and Andres Ramos 2015	Water; Forestry; Fisheries
	Dependence	Basurto et al. 2013	Benthic fisheries
	Harvesting levels	Delgado-Serano and Andres Ramos 2015	Water; Forestry; Fisheries
	Information sharing	Duff 2017	Agriculture
		Delgado-Serano and Andres Ramos 2015	Water; Forestry; Fisheries
	Power differentials	Blythe et al. 2017	Fisheries
	Deliberation processes	Duff 2017	Agriculture
		Delgado-Serano and Andres Ramos 2015	Water; Forestry; Fisheries
	Conflicts	Duff 2017	Agriculture
<i>Outcomes (O)</i>		Delgado-Serano and Andres Ramos 2015	Water; Forestry; Fisheries
	Monitoring activities	Bennett and Gosnell 2015	PES [†]
	Investment activities	Bennett and Gosnell 2015	PES [†]
	Networking activities	Delgado-Serano and Andres Ramos 2015	Water; Forestry; Fisheries
	(Cross level application)	Oberlack et al. 2015	Forestry
	Social outcomes	Duff 2017	Agriculture;
		Blythe et al. 2017	Water; Forestry; Fisheries
		Delgado-Serano and Andres Ramos 2015	
	Ecological outcomes	Duff 2017	Agriculture
		Delgado-Serano and Andres Ramos 2015	Water; Forestry; Fisheries
<i>External ecosystems (ECO)</i>	Pollution patterns	Duff 2017	Agriculture

[†]Payments for ecosystem services [‡]Marine Protected Areas

Table 6. Approaches for applying the social-ecological systems framework for different types of research

Type of research	Purpose, benefits (+) and challenges (-)	Example literature
(1) Mixed method diagnosis or characterization of a case study	<i>Purpose:</i> Comprehensive analysis of a case study (+) Comprehensive and more holistic analysis (+) Most robust type of case study analysis (+/-) Multidisciplinary knowledge and/or team needed (+/-) Multiple types of data generated (-) Data integration, transformation, and analysis can be difficult (-) Extensive field work/data collection period	Ernst et al. 2013, Cox 2014a, Barnett and Eakin 2015, Guevara et al. 2016, Partelow et al. 2018b
(2) Qualitative diagnosis or characterization of a case study	<i>Purpose:</i> Focused analysis of a case study (+) Potential for indepth analysis of social system (+) Discursive understanding (+/-) Qualitative data analysis techniques (-) Potential lack of data on ecological system if no secondary data (-) Smaller N sampling potential	Ban et al. 2015, Hoogesteger 2015, Naiga et al. 2015, Oberlack et al. 2015, London et al. 2017
(3) Quantitative diagnosis or characterization of a case study	<i>Purpose:</i> Focused analysis of a case study (+) All variable measurements quantified and comparable (+) Larger N sampling potential (+/-) Statistical data analysis techniques (-) Difficult to develop quantifiable indicators to measure all variables (-) Lack of discursive elements (-) Potential difficulties in access to needed data or sampling (-) Potential loss of depth by quantification of complex variables	Hearn 2008, Madrigal et al. 2011, Leslie et al. 2015, Sharma et al. 2016
(4) Metaanalysis of the literature	<i>Purpose:</i> Empirical or discursive synthesis of secondhand literature, case studies, or data to advance theory, concepts, or the characterization of a field of study (+) Synthesis across contexts with common framework (+) Increased comparability of findings (-) Lack of access to primary data/data abstraction (-) Difficulties integrating data	Blanco 2011, Stevenson and Tissot 2014, Kelly et al. 2015, Thiel et al. 2015, Mahon et al. 2017
(5) Comparative analysis of case studies/large N	<i>Purpose:</i> Empirical comparison or synthesis of typically firsthand data to advance theory, concepts, or characterization of a field of study (+) Provides a structure and variables for comparison (-) Finding common definitions which apply across cases (-) Data often abstracted out of context	Gutiérrez et al. 2011, Cinner et al. 2012, Oberlack et al. 2016, Rahimi et al. 2016, Ban et al. 2017
(6) As a deliberation tool	<i>Purpose:</i> Transform SESF into a tool to facilitate deliberation or deliberative processes (+) Applied use of framework (+) Knowledge exchange within and between actor groups (-) Transformation of SESF to a contextually understandable form	Partelow et al., <i>in review</i>

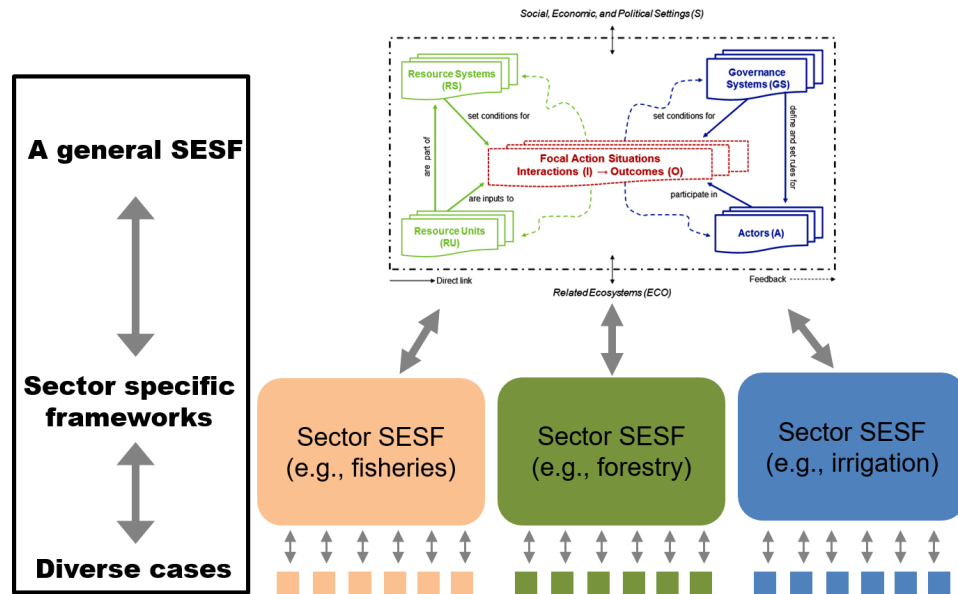
new or modified variables insofar as they may have a causal claim associated with them for how they affect collective action processes. Perhaps broader theoretical inclusion criteria, beyond collective action processes, could be related to a more general SES theory. Variables would then be included if causal interactive effects can be shown between new and existing variables that interdependently influence joint social-ecological outcomes more generally. This would broaden the theoretical scope of inclusion criteria, but would alter the historically consistent development of the framework thus far. This debate should find roots in future research.

This raises a second point. It is important to recognize how the framework's theoretical history has shaped its development (i.e., collective action, CPR theory, institutional analysis). This history has implications for how we view a SES with the framework and how we interpret the concept of sustainability. What is worth knowing about a SES, from an Ostromian perspective, is how

different parts of the system influence cooperation and resource-use behavior through the development of institutions for commons governance. Sustainability, from this perspective, is arguably the development and maintenance of contextually appropriate institutions that can enable actors to cooperate and use resources in a way that allows for the long-term and equitable availability of those common resources. Certainly the broader concept of sustainability is not limited to this view, but it must be recognized that this creates a refined and in some ways path-dependent discourse on sustainability.

It is worth reflecting on how the manifestation of Ostrom's commons research has evolved into the SESF, and how that has shaped broader SES discourse. This leads to a critical reflection on the discourse that the SESF has created with its terminology. "Resource systems" and "Resource units" are the terminology used for biophysical variables in the framework. Similarly, Ostrom (2007, 2009) use the term "Users," which was later changed to

Fig. 3. Conceptualizing the potential evolution of the SESF. Application of the framework to case studies contributes new variables and data to specific resource-use sectors (e.g., small-scale fisheries, forestry, irrigation). Different sectors may evolve separate versions of the SESF. Commonalities between all sectors contribute to the development of the general framework. Theory building may follow a similar path. General theory building across sectors would be informed by cross-sectoral commonalities.



“Actors” in McGinnis and Ostrom (2014) to broaden the utilitarian scope of different people who influence collective action to those who do not directly utilize resources. Nonetheless, this terminology has created an anthropocentric discourse on how the SESF portrays the biophysical environment. Arguably the SESF in large part portrays the biophysical environment through a lens of economic and institutional utility. These are the most obvious examples at the first-tier level, but many other second-tier variables in the framework reflect a similar discursive lens, and it is worth acknowledging how this discourse shapes a certain social-ecological worldview.

In a separate but related terminological discussion, reference to and application of the SESF requires the use of certain practical terminology. The variables of the framework are referred to with a large variety of terms including: variables, tiers, components, processes, indicators, dimensions, concepts, interactions, elements, attributes, and system dynamics, among others. Although inconsistent terminology when referring to the first- and second-tier variables is not inherently problematic, it may create confusion or a lack of clarity in the literature and in the interpretation of findings, particularly confusion between variables and indicators. This may stem from the lack of clarity and clear definitions for many of the second-tier variables. Some are well-defined and nuanced whereas others represent broader concepts that often need further refinement or defining in the context. Not all of the second-tier variables are created equal in this way and may require modification as the framework evolves.

Many articles have suggested variable modifications (see Table 5). This is an inevitable progression as more empirical analysis

emerges. However, reflection is warranted on whether suggested variable modifications are actually new variables (i.e., nested concepts meeting theoretical and ontological inclusion criteria) or are indicators for measuring a variable (i.e., empirically measurable phenomena). Also, what the level of generalizability of suggested modifications is in relation to other cases and sectors. It is evident that separate frameworks are likely to evolve for use in specific sectors because many relevant variables in specific sectors may not be generalizable (Fig. 3) e.g., (Basurto et al. 2013, Marshall 2015, Partelow and Boda 2015). The role of some variables is likely to be unique to certain sectors. However, the relationship between potential specialized frameworks for specific sectors and a general framework cannot be made a priori. This will depend on the degree of empirical support for the specialized framework and the ability to compare data across cases with a sector, and then between sectors (Fig. 3), in coherent and methodologically rigorous ways.

As discussed above, one of the methodological difficulties is that there are no rules or guidelines for variable modifications. Frey and Cox (2015) suggest the use of a consistent ontological logic for adding new variables (i.e., structurally consistent rules for organizing variable relationships between and within tiers), such as having at least a pair of nested subconcepts that are nested under the parent variable. Having an ontological logic would certainly create consistency, but it does not address the theoretical inclusion criteria problem. Second, it is important to recognize that indicators used to measure second-tier variables are not necessarily nested subconcepts that warrant inclusion into the framework. Many articles do not make this distinction. For example, Partelow and Boda (2015) suggest a substantially

modified framework that is specific to lobster fisheries but they do not make a clear distinction between what modifications are nested subconcepts of potentially new variables, and which are indicators for simply measuring the parent variable. They also do not follow a clear ontological logic. The review in this article supports conclusions from Thiel et al. (2015) that most applications and modifications to the framework remain unstructured in similar ways and are largely scattered in their attempt to jointly improve the framework with cohesive rules or inclusion criteria for new or modified variables. Future research and discussion could focus on this issue.

For further guidance on logical criteria for expanding the SESF in a cohesive way, recommendations are provided by Frey and Cox (2015:14) as a starting point. These include developing tiers and variables with meaningful relationships, restrictions, or instances between classes (i.e., tiers or variables) and subclasses. In addition, guidelines for creating classes and subclasses with meaningful relationships between them may include rules such as do not create singular subvariables, too many subvariables, and creating similar or reciprocal classes with related relationships to the parent variable. In reflecting on methodological challenges outlined above, four aspects are useful to consider when suggesting modifications to the framework in the future. (1) Is there a structural or ontological consistency when making modifications? (see Frey and Cox, 2014:14). (2) What is the empirical evidence for any modifications (e.g., case studies or metaanalysis)? (3) What are the theoretical inclusion criteria? (4) To what degree of generalizability do the modifications apply: to all systems or only to a specific resource-use sector (e.g., fisheries, forestry)?

A final point on modifications is warranted on the “Interactions (I)” variables of the SESF and how they relate to the Institutional Analysis and Development (IAD) framework (Ostrom 2005, McGinnis 2011). It is unclear whether applications of the framework in the literature retain the original idea of the “action situation” when relating to the “Interactions (I)” variables, because most of the literature applying the SESF does not refer to the IAD framework or action situations. These variables arguably have the strongest theoretical link to institutional change and collective action theories. However, they are also some of the least focused on second-tier variables despite their central placement (Fig. 1). This may be related to a lack of knowledge about their theoretical origin as the framework has gained a wider audience.

Perhaps “interactions” could evolve into archetypes (e.g., Oberlack et al. 2016), typologies (e.g., Alessa et al. 2009), or bundles of interacting second-tier variables (e.g., Partelow et al. 2018a) from the other tiers. This could be viewed as a process of building a general theory of SES interactions similar to how property rights and biophysical traits are often interpreted as interacting bundles or commonly associated system characteristics with repeating patterns of variable interactions and outcomes. Emerging SES theory could be viewed in this way, by attempting to identify commonly associated and interacting variables in the SESF. For example, a social-ecological trap (Boonstra and De Boer 2014) may be a common archetype or bundle of interacting variables with certain values that could be identified with the SESF variables (e.g., High dependence (A8); Low value (RU4);

Low socio-economic conditions (A2); Declining resources (RU5)), and could be empirically observed as leading to largely repeatable outcomes (i.e., Decreasing livelihood security (O1) and resource degradation (O2)). Thus, a social-ecological trap could be an example of an archetype of interactions that is part of a general SES theory using the framework variables. Use of the “Interactions (I)” variables in this way would alter the original aim of the framework beyond collective action theories (particularly beyond the IAD framework) to general SES theories, but may enhance their usefulness as variables and make this aspect of the framework more generally applicable to diverse cases.

The most important interactions shaping SES outcomes (not referring to the Interactions (I) variables, but general system interactions to be analyzed) may be among variables between tiers rather than within tiers of the framework. Expanding empirical analysis toward building SES theory that accounts for interacting variables across tiers can make progress toward redefining what a resource “system” or governance “system” comprises, beyond existing discursive or disciplinary conceptualizations. If interactions between variables are a primary defining characteristic for the degree to which variables are considered part of a system, the discourse on such systems will necessarily shift toward bundles or typologies of interacting variables, as well as how “interactions” in the SESF are viewed as an analytical tool for building SES theory.

Applying the social-ecological systems framework: methodological gaps and challenges

There are no general methods, guidelines, or procedures for applying the SESF, although numerous articles have provided conceptual guidance (e.g., Hinkel et al. 2015, Partelow 2016) and case examples. However, there is lack of reflection between the different papers that make explicit suggestions regarding the benefits and challenges of different methods. There is no right or wrong way to apply the framework. The variables can be defined, modified, and measured, as needed, in different contexts (Ostrom 2007, 2009). However, this has led to substantial heterogeneity in how the framework’s variables are applied, relating to definitions, indicators for measurement, and modifications. Furthermore, multiple data collection and analysis methods are often used. The discussion below highlights the lessons and reflections learned across the literature and from experience applying the framework. Numerous “methodological gaps” are described below that may be useful to consider. These gaps are not unique to the framework, they relate to general scientific methodologies more broadly, but are explicitly applicable and relevant for applying the SESF.

Variable definition gap

Many variables are not well defined and/ or can have multiple meanings or interpretations when viewed in different contexts. If common definitions of variables and concepts are not used across cases, additional layers of abstraction will hinder the ability for synthesis and comparison. However, there is a trade-off here between specificity and generalizability, as it is often necessary to define variables differently across contexts. For example, the concept of social capital (A6) is not well defined and can vary in meaning across contexts. Social capital may refer to the structure, connectedness, and types of exchanges in a social network (Pretty 2003, Borgatti et al. 2009), or it may refer to degrees of trust, reciprocity, and prosocial or antisocial behavior in a group

(Gutiérrez et al. 2011, Basurto et al. 2016). Definitions can dictate what will be measured and the theoretical conclusions drawn from that data about the role of that variable in a system. Many other variables in the framework create similar challenges because they are defined and measured differently, compromising the ability for comparison if definitions are not transparent to readers or those conducting synthesis research.

The variable-to-indicator gap

The variable-indicator gap refers to which indicators are selected to empirically measure or code variables. Many variables are broad concepts that are not directly measurable or easily defined, such as socioeconomic attributes (A2), norms, trust and social capital (A6), resource unit value (RU4), equilibrium properties (RS6), predictability of system dynamics (RS7), and outcomes (O1; O2; O3). Context-specific indicators are often needed to measure these variables, or at least to understand a variable in context. Two studies may examine the same variable with the same definition, but they may select different indicators to measure them. This creates a degree of abstraction for comparative research. For example, indicators to measure actor location (A4) could be the distance between the home of an actor to the place where they access the resource system (RS) or resource units (RU), or, it could be the distance from the home to other actors or community meeting places where collective decisions are taken.

The measurement gap

The measurement gap refers to how variables or indicators are actually measured or coded. It is evident that two studies can examine the same variable, use a common definition and indicator, but still measure the variable in a different way. For example, economic value (RU4) may be defined as the market value of the resource unit, and both studies use the indicator of price per kilogram. One study may employ qualitative methods, asking individual actors (e.g., fishers) to recall the prices they received on the market over the last month by asking the fisher to explain variability and how prices are negotiated. A second study may collect quantitative data on fish sales from fish markets to establish price averages over the last 6 months. The studies may draw different conclusions on the economic value of the resource and the role that market variability has on system dynamics.

Data transformation gap

The data transformation gap refers to how raw data are transformed into usable or presentable data in an analysis, graphic or written text form. Or, how published data are recorded or transformed from literature review or metaanalysis for additional analysis. Transforming data into different structures (e.g., continuous, ordinal, categorical, text) is often necessary to conduct an integrated or comparative analysis. Many different data types have been used to analyze the variables and their interactions in the SESF. Data transformation can enhance comparability but also compromises meaning and context. For example, raw qualitative interview data may be coded, synthesized, and transformed into ordinal data (e.g., low, medium, high) for further analysis or presentation. Methodological transparency becomes of high importance for interpreting findings, for all the “gaps” above. This problem occurs in both qualitative and quantitative research. Different studies will inevitably use different transformation methods, stressing the need for transparency.

CONCLUSION

Future research with the social-ecological systems framework

Much of the above discussion provides insights into future research considerations given the trends in the literature. However, a few explicit points can act as a more general set of concluding remarks for future research related to the framework’s general aims. Ostrom (2007, 2009) argued that the SESF could provide numerous benefits for scholars, including (1) a general framework that could be adapted and applied to diverse cases, (2) a core set of variables and a common language to better enable comparison and communication, as well as (3) a diagnostic tool, potentially enabling new theories to be developed through analysis of interlinkages between variables and outcomes. Each is briefly discussed below as to how future research may be able to make progress toward achieving them.

(1) A general but adaptable framework

The framework can be tailored to context by modifying the definitions of variables, indicators to measure them, data collection, and analysis methods. As a result, the framework can be, and has been, applied to a wide variety of cases. This is arguably its strong point. However, it is also clear from this study that applying the framework has led to many suggested modifications to variables. Some articles suggest more generalizable modifications (McGinnis and Ostrom 2014), some for use in specific sectors (Table 5). It appears that the general framework will evolve, but specific frameworks will also evolve for use in specific sectors (e.g., small-scale fisheries, forestry, and irrigation). Following the guidelines in the “methodological gaps” discussion section and those provided by Frey and Cox (2015), future research can find useful recommendations for addressing some of the challenges stemming from a lack of cohesion in how the framework is adapted and modified for use in diverse cases (i.e., data comparability) while maintaining the ambition to continue advancing a general framework.

Figure 3 conceptualizes this potential future research process. An intermediary step may be the development of sector-specific frameworks (e.g., for fisheries, irrigation, forestry) that can help bridge the gap between diverse but related case studies and a general framework. Sector-specific frameworks, which would add, develop, and define new or existing variables of the framework within the scope of a sector (e.g., small-scale fisheries), could contribute to evolving a general framework after modifications are empirically assessed for their degree of generalizability. Methodological transparency is essential for future research addressing the “methodological gaps” and attempting to adhere to the suggested guidelines for variable modifications. Sector-specific frameworks could help avoid confusion between the many diverse studies that apply the framework and allow more robust comparison between similar cases before attempting more abstract comparisons between cases where the social and ecological conditions may be less similar. Degrees of generalizability could be assessed between similar cases within sectors before abstracting their potential generalizability to the general framework. Overlapping commonalities could then more robustly inform a general framework (which would remain the pillar for collective action theory across contexts). Additional theory (beyond collective action) could include the development of interacting bundles, typologies, or archetypes of social-ecological interactions

discussed above that lead to empirically identifiable and patterned outcomes across cases using the framework's variables as theoretical building blocks; this is discussed further below.

(2) Enabling comparison

The literature applying the SESF is heterogeneous, and it is unclear the extent to which the empirical data can be compared across cases in a meaningful way without substantial recoding, transforming, or simplifying heterogeneous data. A key step for future research will be increased methodological transparency in the use of research design for primary data collection and the use of secondary data by considering the "methodological gaps" discussed above. Without general but clear guidelines, a metaanalysis of empirical case studies would currently be a monumental effort to overcome methodological blind spots and integrate data, and with current SESF studies, provide largely unreliable data given the high degrees of heterogeneity in data collection methods, context, and system scales examined in the literature. A few studies have been successful with large comparative studies, but they have largely relied on highly systematized primary data collection on common variables controlled by the authors e.g., (Cinner et al. 2012, Leslie et al. 2015) or substantial secondary data mining and coding efforts e.g., (Gutiérrez et al. 2011, Oberlack et al. 2016, Rahimi et al. 2016). Either way, successful comparative studies are made easier when the data available were collected with the intention to be compared. However, many individual case studies are not designed to be compared with other cases within or between sectors, and efforts to do so without methodological transparency would likely draw highly abstracted conclusions about the empirical studies being examined.

Databases are a promising way forward for enabling comparison, where the authors of individual studies format their data themselves into shared digital repositories. This eliminates data abstraction barriers by nonauthors but also requires incentives for authors to contribute to common databases, which is a provision of the public goods collective action dilemma itself. Many of the databases presented in Table 2 are attempting to facilitate this, but their success requires largely voluntary contributions, which are encouraged by those facilitating them and recommended for scholars using the framework to engage with.

(3) A diagnostic tool for theory building

The SESF is not a theory-neutral tool. Historically, the inclusion criteria for variables were based on their influence on collective action in small-scale CPR systems. However, the generalizability of these variables seems to be broad in scope, with numerous studies using the variables to generally characterize SES or to develop other closely related theory on natural resource governance (Cox et al. 2016). It is evident that the framework's variables provide a template for expanding commons research and asking new theoretical questions about social-ecological interactions and outcomes. This has not yet been fully explored in the literature, and it remains unclear, although still promising, that the SESF can aid the process of theory development for general SES research. Perhaps future research can further explore further uses for the framework, particularly its potential to contribute to building general theories of social-ecological interactions by identifying typologies or archetypes of social-ecological interactions (Alessa et al. 2009, Oberlack et al. 2016, Partelow et al. 2018a). Integrating

the framework with other conceptual and theoretical frameworks may expand its usefulness for contributing to other theories and frameworks in associated fields such as ecosystem services, sustainability science, the Coupled Infrastructure Systems framework, and resilience theory (Binder et al. 2013, Anderies et al. 2016, Partelow 2016, Partelow and Winkler 2016). This would somewhat remove the theoretical history with collective action theory in parts of the literature engaging with the framework. However, there is also recognition that collective action theory is nested within broader concepts of SES and sustainability, both of which are likely to evolve.

Responses to this article can be read online at:

<http://www.ecologyandsociety.org/issues/responses.php/10594>

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2nd tier variable name and code	Indicators used/ potential indicators to use/ definitions
Economic development (S1)	Economic growth (e.g. GDP); Standards of living; Economic health of the area (e.g. number of jobs, sectors, diversification)
Demographic trends (S2)	Population growth; Population trends, changes and/or status
Political stability (S3)	Regulatory framework of country or region; Regularity rules and values present
Other governance systems (S4)	Traditional tenure/ simple operational rules; Government resource policies; Top-down policies adopted by the national, regional and local governments
Markets (S5)	Market demand; Tour operators; Environmental awareness; Market conditions; Markets for natural resources and conservation incentives; Distance to external markets (km)
Media organizations (S6)	Number, diversity and freedom of private and public media
Technology (S7)	Relevant technology present; Communication (e.g. mobile phones, broadcasting, information storage)
Clarity of system boundaries (RS1)	Resource unit distribution; Resource unit recruitment sourcing (within/outside governance system boundaries); Zoning districts/Marine Protected Areas; International boundaries (e.g. EEZ, national borders); Clarity of the system's geographical, social and legal boundaries; Biophysical characteristics that make it feasible for actors to determine where the resource system starts or ends
Size of resource system (RS2)	Absolute or relative descriptions of the spatial extent; Size in appropriate units (e.g. square kilometers, square miles); Carrying capacity of for relevant species; Size of relevant system patches of interest; Area of exclusive interest or value within system; Physical proximity to markets; Area under management (e.g. irrigation); Percentage of system under production; Percentage area of system under different production systems
Human-constructed facilities (RS3)	Tourism industry infrastructure; Resource units storage facilities (e.g. tank-houses, lobster cages, fish pens); Irrigation infrastructures; Access structures (e.g. piers, harbors, trails, airport); Artificial habitat; Accommodation facilities; Anthropogenic structures facilitating resource management (e.g. fences, access ways, storage or transformation facilities); Tracking and/or data infrastructure

Productivity of system (RS4)	Population/ stock status; Biophysical properties; Biodiversity; Species risk; Biomass produced; Qualitative estimation of productivity; Number of users/ visitors; Production-consumption rates per unit of time, surface, or volume
Equilibrium properties (RS5)	Temperature threshold of system; Seasonality; Electric energy; Influences (positive and negative) on the equilibrium of the resource system (interaction between species, or between biological and anthropological systems); Consumption-reproduction-harvest ratio (e.g. of nutrients, species); MSY; Characterization of the type of attractor of a resource system along a range from one to multiple (chaotic) attractors
Predictability of system dynamics (RS6)	Seasonality; Risk of extreme events(e.g. Flooding, earthquakes, volcano, hurricane, fire); Rainfall variability; Weather variability; Upwelling and current variability; Spatial and temporal variability of fish population; Capacity to estimate the evolution and dynamics of the resource system and the impact of interventions or external influences; Degree to which actors are able to forecast or identify patterns in environmentally driven variability on recruitment
Storage characteristics (RS7)	Elevation and/or slope of landscape; Retention of information about the system dynamics; Degree to which the resource units can be held captive until harvested
Location (RS8)	Locations between key system components; Geographic location (e.g. coordinates); Distance to nearest hub airport; Spatial and temporal extent where resource units are found by actors; Spatial and temporal extent where system is or can be accessed by users
Resource unit mobility (RU1)	Degree of fluidity or fixed (e.g. tree vs water); Spatial and temporal distribution of larvae; Spatial and temporal distribution of adults; Extent of resource system/ infrastructure (e.g. Electricity grid); Temporal patterns (e.g. nocturnal species); Migration patterns; Park boundaries; Speed of mobility (e.g. tuna vs worms); Life cycle assessment
Growth and replacement rate (RU2)	Modelled results of growth; Years to sexual maturity; Reproductive age; years to legal commercial harvest size; Years of calving/ rearing; Life cycle assessment; Absolute or relative descriptions of changes in quantities (x) of resource units over time (t)
Interaction among resource units (RU3)	Reproduction patterns/ needs; Symbiotic relationships; Patterns/ relations between resources in similar time and space (e.g. competition, collaboration); Interactions among resource units during different life stages affecting the future structure of the population; Ecosystem structure/ trophic interactions (e.g. keystone species, Dependencies between species)
Economic value (RU4)	Price per kilo; Cultural value of individual resource units; Value of total annual landings/ harvest; Quality of resource; Value of units per unit area; Nutritional value (Calorific value/ha, Calories produced/ha, Protein

	produced/ha, Fodder quality-nutritional content of fodder); Differences between live and dead/ frozen value; Market predictability; Market diversity; Recreational value; Opportunity Costs; Non-market values; Value ration in relation to the portfolio of resources available to actors
Number of units (RU5)	Total catch per year (tons); catch per individual gear type; Catch per unit effort; Differentiation between unit types (e.g. Domesticated vs wild units); Percent land cover (e.g. forest cover or density); Legal harvest rate vs Illegal, Unreported, Unregulated (IUU) rate; Total volume or amount of resource (e.g. wood volume, agriculture production volume), Number of activities for users (e.g. in a park, ocean); Number that could be potentially harvested
Distinctive characteristics (RU6)	Male/ female differences; Age differences; Reproductive indicators (e.g. carrying eggs, molting, behavioral signs); Artificial markings (e.g. branding, tagging, v-notch for lobsters); Landscape features; Markings and/or behavioral patterns that can be identified in resource units and affect actors' behavior toward them
Spatial and temporal distribution (RU7)	Elevation or depth distributions per unit time; Coverage or density across area per unit time; Migration patterns; Seasonality; Larval distribution range; Geographic limitations; Species range; Range/ distribution of viable habitat or food sources
Government organizations (GS1)	Government regulators; Public-private initiatives; Administrative Levels present(e.g National, Regional, Local); Support Enforcement; Support Funding available; Number Government departments; Quasi-government organisations (e.g. Combined state and civil society managed agencies); Presence or absence of different organizations at local level; Institutions present with governmental authority
NGOs (GS2)	Presence of organizations or active initiatives; Conservation/ environmental organizations; Universities/ research organizations; Private sector institutions; Voluntary initiatives;; Social/Welfare Organizations; Restoration orgs; NGOs at different levels (e.g. International, National, Local, Community-based organizations); Other institutions without governmental authority mandated
Network structure (GS3)	Funding providers; Multilevel governance structure; Vertical structure; Horizontal structure; Transparency; Vertical and horizontal partners in co-management; Representation of actors; Stakeholder participation options; Information flows; Network configuration at local level and their interactions; Administrative structure of organization; Social or political connections among the rule-making organizations and the population subject to these rules
Property rights systems (GS4)	Presence of property rights systems (e.g. Open access, private property, common property and no access); Informal or traditional tenure systems; Quotas; Lease agreements; Security and/or strength of tenure; Percentage of system with property rights; Local property-rights systems and their relation

	to resource management; Conflict between multiple property rights systems; Particular types of rules determining which actors have been authorized to carry out which actions with respect to a specified good or service; Patents/ licensing agreements; Different forms of privatization; Strength of land rights
Operational choice rules (GS5)	<p>Presence of formal written rules (e.g. legislation, legal documents, community documents); Rules for resource harvesting and distribution (e.g. size limits, seasonal closures, species distinctions, quotas, harvesting limits, caps on pollution, etc)</p> <p>Presence of informal rules (e.g. non-written agreements, norms, etc.)</p>
Collective choice rules (GS6)	Presence of formal and/or informal rules related to actor participation, collective action procedures and/or decision making processes to modify operational rules; Structure of management; User group distinctions; Level of stakeholder involvement; The processes through which institutions are constructed and policy decisions made by actors authorized (or allowed) to do so; Rules set defined by involved actors according to local environment and political and economic conditions
Constitutional choice rules (GS7)	Presence of regulatory framework under which collective choice and operational rules are situated within; National law; Legal mandates; International law; Taxation; Subsidies; Conservation regulations; Legal framework defined by regional and national governments; The process through which collective-choice procedures are defined and legitimized.
Monitoring and sanctioning (GS8)	Presence of enforcement authority; Locally adapted processes to monitor and sanction natural resource use and management strategies; Local actors or those legitimized by them are responsible to observe and report changes in the SES; Monitoring social or biophysical changes; Data collection activities; Graduated sanctions(Whether sanctions increase with numerous offenses)
Number of actors (A1)	Number of resource harvesters/ users; Number of boats/gear to access system; Number of different actor groups; Population growth per unit time; Availability of labour; Labour reduction(time taken to perform task); Number of IUU actors; Size of community; Number of representatives on management committee; Population in surrounding areas
Socioeconomic attributes (A2)	<p>Income; Age; Gender; Affluence; Tourism firms; Economic characteristics of the users; Proxies of user wealth; User welfare; Labor availability;; Year of household establishment; Number of people at home; Number of children at home; Number of elders at home; Age of eldest; Assets owned (Y or N); Education level of household head; Place of origin of household head; Immigration status; Socioeconomic resilience (e.g. Insurance availability); Operating costs (Replacement/renewal rates); Number of livelihoods; Population share below age 18; Unemployment status; Median income; Share in top quartile of country income; Ethnicity; Age of surrounding buildings;</p> <p>Material style of life; Education and knowledge</p>
History or past	Historical resource use; Experienced/ exposure crisis or extreme events;

experiences (A3)	Duration living in area or using resources; Chronological description of the main events related to the resources and its management; Year founded (e.g. village, city, park); Process of management over time; Age of users/ group/ community; Past interactions that affect current actor's behavior and fisheries dynamics
Location (A4)	Is system remote and isolated; Clarity of boundaries; Exclusion problems; Geographic proximity to resource/ system; Distance to resources; Port/Harbors/Built Infrastructures (Man-made); Beaches/ Non-built/ natural access (Natural); Geographical location of resource system's users (e.g. settlements, villages, dispersed); Physical place where the actors are in relation to the resource itself and the market
Leadership/ entrepreneurship (A5)	Presence of formal leaders; Educated and well-connected leaders are present; Active individual(s) to lead collective action; Existence of, and attitude towards leadership and entrepreneurship among users; Local individuals who are capable of leading resource management and are respected by their peers; Actors who have skills useful to organize collective action and are followed by their peers; Trust in community
Norms, trust, social capital (A6)	Closeness of community; Degree of shared norms; Substantial social capital; "Sticking together"; Spatially significant organization of actors (Clubs/Organizations/Chapters); Non-spatially significant organization of actors (Online format, publications); Social capital(Degree to which each actor can depend on the other; actors share the same code of ethics and develop levels of trust; Motivations and attitudes of actors; Confidence and cooperation among actors; Levels of social and institutional interactions among users, including aspects like reciprocity and trust; Years of educational attainment; Voter turnout rates; Trust in community ;Migration status; Attendance at community events; Social network strength
Knowledge of SES/ mental models (A7)	Education rates; Degree of knowledge about system; Educational level of the user; Number of trainings received/a certain period of time; Presence/ degree of Traditional ecological knowledge (TEK); Presence/ degree of Western science and management knowledge (SMK); Presence/ degree of Local ecological knowledge (LEK); Degree of knowledge sharing/social learning;Which perceptions exist and how are they formed by SES conditions; Management practices; Level of knowledge among the users of the SES conditions, the potential and real disturbance patterns and its possible effects; Degree to which stakeholders understand and make sense of the characteristics and/or dynamics of the SES; Human agency (Perceptions about whether human activities can increase the number of fish in the sea)
Importance of resource (dependence) (A8)	Number of alternative livelihood opportunities; Degree of economic dependence; Degree of social/ cultural dependence; Occupational diversity; Dependence on natural system to sustain livelihood; Dependence on subsidies; Land ownership
Technologies available (A9)	Degree of access to appropriate technologies; Number of technologies adopted over time; Percent of land on which a technology has been adopted;

	<p>Percentage of users adopting a technology;</p> <p>What technology is used for harvesting, repairing, access, communication, decision making, management</p>
Climate patterns (ECO1)	Sea level rise; Climate change; Coral bleaching; Ocean acidification; Biohyiscal changes in system
Pollution patterns (ECO2)	Levels of toxic chemicals or materials; Presence of point sources (e.g. runoff pipes, rivers); Regional pollution pattern trends
Flows in/out of SES (ECO3)	--
Harvesting (I1)	Quantity of resources harvested by different users
Information sharing (I2)	Forums and media to keep actors abreast of developments; Methods for information sharing among users; Exchange of information regarding management process through written or spoken means
Deliberation processes (I3)	Presence of organizational/ decision making processes among users; participation of users
Conflicts (I4)	Presence of forums to address conflicts and reach amenable conclusions); Existence of new types of actors (foreign tourists, kites); Presence of existing conflicts among users
Investment activities (I5)	Presence of subsidies; Private investment or development; Building of human and resource capacity in SES; Investments for improving and managing the resources (e.g. time, money); Budgets (in dollars per visitor)
Lobbying activities (I6)	Internal and external influential capacity of the users
Self-organizing activities (I7)	Collective action activities to govern SES; Internal rules for the extraction and management of resources among users
Networking activities (I8)	Interactions within the social sub-system (e.g Informal networks; Formal networks); Liaise with horizontal and vertical partners to foster collective action; Networking and partnership activities of the users within and outside the community; market access
Monitoring activities (I9)	Monitoring activities on the use and management of resources (e.g. locally-defined by users, controlled by the government) and their performance;

	Community-based monitoring of social and/or ecological outcomes
Evaluative activities (I10)	Processes of evaluation of the resource situation and of the effects of management initiatives
Social performance measures (O1)	Co-management outcomes; Coproduction of knowledge; efficiency; learning; Evolution and impacts of the socio-economic characteristics; Measure of social outcomes resulting from interactions; Perceived impacts on livelihoods; gender equity; resource use efficiency
Ecological performance measures (O2)	Ecosystem services; Wildlife conservation; Evolution and impacts of the ecological conditions; Measure of ecological outcomes resulting from interactions; GHG emissions; soil erosion; agricultural yield; water footprint; livestock welfare; yield gap; yield variability; CO2 emissions; salinization; carbon sequestration
Externalities to other SES (O3)	Non desired effects (positive and negative) that occur as results of processes