Where is the ecology in social-ecological systems research? A review of methods

Adena R. Rissman and Sean Gillon

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adena.rissman@wisc.edu

This will be targeted to a short-format ecology journal. I am interested in pursuing another publication on the review for a social science journal.

Abstract

Research on social-ecological systems (SES) is rapidly advancing, but SES methods and implications have not been systematically analyzed. Our systematic review of 120 empirical papers on social-ecological systems examined methodologies for coupling social and ecological variables. Just over half (58%) of papers measured an ecological variable, while nearly all measured a social variable. Six primary approaches linked social and ecological variables: ecological models, causal loop diagrams, quantitative correlations, separate quantitative analyses, indicators of the link, and rich narratives. We examined whether researchers developed decision-relevant recommendations and how they framed human – environment relationships. Papers with an ecological variable were more likely to make recommendations about social-ecological systems than papers with only social variables. Making strong recommendations about improving SES sustainability requires understanding the ecology of systems in relation to their social dynamics. We outline methodological linkages for ecologists and other scientists seeking to make these important connections.

Keywords: applied research, interdisciplinary, social-ecological systems, sustainability science, systematic review

Introduction

Understanding the connections between ecological and social systems is critical for sustainability (Liu *et al.* 2007). Research on social-ecological systems (SES) is rapidly advancing to understand relationships between social and ecological conditions, interactions, and outcomes (Ostrom 2009). After a chorus of calls for interdisciplinary and solutions-oriented research (Palmer *et al.* 2005, Pickett *et al.* 2005), governments and foundations have increased their investments in research that couples social and ecological analyses. The International Geosphere-Biosphere Programme and International Human Dimensions Programme on Global Environmental Change have fostered innovative research linking physical and ecological sciences, and increasingly social sciences (Steffen *et al.* 2006). The Millennium Ecosystem Assessment was the first global assessment of ecosystems' benefits to society (MA 2005). In the United States, social-ecological research is funded by programs including the National Science Foundation's (NSF) Dynamics of Coupled Natural and Human Systems and the National Socio-Environmental Synthesis Center (SESYNC).

Although interest and investment in coupled social-ecological research are increasing, the emerging field of SES research has received little systematic analytical attention. The SES field represents one important effort to develop innovative research methodologies to operationalize transdisciplinary research (Ostrom 2009). Transdisciplinary, problem-oriented SES research often provides more comprehensive analyses than research focused on social or ecological dynamics alone, with different implications for achieving desired outcomes (Folke *et al.* 2005). Numerous challenges, however, face efforts to integrate ecological and social research, from institutional and disciplinary conventions and disincentives to contrasting methodologies (Miller *et al.* 2008). SES researchers work to overcome these challenges to explain connections between

social and ecological changes and outcomes, assess and inform policy, and better understand and improve human-environment relations. But it is unclear whether SES research is succeeding in being both interdisciplinary and solutions-oriented or how such efforts might be strengthened.

To better understand the emerging field of SES research, we conducted a systematic review of 120 research articles on social-ecological systems to examine methodologies for coupling social and ecological variables, whether the researchers developed decision-relevant recommendations, and how they framed human – environment relationships. We posed four questions about the SES literature:

1) How are ecological variables incorporated in SES research?
2) How do researchers analyze connections between social and ecological variables?
3) Does the SES literature make clear recommendations for social-ecological systems, and do these recommendations differ for papers with ecological variables compared to those without?
4) How does the SES literature frame human-environment relationships?

SES research claims an inherently interdisciplinary approach, but whether and how ecological and social variables are linked in empirical research is unclear. SES research shares many theoretical and methodological approaches with ecologists and those who study ecosystem management, but has been widely adopted by social scientists and includes a growing diversity of approaches that emphasize different social and ecological variables, system interactions, and epistemological perspectives (Binder *et al.* 2013). Many of the first SES ecologists were

modelers, for example, but a wide range of methodologies are now used to understand relationships between a diversity of quantitative and qualitative variables (Miller *et al.* 2008).

One critical motivation for SES research is to enhance ecological and social outcomes by improving sustainability or system resilience (Berkes *et al.* 2003, Folke 2006). Is interdisciplinary SES research more likely to be solutions-oriented? Scientists have suggested that environmental research that better integrates social and political contexts is more likely to be effective (Robertson *et al.* 2004). The types of recommendations for management or policy that emerge from research are likely to be linked to the types of variables and social-ecological linkages that were studied. Although many SES frameworks suggest diagnostics with practical implications for sustainability (Ostrom 2007), it is not clear whether SES papers with both ecological and social variables are more likely to make clear recommendations for policy or practice, and what approaches might be most helpful for diagnosing problems and developing solutions.

The human-environment framing is likely to shape the development of research questions, methods, findings, and recommendations (Binder *et al.* 2013). Ecosystems both provision and threaten humans. These two types of human-environment relationships have distinct research trajectories, but the links between the ecosystem service, environmental hazard, and SES literatures have not been well examined. Given the emphasis on common pool resources and common property regimes in the Ostrom workshop, which became a major proponent of the widely-used SES framework, we anticipate that a significant portion of the SES literature is more likely to focus on services or benefits from ecosystems, such as productive fisheries, forests, aquifers, or rangelands, as opposed to environmental threats to humans. However the SES

literature is broad and springs from multiple origins, so it is likely to reflect multiple human-environment framings.

In what follows, we elaborate on the results of a systematic review of SES literature to explore each of these questions in order to inform ecologists, social scientists, funders, and science-policy boundary spanners interested in advancing research and practice.

Systematic Review Methodology

We systematically reviewed the published literature on social-ecological systems. We allowed researchers to self-identify as doing SES research by retrieving all articles with a title, abstract, or keyword phrase of "socio-ecological" or "social-ecological" in Web of Science as of August 2012. We restricted the sample to journal articles in English reporting empirical results in the ten journals with the highest number of SES publications (for full methodology see Gillon et al. unpublished manuscript). This produced a set of 290 articles, and we randomly selected 120 articles for analysis (see WebTable 1 for journals and sample selection).

We coded the articles for types of variables, connections between independent variables (IVs) and dependent variables (DVs), qualitative and quantitative approaches for linking social and ecological variables, recommendations, and the framing of human-environment relationships. We identified papers that included both a social variable (socioeconomics OR governance OR management) and an ecological variable (resource productivity OR land cover OR biodiversity OR abiotic). Definitions are in WebPanel 1. We asked if papers with social and ecological variables were more likely than social-only papers to have different recommendations and human-environment framings, tested with two-tailed chi-squared analysis. Five tests of inter-

coder reliability were conducted during the coding period in which researchers read and coded the same paper and compared results.

Where is the ecology in social-ecological systems research?

The SES literature is diverse with a strong emphasis on social variables (Figure 1). Just over half of papers (58%, 69 of 120) included both social and ecological variables. Under half (42%, 50 of 120) had social variables but no ecological variables, and one paper had an ecological but no social variables.

Most papers (101 of 120) had recognizable connections between independent and dependent variables. We coded 970 IV-DV connections in these 101 papers. Socioeconomic variables were most likely to be examined in association with governance, followed by management and then resource productivity (Figure 2). Connections between biodiversity and other variables were least commonly researched.

Of the 101 papers with identifiable IV-DV connections, 86 examined if a social IV influenced (→) a social DV, 39 ecological IV → social DV, 31 social IV → ecological DV, and 26 ecological IV → ecological DV. This illustrates that the SES literature is most focused on interactions among social variables, followed by the influence of ecological variables on society. When considering all seven variable categories across the 970 IV-DV connections, we found that abiotic, governance, and socioeconomic variables were more often IVs than DVs, while land cover, resource productivity, management, and biodiversity were more often DVs (Table 1).

What binds social and ecological variables in analysis?

The SES literature includes both qualitative and quantitative methods, with somewhat more emphasis on qualitative methods. Half the papers (51%) were qualitative-only, one-third (32%) were quantitative-only, and 17% included both qualitative and quantitative methods. Papers with ecological variables were slightly less likely to include qualitative data than papers without an ecological variable, but this was not a significant difference in a chi-squared test.

We identified 6 primary approaches to linking social and ecological variables: ecological models, causal loop diagrams, quantitative correlations, quantitative but separate analyses, indicators of the link, and rich narratives.

Ecological modeling: Ecological modeling is frequently deployed to quantify some aspects of an SES, in which a quantitative mechanistic or probabilistic model connects system components. For instance, a multi-agent model of the behavior of competing lobster fishers is linked to a biophysical model of a patchy natural environment, with dynamic learning based on changing environmental and social conditions; the model reveals when individual incentives are aligned with collective action by groups (Wilson *et al.* 2007). SES modeling is "maturing as a discipline in its own right" drawing on natural resource modeling and complex systems research to tackle nonlinear behavior, cross-scale and interdependent dynamics, uncertainty, and microscale human decision-making (Schlueter *et al.* 2012).

Causal loop diagrams: Several articles presented system dynamics through causal loop diagrams (also called influence diagrams or cognitive mapping). Causal loop diagrams typically translate qualitative information into simple quantitative relationships with negative and positive feedback loops. For instance, Fazey et al. (2011) developed a conceptual model of social-ecological system changes in the Solomon Islands based on 76 focus groups, which revealed that population

153 growth and a desire for monetary prosperity "act synergistically to generate stress in
154 communities" and result in "maladaptive trajectories of change" including declining provision of
155 ecosystem services from fisheries, forests, and subsistence gardens. An advantage of causal loop
156 diagrams is their relatively accessible communication of complex feedback dynamics involving
157 many variables; a disadvantage is that the simple positive or negative polarity of loops may
158 inadequately describe complex and variable relationships and obscure threshold effects
159 (Richardson 1986).

160 *Quantitative correlations:* Another common approach was to quantify and then correlate social
161 and ecological variables, relying on statistical analysis to bind system components, with or
162 without causal inferences. For example, in a study of over 50 marine reserves in the world's
163 coral reef regions, multiple linear regression identified relationships between fish biomass in
164 marine reserves (from visual census) and indices of socioeconomic development, stated
165 compliance with reserve rules, human population density, and local democratic participation
166 (largely from surveys) (Pollnac *et al.* 2010).

167 *Separate quantitative analyses:* Some papers presented quantitative analyses on social and
168 ecological variables in different sections of the paper and linked them through narrative. For
169 example, an interdisciplinary project in the Siberian Arctic used narrative to tie together three
170 types of results that were presented in different sections of the paper and together presented a
171 nuanced perspective on social and environmental change: participant observation of impacts on
172 migratory reindeer herders; remote sensing of land cover change; and field sampling of shifts in
173 vegetation biomass (Forbes *et al.* 2009).

Indicators of the link: In a small number of papers, a variable itself linked social and ecological systems. For example, the variable Human Appropriation of Net Primary Production (HANPP) is itself an indicator of the link between humans and environments (Krausmann *et al.* 2012). Indicators such as HANPP and ecological footprints indicate the extent to which humans have appropriated limited resources; the precursor to HANPP was developed in the 1970s (Haberl *et al.* 2014).

Rich narratives: A few papers provided a rich narrative, what could be termed a social-ecological thick description, of the complex intertwining of social and environmental phenomena with little to no quantitative data. For example, through ethno-biological interviews, historical documents, and maps, researchers traced a century of decline and renewal of managed forests of chestnut trees and holm-oak associated black truffles, shaped by cross-scale socio-political legacies, social values, knowledge, technology, economies, and institutions (Aumeeruddy-Thomas *et al.* 2012). Thick description ascribes intentionality to behavior with detailed information about the context of a situation (Ponterotto 2006).

Making recommendations

Most papers (71%) included recommendations for policymakers, managers, or community members. Papers with social and ecological variables were significantly more likely than social-only papers to make recommendations that addressed interlinked social and ecological systems (Table 2). For research to generate recommendations about social-ecological systems, it needs to examine ecology, which requires ecologists to engage in SES research.

Human-environment framing

Social-ecological papers were more likely to consider how humans negatively impact the environment, how the environment provides services to humans, and how environmental change might affect services to humans, as compared to social-only papers (Table 3). Papers with an ecological variable were also more likely to assert that humans and environment cannot be analyzed independently. Papers with an ecological variable were less likely to consider how humans affected other humans.

The SES literature commonly relies on the concepts of adaptation, resilience, and vulnerability to analyze and explain social and ecological relationships. Most papers mentioned adaptation (73% of papers), resilience (69%), and vulnerability (58%). These were not mentioned significantly more often in papers with social-only variables compared to those with social and ecological variables.

Insights, challenges, and opportunities for ecology in social-ecological systems research

The SES field is expanding rapidly, with an emphasis on interdisciplinary and solutions-oriented research. Our systematic review of this literature aims to reflect on these emphases and is meta-policy relevant since we examine the policy-relevance of the emerging SES research field which engages a wide range of social-ecological contexts. Research methodologies affect the policy relevance of research findings. Ecologists face the challenge of making their work policy relevant in complex social systems. In order to make strong recommendations about improving the sustainability or function of social-ecological systems, researchers have to know how ecological dynamics relate to social choices and influences. The social-ecological systems literature is growing quickly, yet only 58% of papers included ecological variables. Based on our analysis, many SES publications do not entirely succeed at coupling social and ecological

aspects of systems. However, papers with an ecological variable were over twice as likely to make recommendations addressing integrated social-ecological systems. We see in this result an indication of the potential for interdisciplinary work to address boundary-spanning and complex contemporary problems. Still, less than a third of papers made recommendations for integrated social-ecological systems, indicating the challenge of this work.

SES frameworks stress the need to integrate ecological information with research on how people behave and the effects of institutional configurations to better understand robustness, resilience, and capacity (Anderies *et al.* 2004). Approaches for linking social and ecological variables are widely divergent; we grouped them into six primary approaches that could help interdisciplinary teams conceptualize their collaborative papers: ecological modeling, causal loop diagrams, quantitative and correlated, quantitative but told separately, indicators of the link, and rich narratives. Aspects of ecosystems such as land cover, the production of crops, fish, or timber, and abiotic variables were most commonly measured, followed distantly by biodiversity. Both narrative and quantitative analytical links between social and ecological can produce papers with fascinating insights. Methodological pluralism is likely an advantage to the field since different methods answer questions in different situations better than others (cf. Norgaard 1989). Quantitative studies rely on modeling and statistics to link social and ecological variables, indicating the necessary or likely characteristics that predict sustainable resource or livelihood outcomes. Qualitative studies can provide rich descriptions and histories, asking nuanced questions about how and why processes have occurred. However, clear analytical pathways and standards for interdisciplinary SES research are lacking, which would provide structure for researchers seeking best practices and the opportunity for transdisciplinary, comparative analysis.

240 Humans were equally likely to be framed as threats to ecosystems or as beneficiaries of
241 ecosystem services, while somewhat fewer papers examined environmental threats to humans.
242 Papers with only social variables were more likely to consider how humans impacted other
243 humans (incorporating equity or power) than papers with both social and ecological variables.
244 This finding illustrates a potential trade-off in focusing on social-ecological linkages or on
245 complex dynamics among social groups.

246 Several factors create obstacles for more robust analysis of both social and ecological
247 dimensions of contemporary conditions and problems. These include disciplinary incentives,
248 cultures, and epistemologies; funding; high transaction costs; and incommensurate driving
249 research questions (Campbell 2005, Metzger and Zare 1999, Turner and Carpenter 1999). In
250 many fields, research papers are the building blocks of scientific knowledge. Yet the manuscript
251 itself, with its space constraints, peer-review process, and authorship cultures, may constrain
252 interdisciplinary synthesis. In academia, progress "is measured in terms of multiple separate
253 types of expertise and publications rather than a shared enlightenment among scholars"
254 (Norgaard and Kallis 2011). Analysis that connects changes in environment, technology,
255 knowledge, organization, and values is not simple – it faces an internal tension between mind-
256 opening integration and the analytical categorization that supports empirical work and scholarly
257 communities (Kallis and Norgaard 2010). We experienced this tension in categorizing papers,
258 some of which aimed to break down the very categories of social and ecological.

259 Many opportunities exist for the field of ecology to engage in SES research. Ecologists are
260 undertaking innovative social-ecological systems research, and the sophistication of coupled
261 social-ecological or natural-human systems research is growing (Binder *et al.* 2013, McGinnis
262 and Ostrom 2014). Likewise, many ecologists want to do applied research but may lack the

conceptual frameworks and understanding of what kinds of methods are likely to be complementary. SES research requires broad, systems-thinking that allows for surprise and recognizes complex dynamics. Researchers may need to push forward with new methods and research norms – since, for example, the desire for tightly-controlled experimental data has pushed ecological researchers away from anthropogenic landscapes where they might usefully contribute to sustainability (Martin *et al.* 2012). This analysis indicates that it will likely continue to be productive to support the continuation of trends to incentivize multi-author work through grants directed to interdisciplinary teams. Syntheses that bridge from specific methods to broad frameworks can help train scholars in how to pursue social-ecological research. The emerging field of sustainability science emphasizes systems thinking and is beginning to identify noteworthy "classics" for training scholars about different qualitative and quantitative methodologies (Wiek *et al.* 2011). While multiple methods are needed, greater systemization of methodologies can also allow for case-comparisons, such as in the social-ecological systems meta-analysis database on common-pool resource systems (Cox 2014).

In conclusion, we suggest that more integration of ecological drivers and outcomes is needed in research on social-ecological systems. Papers that measured a biotic variable were more likely to make recommendations for both social and ecological systems, compared to papers without a biotic variable, indicating that more solutions-oriented lessons have been learned in research linking social and ecological analyses. Just over half the papers we examined, however, included an ecological variable. Challenges to integrating social and ecological information in a single research publication are numerous. However, we cannot expect to effectively inform policy and management and improve human-environment relations without a clear link between ecological

285 and social drivers and outcomes. Thus, ecologists' contributions to challenging, but rewarding,
286 problem-oriented SES research will be important.
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367 Table 1. Percent of the 970 independent variable – dependent variable (IV-DV) connections in
368 which each variable was an IV or a DV.

		IVs (percent of IVs)	DVs (percent of DVs)
Social	Socioeconomics	53.9%	48.1%
Social	Management	8.7%	14.7%
Social	Governance	14.8%	12.7%
Ecological	Resource Productivity	4.1%	9.0%
Ecological	Land Cover	6.2%	7.7%
Ecological	Abiotic	11.4%	4.2%
Ecological	Biodiversity	0.9%	3.6%

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370 Table 2. Papers with social and ecological variables are more likely to have recommendations for
371 social-ecological systems; statistical tests compare social-ecological with social-only papers.

	Overall (n=120)	Percent of social-ecological papers (n=69)	Percent of social - only papers (n=50)	χ^2	p-value
Any recommendation	71%	73%	70%	0.086	0.769
Social-ecological system recommendation	29%	41%	14%	9.866	**0.002**
Example:	"With an improved understanding of ecosystems and the integral role humans have in global ecosystem management, new policy recommendations to ensure ecosystem performance and resilience can be developed that incorporate the view of marine ecosystems as complex adaptive systems with non-linearities, discontinuities, and multiple-stability domains and thresholds…A major innovative institutional change needs to occur that will allow development of a new marine governance system that makes it possible to manage natural capital in a way that secures its capacity to support human welfare for a long time" (Villasante 2012).				
Social system recommendation	55%	52%	60%	0.719	0.397
Example:	"Addressing issues such as corruption, transparency, and stability of national governments will be key to building effective social organization and adaptive capacity at all scales" (Cinner *et al.* 2012).				

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376 Table 3. Framing human-environment relationships; statistical tests compare social-ecological
377 with social-only papers.

	Percent of all papers (n=120)	Percent of social - ecological papers (n=69)	Percent of social - only papers (n=50)	χ^2	p-value
How humans manage the environment	82%	83%	80%	0.131	0.717
The benefits or services the environment provides to humans	57%	67%	44%	6.082	**0.014**
How humans negatively impact the environment	53%	62%	42%	4.815	**0.040**
How humans affect other humans	48%	41%	60%	4.376	**0.036**
Environmental or ecosystem change and its consequences for ecosystem service provision to humans	45%	57%	30%	8.227	**0.005**
Environmental harms, threats, or risks to humans.	43%	42%	44%	0.853	0.489
The authors conceptualize human and environmental systems as separate	43%	35%	52%	3.528	**0.060**
The authors suggest that humans and environment cannot be analyzed independently	32%	37%	24%	2.497	0.114

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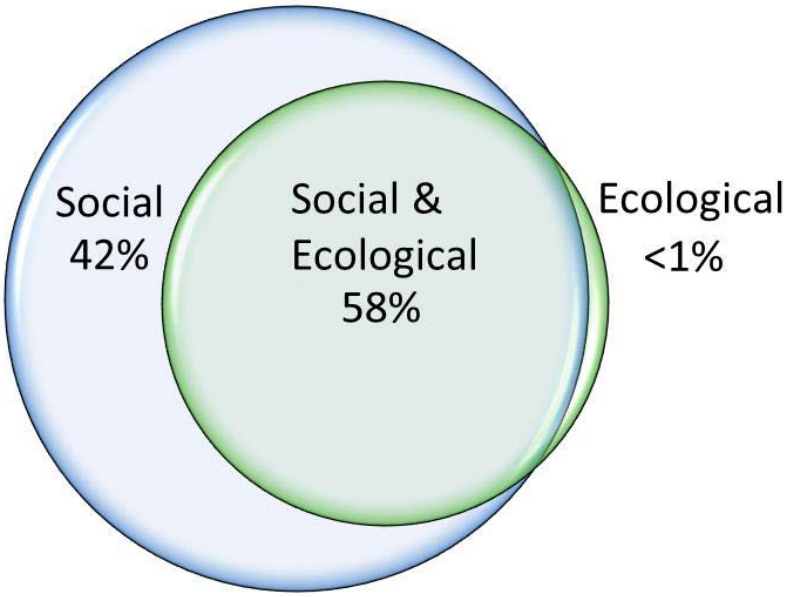

Figure 1. Social variables were more common than ecological variables in SES papers (n=120).

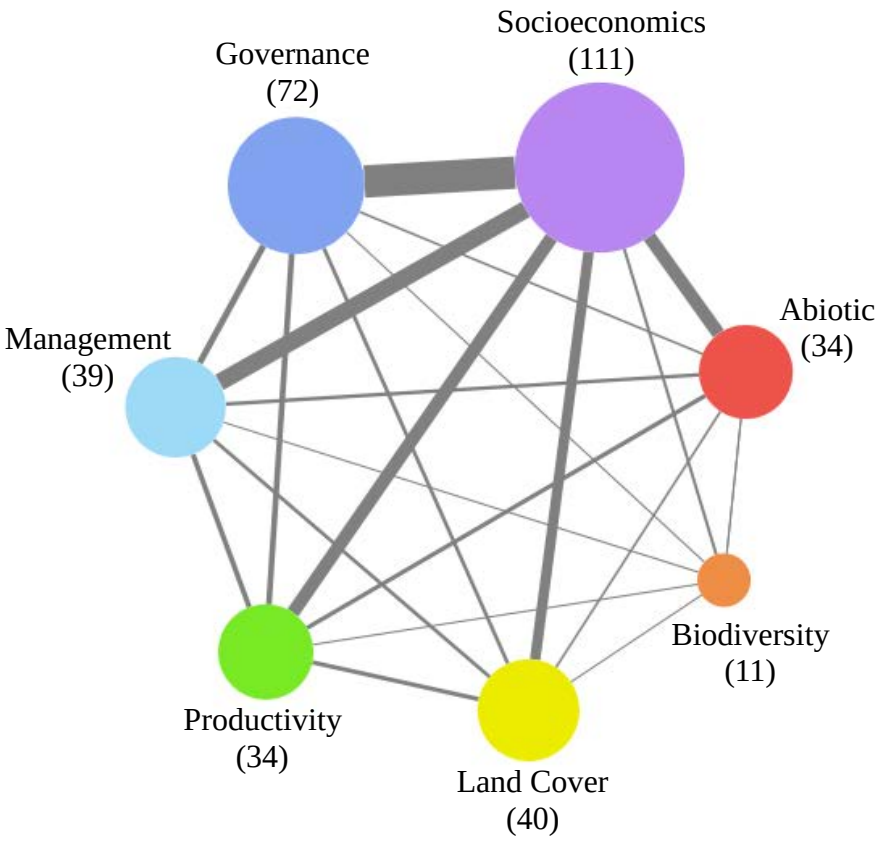

Figure 2. Bubble size and number in parentheses indicate the number of papers that include each type of variable (n=120). Line width indicates the number of papers with each type of IV-DV connection (n=101). Line lengths do not signify meaning.

Web material

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WebTable 1. SES article sampling approach by journal

	Papers from keyword search	Papers with empirical research	Papers included in sample
Ecology and Society	202	133	53
Global Environmental Change	49	35	12
Ecological Economics	40	26	10
Marine Policy	24	18	10
Environmental Science and Policy	18	11	8
Proceedings of the National Academy of Sciences	25	15	7
Environmental Management	23	19	7
Landscape and Urban Planning	15	13	6
Human Ecology	15	14	5
Environmental Conservation	14	6	2
Total	425	290	120

WebPanel 1. Variable Definitions

The set of variables coded draws on and adapts several frameworks for analyzing socio-ecological systems (SES) (e.g., Turner et al. 2003, Ostrom 2009, Miller et al. 2012). Variable codes were aggregated and adapted to suit broad, non-modeling analytical purposes and to reflect evolving foci of SES research. More specific variable codes were aggregated as detailed below under several categories of social and ecological variables for the analyses presented in this paper.

Papers were coded as either having or not having independent and dependent variables. The papers included in this analysis were those coded as having independent and dependent variable. Papers without independent and dependent variables were those that did not attempt to analyze the causal connections among components and dynamics of a SES. Definitions of independent and dependent variables are described below, based on Creswell (2014). Explanations of specific Social and Ecological Variables follow these.

Independent Variable

Independent variables are measured phenomena assumed to affect, influence, or cause an outcome.

Dependent Variable

Dependent variables are measured phenomena that depend on or are the expected outcome of or results created by independent variables.

Ecological Variables

Abiotic

Variables coded as abiotic included measurement of the nonliving features of ecosystems, including weather and climate (temperature and precipitation), carbon sequestration or greenhouse gas reduction, disturbance regime (e.g. flood, fire, hurricane), nutrient cycling, water quality, water quantity, and soil characteristics.

Biodiversity

Variables coded as biodiversity were measures of biological diversity including genetic, species, or population richness.

Land Cover

Variables coded as land cover included measurement of the biophysical cover on the earth's surface. A small number of other measures of vegetation composition or structure that were not tied to biodiversity or resource productivity are grouped with land cover.

Resource Productivity

Variables coded as resource productivity included measurement of the productivity or quality of crops, grassland, forest, animal production activities, hunting or foraging, or fishing.

Social Variables

Governance

Variables coded as governance included measurement of governance & institutional arrangements (including specific policies, practices, and capacity), accountability (obligation to report, explain, or answer for actions), legitimacy (public recognition and acceptance of governing authority), or politics (social relationships involving negotiations of practice, authority, or power).

Management

Variables coded as management included measurement of intentional and specific human interaction with ecosystems to effect a desired ecosystem change or outcome.

Socioeconomic

Variables coded as socioeconomic included measurement of one of the following: human demographic characteristics (e.g., population, migration characteristics, race, gender, age), human wellbeing (including health and education), livelihoods (including income and ability of derive a living from available resources), characteristics of technology use**,** economic conditions and policies, market structure (access or function)**,** equity (distribution of opportunity or outcome among groups or individuals)**,** human perceptions, aesthetic**,** cultural and spiritual values**,** entrepreneurship**,** knowledge and learning (includes capacity, exchange networks, and creation or assimilation of information)**,** social capital, social networks, and media organization (including communication on and representations of SES).

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