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Research

The "social" aspect of social-ecological systems: a critique of analytical frameworks and findings from a multisite study of coastal sustainability

Tim Stojanovic [1], Hilda M. McNae [1], Paul Tett [2], Tavis W. Potts [3], J Reis [4], Hance D. Smith [4] and Iain Dillingham [1]

ABSTRACT. We evaluate whether society can adequately be conceptualized as a component of social-ecological systems, given social theory and the current outputs of systems-based research. A mounting critique from the social sciences posits that resilience theory has undertheorized social entities with the concept of social-ecological systems. We trace the way that use of the term has evolved, relating to social science theory. Scientometric and network analysis provide a wide range of empirical data about the origin, growth, and use of this term in academic literature. A content analysis of papers in *Ecology and Society* demonstrates a marked emphasis in research on institutions, economic incentives, land use, population, social networks, and social learning. These findings are supported by a review of systems science in 18 coastal assessments. This reveals that a systems-based conceptualization tends to limit the kinds of social science research favoring quantitative couplings of social and ecological components and downplaying interpretive traditions of social research. However, the concept of social-ecological systems remains relevant because of the central insights concerning the dynamic coupling between humans and the environment, and its salient critique about the need for multidisciplinary approaches to solve real world problems, drawing on heuristic devices. The findings of this study should lead to more circumspection about whether a systems approach warrants such claims to comprehensiveness. Further methodological advances are required for interdisciplinarity. Yet there is evidence that systems approaches remain highly productive and useful for considering certain social components such as land use and hybrid ecological networks. We clarify advantages and restrictions of utilizing such a concept, and propose a reformulation that supports engagement with wider traditions of research in the social sciences.

Key Words: *coastal; scientometric analysis; social-ecological; social-ecological systems; social science; socio-ecological*

INTRODUCTION

Interdisciplinary and transdisciplinary approaches are increasingly demanded in research to examine the interactions between humans and the natural world. We explore the challenges of research that seeks to undertake an interdisciplinary approach. This is a theoretical and methodological challenge to the practice of science.

Although the development of scientific methodology has relied upon reductionist approaches to isolate phenomena for investigation, many sustainability issues faced by society involve complex chains of interaction, involving a broad range of environmental and human factors, spanning global to local scales. This has led to a call for more multidisciplinary and interdisciplinary approaches to scientific investigation focused around real world problems and the emergence of the field of sustainability science (Kates et al. 2001, Turner et al. 2003). To develop effective methodologies for these interdisciplinary approaches, a number of challenges must be overcome (Dronkers and De Vries 1999, Köhn and Gowdy 1999, Pennington 2008, Wesselink 2009, Stock and Burton 2011, Haapasaari et al. 2012, Kueffer et al. 2012, Beichler et al. 2014), including the following: differing and sometimes philosophically conflicting methodological approaches; addressing the contrasting terminologies used by a broad range of academic and professional disciplines; taking account of uncertainties within existing fields of knowledge; positioning of research within the social and political context; and cultural challenges in the process of interdisciplinary scientific knowledge production, such as the disciplinary turf wars, current academic "rewards" systems that inhibit interdisciplinary work, and potential for openness and trust, and finally, and not least, the cognitive challenge of capturing breadth without sacrificing depth of knowledge.

We analyze how the term "social-ecological systems" [SES] has evolved within intellectual traditions, and review the outputs of SES research within the wider literature, and within a large-scale interdisciplinary project on the sustainability of coastal zones. The term "social-ecological systems" evolved when an ecology-dominated community used this term to differentiate themselves from those colleagues who disregard the human footprint in ecosystems. Now the term has become used in a broader setting, it is apt to review the way that the term relates to conventional social science perspectives. In a recent review of 10 major conceptual frameworks, Binder et al. (2013) characterize SES as the most comprehensive concept for structuring a research framework, because it allows analysis of two-way dynamics between social and ecological systems. We review whether the hopes raised by this claim of comprehensiveness are warranted. (The focus is on the SES concept, though we accept broader frameworks for human-nature interactions may be considered [Flint et al. 2013])

SOCIAL ENTITIES AND SYSTEMS

Origins of a systems approach

Systems approaches are descended from general systems theory, epitomized in the work of L. Von Bertalanffy, K. E. Boulding, and J. W. Forrester among others. Key concepts include: relationships between interacting parts, feedbacks, boundaries, emergent properties, self-organization, and hierarchies. Many of these concepts are reflected in other fields that have developed

[1]University of St Andrews, [2]Scottish Association for Marine Science, [3]University of Aberdeen, School of Geosciences, [4]Cardiff University

from these tenets, areas of complexity science such as complex adaptive systems theory; actor-network theory; and agent-based modeling. The founders of systems theory envisaged a conceptual framework that would encourage interdisciplinary research and could span all disciplines. However, defining social aspects in systemic ways has proven challenging. In particular, it is challenging to define functions in the social domain. For example, if society and its components do form a "system," what are the functional goals (telos) of that system: Adaptation? Goal Attainment? Maintenance of a Culture? Integration? Evolution? Careful consideration in formulating a social system will reveal a paradox in defining the goal of its development. This paradox has been central to the debate in the social sciences and humanities to characterize, understand, and explain the human condition.[1]

Roots of systems approaches for social science

Nevertheless, systems approaches have been employed in the social sciences for a number of decades. Key theorists include N. Luhmann (Luhmann 1995) and T. Parsons (Parsons 1971). More recently, systems approaches have also been applied in the social and technical sciences through soft systems methodology (Checkland and Scholes 1999).

In soft systems methodology, a problem situation is conceptualized as a human activity system to understand the actions or interventions that might be required to improve a real world situation to which the system approximates. The methodology emphasizes social learning, and works by exploring perspectives and perceptions of systems dynamics. It has been applied to the social dimensions of sustainability issues (Potts et al. 2015). The approach is commonly applied at the level of institutions or organizations. The paradoxical problem of defining system goals can be circumvented by qualitatively modeling idealized system outputs, e.g., goals of an education system or goals of a healthcare system.

Luhmann's theory of systems functionalism is based on a three-level model of interactions between individuals, organizations, and society in social space and historical time. Luhmann's theory aims to explain the functioning of society as a whole (Luhmann 1995). In particular, it renders human existence as systemic in bodily, mental, and linguistic ways. For example, the human mind provides the "substrate" for institutions and subsystems that make up society. Communication takes on an important role in this theory as the means by which sense is made of a social system.

Parson's theory is sometimes termed structural functionalism. This theory developed in a number of phases in an attempt to render the relationship between structure and action. In Parson's theory the key subsystems of society include the cultural, social, personality, and behavioral systems (Parsons 1971). Each of these subsystems coordinate the consequences of actions to make up a functional whole from the perspective of an actor. Subsystems are significant according to their contribution to boundary-maintenance or evolution of the total system. Parsons later proposed a "telic system" (Parsons 1978), a metaphysical component of the system that proffered end goals for the social system, based in religious, spiritual, cultural worldviews that make sense of the function of society in different ways, and that are influential for a large proportion of the world's population. However, he was criticized for being unscientific in doing so, in terms of lacking a suitable analytical approach and making the metaphysical domain an object of scientific study (Habermas 1987). Figure 1 provides a graphic representation of his synthesis of system and action in his later writings.

Systems approaches are not currently dominant in the social sciences[2]. J. Habermas makes an extensive review of Parsons's theory in *The Theory of Communicative Action Vols1 and 2* (1984, 1987). Two key insights may be drawn from Habermas's critique. First, certain components of society are particularly amenable to systems analysis, e.g., economy, polity, certain dynamics of human interaction, or collective action. Second, systems approaches provide key insights, but on their own are insufficient for theorizing society in its totality. This is because systems approaches provide partial and inadequate theorization of social entities[3]. They fail to recognize that an effective cause from the point of view of culture is also a rationally compelling cause from the point of view of an agent's action. Further, this perspective tends to introduce an institutional bias in analyses of causality over and above considerations of culture and personality formation (because a systems approach renders the latter less susceptible to empirical investigation). In response, Habermas proposes a two-component model of society as "lifeworld plus system," which draws on both analytical and hermeneutical methodologies to characterize social structures and social change.

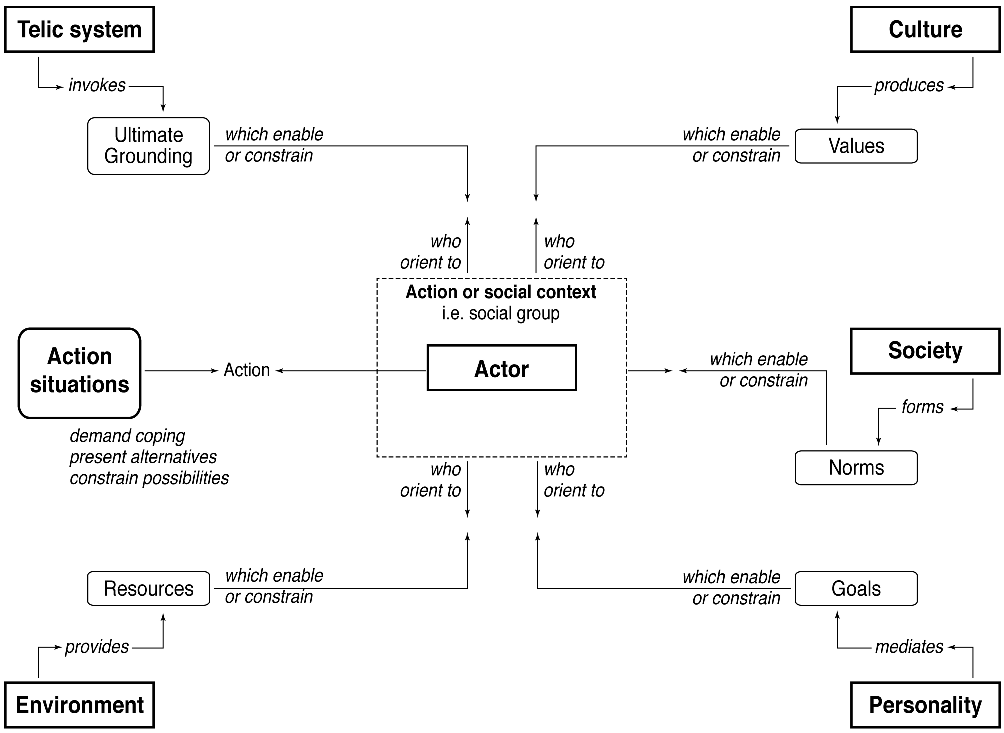
LITERATURE REVIEW: CRITIQUING SOCIAL-ECOLOGICAL SYSTEMS

A mounting critique from the social sciences, including diverse fields such as geography, political and human ecology, anthropology, sociology, planning, and conservation science posits that social-ecological systems inadequately theorize and operationalize "the social." It is beyond the scope of this paper to elucidate whether these critiques have properly understood SES theory. Nevertheless it is interesting to consider the broad themes of critique. The critiques are often part of a broader critique of resilience theory, however it is important to recognize that the SES concept is deployed in many ways and need not necessarily be framed by resilience theory (for an introduction to resilience theory, see Walker and Salt 2006). Furthermore, some critiques remain sympathetic to the term SES and seek to refine the term. Four broad themes can be categorized from the critiques.

Critical theory

A first critique comes from researchers with a background in critical theory[4]. The core of this critique is that systems approaches depoliticize the situation being represented (Welsh 2014). "Political foreclosure occurs because SES frame the governance choices that are available, often in feedback mechanisms that are seemingly neutral" (Evans 2011:232). Using a systems metaphor leads to existing social relations being taken for granted as "natural" (MacKinnon and Derickson 2013). For example, an SES approach might model how flows of capital reduce forest cover, which has a knock on effect on agricultural practices, which change the culture of subsistence cattle farmers, but throughout this case globalization (or the nature of capital flows) is seen as an inevitable process. An inherent conservatism is suspected. In this criticism, commentators align with the Habermas analysis that a "systems approach alone is insensitive to social pathologies, because lifeworld is merely assimilated to disequilibria in exchange relations" (Habermas 1987:376). Thus a systems approach is able to elucidate governance pathologies,

Fig. 1. Parsons's systems framework: structural-functionalism.



for example, how lack of adaptive learning mechanisms in command and control structures prevent knowledge of dynamic change in ecosystems (McLaughlin and Krantzberg 2012), but is blind to pathologies of society caused by interactions of social, cultural, and economic realms such as the breakdown of bonds between the individual and community. Critics add that this misses the question of what analysis aims for (Smith and Stirling 2010, Fabinyi et al. 2014) because sustainable futures almost always involve questions of politics and power.

Antinaturalism

A second critique comes from a broadly antinaturalist position [5]. Here the main critique is that applying a systems approach is a kind of methodological determinism: choosing an approach that fits the requirements of systems modeling rather than an accurate representation of social entities. A naturalistic concept is being imported into the social science domain. Systems approaches "fail to recognize that essential differences in behavior, processes, and structures exist between social systems and ecological systems" (Armitage et al. 2012). Chief among these differences are the notions of volition or agency, human capacities to self-reflect, consciously act, and learn from one another. However, agency is veiled in a systems approach (Coulthard 2012), where the focus is more on rules, material causes, and influence in collective situations, rather than reconstructing intention from a subjective point of view. It is argued that this restricts models of social-ecological evolution, for example, failing to capture the potential role of creativity and imagination in dealing with sustainability issues (Davidson 2010).

Adequacy of depth of conceptualization

A third critique is that systems approaches inadequately conceptualize social-ecological complexes. This is implicit in the two critiques above. A systemic approach has particular weaknesses in capturing certain realms of social reality, and consequently fails to employ related methodological strategies such as the double hermeneutic. In the case of power dynamics and normative questions, SES approaches fail to "address normative questions and to capture how power and competing value systems are not external to, but rather integral to the development and functioning of SES" (Cote and Nightingale 2012:475). As a consequence, impacts of material change on certain cultural groups are not well investigated (Crane 2010) nor is the mortality of individuals commonly considered. Of particular interest is the consideration of social dynamics. The decision to systematize social dynamics rather than rendering "the social" in other comprehensive ways, obscures certain social issues such as inequity or economic marginalization which only become apparent at certain scales of investigation (Glaser and Glaeser 2011). Similarly, it is argued that SES approaches do not sufficiently problematize the choice of social variables under consideration (Turner 2014). For example, resource extraction, population, and material benefits receive greater consideration than values, equity, nonmaterial and psychological aspects of well-being.

At the same time, leading SES researchers have themselves highlighted vagueness or inconsistency in the practice of defining social components, and setting spatial and functional boundaries of SES (Walker et al. 2012). Thus, there is a debate whether the challenge of applying the approach is merely practical or actually conceptual. Critics of SES point to problems that are inherent in the way SES are conceptualized, and make a distinction between the principles of systems modeling, which simplifies to explain key drivers, versus social analysis, which aims to deepen understanding to explicate the human significance of change in a given place.

Adequacy of explanatory power and scope

A fourth and final critique concerns a lack of explanatory power, and bias in explanations, generated by the preceding assumptions. If certain aspects of social reality are not well captured by SES, as argued above, it follows that these are not translated into the ways in which the social-ecological is problematized. Certain categories of explanation are bypassed because the focus on an external web of interactions is offset by a lack of consideration of internal, socially constructed meanings and normative values that may influence material behaviors and environmental outcomes (Crane 2010). Top-down functional analysis and a concern with the persistence of system structure, rather than the way in which subcomponents of the system differ, leads to theorization of self-organization or concern with institutions and governance, rather than political action or deliberation to influence the direction of cultural change. Further, the explanatory potential of certain modes of analysis are avoided. A systems ontology may steer analytical preferences toward collaboration with disciplines that have quantifiable dynamics; theories of society that avoid questions of power; and highly aggregated data with little insight into the realm of the subjective (Glaser and Glaeser 2011).

A riposte or receptivity?

The above literature review summarizes why many scholars in the human sciences have been critical of the notion of SES. A key riposte to these critiques is that they simply amount to a call for "doing their kind of research." Further, one might argue that certitude about approaches in the social domain is problematic because there are a great heterogeneity of approaches to research in social sciences and lack of agreement on key terms such as equity, well-being, or justice. Proponents of systems approaches point to the fact that the "social" is well represented within studies of SES and that issues of equity, power dynamics, and questions of agency receive attention. Researchers have begun to respond to the above critiques. For example, with respect to power dynamics, there are analyses of the role of political systems in predefining desired ecosystem states and trade-offs: these often favor short-term benefits for those with power (Robards et al. 2011). With respect to agency, there is research by Olsson et al. (2004), Westley et al. (2013), and Moore et al. (2014) that characterizes the use of experimental and innovative strategies by shadow networks and leaders to transform SES. With respect to equity, Bacon et al. (2012) provides evidence of reduction in socioeconomic inequities in certain agroecosystems. Altogether, a wide range of social entities are considered within SES conceptualizations, although these tend to focus on institutional aspects with broader consideration of society, political systems, and economy (Anderies et al. 2004).

However, if founded, the critiques summarized in the literature review above have significant implications for the way in which SES approaches are applied. A second potential response is to consider the limitations or potential improvements to an SES approach, both analytically and as a foundation for real world action. In the brief decades since the development of approaches that operationalize SES, there has been considerable methodological and theoretical evolution to respond to a number of gaps recognized within the literature. It is recognized that continued development is needed to adequately conceptualize the interactions between societies and ecosystems (Haberl et al. 2006). In the spirit of constructive dialogue, we explore how these critiques might be used to further reformulate the SES concept. To empirically investigate the critiques, we review three linked sets of analysis: scientometric analysis of the literature, content analysis of a journal, and case study analysis of how SES are operationalized in 18 coastal zones.

METHODOLOGY

Three sets of analysis are provided. Scientometric analysis at the level of a corpus of literature reveals general trends in the use of terms. Content analysis of papers (n = 260) at the level of a key journal reveals how a systems approach is utilized in the practice of research. Case study analysis at the level of a large-scale research project reveals the methodological implications of a systems approach. For the case studies, a questionnaire survey and focus group workshops were utilized to understand how researchers deployed systems approaches in concrete research situations. Together these analyses allow a broad and deep exploration of how the term social-ecological systems is deployed to structure interdisciplinary research.

Scientometrics of social-ecological systems

Scientometrics particularly focuses on the evolution of academic disciplines and how theoretical concepts are operationalized. To identify trends in the use of the terms "social-ecological" and "socio-ecological," two global databases were investigated: Elsevier's Scopus, and Thomson Reuter's Web of Science Core Collection. The results of the analyses revealed similar trends between the databases (Fig. 2). The data reported in this paper is mainly from Web of Science because both the science and social citation indexes provide coverage from 1900 onward, whereas complete records are only included in Scopus post 1995[6]. However, this is a robust dataset for showing change over time and trends are supported by our initial analysis in Scopus as well. Two key methods were employed for analysis. First, the corpus of academic literature was reviewed (Bettencourt and Kaur 2011). In this case, key terms within papers were the basic units of analysis. The research reviewed change in the use of terms over time, across disciplines, and across journals. We also conducted cited reference analysis of the term "social-ecological systems." In this case, publications and related academic networks were key units of analysis. A number of search and analytical strategies were adopted (see Appendix A1.1).

Second, network analysis was conducted to produce visualization of knowledge domains using Citespace Visualization Software (Chen 2006). This utilizes a smart, local, moving algorithm to identify clusters (Waltman and Van Eck 2013). It is possible to conduct the analysis according to authors, documents (references cited between them, i.e., cocitation), or journals. In our analysis we consider authors and cocitation between documents. Papers with the key term social-ecological systems were uploaded to the software from Web of Science. For the author network, we used the structural metric Betweeness Centrality, ranging from 0 to 1, to identify influential nodes (Baggio et al. 2015). For the document cocitation, we used progressive network analysis, which produced a visualization formed of 14 clusters. The metric Modularity Q, ranging from 0 to 1, provides some indication of the distinctiveness and homogeneity of the overall network.

Fig. 2. Number of articles published using the terms "social-ecological" or "socio-ecological" 1928-2013, from Elsevier's Scopus, and Thomson Reuter's Web of Science Core Collection.

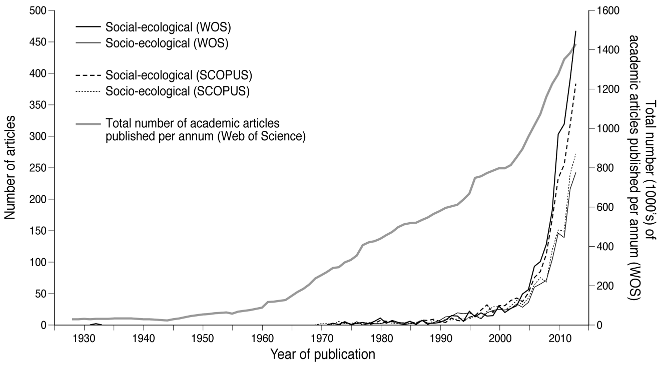
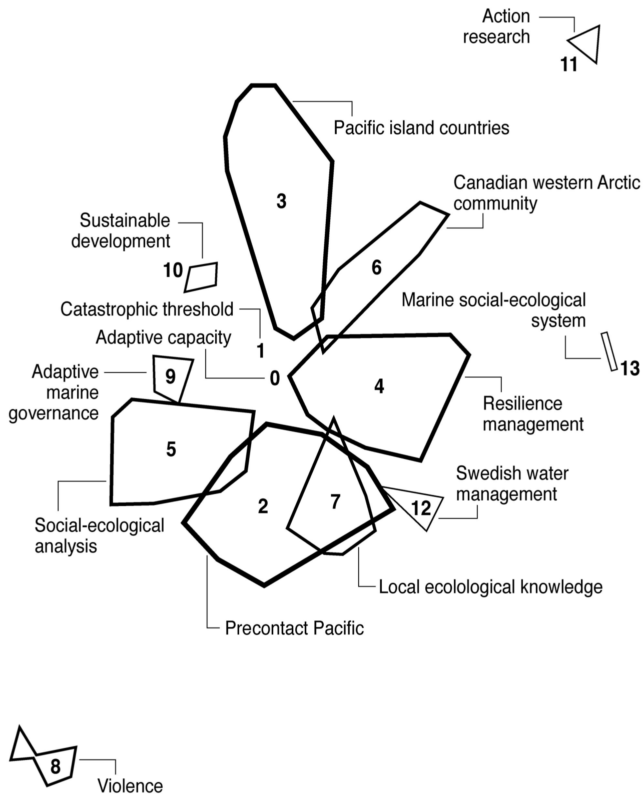


Fig. 3. Network visualization of document clusters.



For the visualization graphic (Fig. 3), visual distance and overlap provide some indication of the connectedness of clusters. A number of metrics were available to analyze the significance of patterns. "Silhouette" provides a measure of the level of homogeneity of the clusters. Three metrics, Term Frequency Inverse Document Frequency (TFIDF), Log Likelihood Radio (LLR), and Mutual Interactions (MI) can be used to characterize the clusters. These metrics draw on cited article's titles, keywords, and abstracts to form a corpus of words, from which a characteristic label can be identified. In the analysis provided below only LLR is used (Table 1), to avoid information overload. It is argued that LLR provides a superior result in terms of uniqueness and coverage (Chen et al. 2010). Further details of the methodological steps taken for visualization and cluster labelling are provided in Appendix 1.

Content analysis

A content analysis of journal articles for *Ecology and Society* was conducted for the period 1997–2013. This time period was chosen in line with foundational texts identified for social-ecological systems research and the "inception phase" shown from trends in the literature. Those articles from *Ecology and Society* that used the term social-ecological in abstract, title, or keywords were exported into the qualitative data analysis software Nvivo 10 (n = 260). The creation of a word tree enabled analysis of the range and frequency of coterms used with social-ecological. Coding of documents at nodes where key terms were used allowed for exploration of their context, and interpretation based on a review of 2569 uses of the term social ecological system. Axial coding (Strauss and Corbin 1998) developed broader themes such as subjects covered, methods deployed, and aspects of social systems considered. Thematic analysis was also conducted using Becker's (2012) three-way classification of the SES concept in practice, to identify whether the term was being used as a "boundary object," "epistemic object," or "defined relative to biogeophysical unit."

Analysis of SPICOSA case studies

A review of social components of a systems approach was provided at the level of a research project, based on 18 interdisciplinary coastal assessments, conducted as part of the Science Policy Integration for Coastal Systems Assessment (SPICOSA) EU Framework 6 research project. The SPIOCSA project demonstrated a number of properties that can be considered characteristic of the use of the SES concept, including a commitment to interdisciplinarity, dynamic exploration of linked socioeconomic and ecological phenomena, and identification of feedbacks and emergence. SES terminology is prominent in the synthesis of findings from the research project (Hopkins et al. 2011, Tett et al. 2011).

We evaluated the types of data and information utilized in this systems based research, and the extent to which the social component of the sustainability issue in the coastal zone was addressed. The data collection is described in Reis et al. (2014) based on a questionnaire survey (n = 14) followed by focus groups to validate findings. In addition, internal project reports (L. McFadden, S. Priest, A. Sandberg, D. Bailly, and J. D'Hernoncourt 2009, *unpublished manuscript*) provided a basis for comparison of the systems modeling conducted by different teams in the research project. This analysis allowed investigation of an integrated project seeking to operationalize a systems approach across a range of case study contexts (Tett et al. 2011). This adds significantly to the analyses above because it allows an

Table 1. Network analysis visualization of social-ecological systems clusters.

ClusterID	Size	Silhouette	mean(Year)	Label (LLR)
0	65	0.458	2004	adaptive capacity (68.49, 1.0E-4); multilevel connection (29.47, 1.0E-4); research framework (25.92, 1.0E-4);
1	49	0.458	2000	catastrophic threshold (35.2, 1.0E-4); concept (38.73, 1.0E-4); multiuse boreal forest (21.1, 1.0E-4);
2	43	0.803	1997	precontact Pacific (59.41, 1.0E-4); social-ecological system (59.41, 1.0E-4); history (24.68, 1.0E-4);
3	41	0.942	1996	Pacific island countries (186.26, 1.0E-4); uncertainty (186.26, 1.0E-4); problem (177.19, 1.0E-4);
4	34	0.841	1993	resilience management (39.41, 1.0E-4); working hypothesis (39.41, 1.0E-4); participatory approach (39.41, 1.0E-4);
5	28	0.762	2003	social-ecological analysis (33.21, 1.0E-4); biodiversity (26.09, 1.0E-4); multilevel water (26.09, 1.0E-4);
6	17	0.967	1994	Canadian Western Arctic community (135.77, 1.0E-4); social-ecological resilience (72.77, 1.0E-4); migration (14.96, 0.001);
7	15	0.92	1992	local ecological knowledge (65.86, 1.0E-4); Racken Watershed (70.19, 1.0E-4); lake (65.86, 1.0E-4);
8	9	1	2001	violence (95.69, 1.0E-4); youth (95.69, 1.0E-4); building community connection (95.69, 1.0E-4);
9	5	0.938	2001	adaptive marine governance (9.35, 0.005); patron-client relation (9.35, 0.005); southern Kenya (9.35, 0.005);
10	4	0.979	1997	sustainable development (42.67, 1.0E-4); world (42.67, 1.0E-4); transformation (21.22, 1.0E-4);
11	3	1	1999	action research (36.43, 1.0E-4); support (36.43, 1.0E-4); theoretical framework (36.43, 1.0E-4);
12	3	0.996	1998	Swedish water management (34.92, 1.0E-4); strategic adaptation (34.92, 1.0E-4); social conflict (34.92, 1.0E-4);
13	2	1	1999	marine social-ecological system (13.1, 0.001); introduction (13.1, 0.001); lagoon (10.33, 0.005);

investigation of how SES frames the practice of research, including choice of variables, choice of analytical strategies, and how this influences the way in which social things are considered.

RESULTS (1): SCIENTOMETRIC ANALYSIS-INTELLECTUAL PROVENANCE OF THE TERM SOCIAL-ECOLOGICAL SYSTEMS

Uses of the term social-ecological

Conceptualizing the interactions between humanity and nature as "social-ecological systems" is an important organizing concept within the emerging approach of sustainability science. The term social-ecological is closely related to the term socio-ecological. (Furthermore, there are permutations in the use of a hyphen). As with many abstract concepts, the use of these terms has evolved in academic literature. The term has been employed in diverse fields (see Appendix A1.2), including: (1) public health; (2) ecology, on species-environment interactions; and (3) within a constellation of fields such as human/social ecology, systems theory, and resilience theory, where the term social-ecological has been coupled with the notion of system to conceptualize the relations between society and nature (Walker et al. 2006). It is this third use of the term that is of key interest in this paper, but the contrasting uses of the term are important to consider as a preliminary to conducting scientometric analysis.

Development of the term social-ecological within academic literature

Before the 1970s there was only single figure use per annum of the keyword social-ecological and its coterms within academic literature (Fig. 2). From the period of the late 1990s, the use of these terms expanded rapidly. For example, between 1974-1999 there were 62 uses of socio-ecological, and between 1999-2013 there were 1787 uses. This increase in the use of terms is consistent with the exponential rise in the number of journal articles being published. From 2004 onward, social-ecological became the dominant term, and from 2006 onward, social-ecological saw a much sharper increase than socio-ecological (Fig. 2). Bibliographic databases produce different tallies because of the variation in journals that they index, but as of end 2013 there were 2381 articles using the term social-ecological and 1404 articles using the term socio-ecological (Table 2).

Origins and disciplinary norms in the use of terms

The above analysis provides some indication of the popularity of the term. Academic knowledge can be organized according to fields of literature, and bibliographic databases permit the grouping of journals into subject categories, which reveal patterns in the use of the two terms.

In the Oxford English Dictionary the earliest occurrences of the forms socioecologic, socioecological, and socioecology are 1970, 1936, 1952. Literature searches concentrated only on title, abstract, and keyword search and show that the phrase social-ecological first became dominant in the field of public health and psychology. Analysis of the period prior to 1990 showed that 86% of articles using social-ecological were in psychology or health-related journals and it was only after 1990 that it showed significant use in the area of environmental sciences. This use of the term within psychology and psychiatry continues, with 13.5%

Table 2. Use of terms by disciplines.

	Records		Records
Social-ecological pre-1990		Social-ecological post-1990	
Web of Science Categories		Web of Science Categories	
PSYCHIATRY	19	ENVIRONMENTAL STUDIES	745
SOCIOLOGY	14	ECOLOGY	538
PSYCHOLOGY EDUCATIONAL	11	ENVIRONMENTAL SCIENCES	447
PSYCHOLOGY	9	PUBLIC ENVIRONMENTAL OCCUPATIONAL HEALTH	251
PSYCHIATRY SSCI	6	GEOGRAPHY	135
PSYCHOLOGY CLINICAL	5	SOCIOLOGY	99
PSYCHOLOGY DEVELOPMENTAL	5	PSYCHOLOGY MULTIDISCIPLINARY	85
PSYCHOLOGY MULTIDISCIPLINARY	5	WATER RESOURCES	74
PLANNING DEVELOPMENT	4	ECONOMICS	69
PSYCHIATRY SCI	4	SOCIAL WORK	66
OTHERS	< 4	OTHERS	< 65
Socio-ecological pre-1990		Socio-ecological post-1990	
Web of Science Categories		Web of Science Categories	
ZOOLOGY	11	ZOOLOGY	241
ECOLOGY	7	ECOLOGY	229
BEHAVIORAL SCIENCES	4	ENVIRONMENTAL SCIENCES	226
INFECTIOUS DISEASES	4	ENVIRONMENTAL STUDIES	206
PUBLIC ENVIRONMENTAL OCCUPATIONAL HEALTH	4	PUBLIC ENVIRONMENTAL OCCUPATIONAL HEALTH	111
SOCIOLOGY	4	BEHAVIORAL SCIENCES	103
MEDICINE GENERAL INTERNAL	3	ANTHROPOLOGY	89
PHILOSOPHY	3	GEOGRAPHY	82
ANTHROPOLOGY	2	SOCIOLOGY	55
BIOLOGY	2	BIODIVERSITY CONSERVATION	49
OTHERS	< 2	OTHERS/ esp. ECONOMICS	< 47

of uses of term in the literature in 2013. At the present juncture, the dominant use of the term social-ecological is in the fields of environmental science, environmental studies, and ecology (Table 2). Of all articles classified, 30% were in the subject category of environmental studies. This classification includes a number of journals that have an interdisciplinary perspective including *Ecology and Society.* In contrast, the term socio-ecological remains most frequently used within the subject categories zoology, ecology, and environmental sciences (Table 2).

The patterns within the corpus of academic literature can be analyzed at a finer scale of academic production. At the level of journals, *Ecology and Society* has the most common use of the term social-ecological (Table 3). In contrast, in *Ecological Economics* use of the term socio-ecological dominates (Table 3). In some cases, it is unclear whether there is a semantic variation in the use of these terms, or whether terms are being used interchangeably because of the lack of a formal, contrasting definition in common practice. It may be that in the fields of environmental and ecological economics a tradition persists in using the term socio-ecological. Arguably, social-ecological can be considered in contradistinction to the term socio-ecological because the syntax of the latter term tends to reduce the social to a component of the ecological.

The term social-ecological is used in 314 articles in *Ecology and Society* with an increase from 6 articles per annum in 2004 to 80 in 2013. Comparing this trajectory with the growth of the total number of publications in *Ecology and Society* within the same time period, both increased at a similar rate until 2011 when there was a more sudden increase in the number of articles using the

Table 3. Use of terms by journals.

	Records	% of total records
Source Titles Social-Ecological Keyword		
Ecology and Society	314	13.08
Global Environmental Change Human and Policy Dimensions	62	2.58
Ecological Economics	37	1.54
Marine Policy	32	1.33
Proceedings of the National Academy of Sciences of the United States of America	28	1.17
American Journal of Community Psychology	26	1.08
Environmental Management	25	1.04
Journal of Environmental Management	23	0.96
Environmental Science Policy	20	0.83
Human Ecology	20	0.83
Source Titles Socio-Ecological Keyword		
International Journal of Primatology	49	3.47
Ecological Economics	31	2.20
American Journal of Primatology	28	1.98
Behavioral Ecology and Sociobiology	27	1.91
Animal Behaviour	26	1.84
Primates	23	1.63
PLoS ONE	18	1.28
Behaviour	17	1.21
Human Ecology	17	1.21
Global Environmental Change Human and Policy Dimensions	15	1.06

term social-ecological than there was the total number of articles published, indicating a "take-off" period in the use of the term.

Foundational texts and deployment of the term social-ecological

The monographs edited by Berkes and Folke (1998) and Berkes et al. (2003) are often referenced as key publications in the modern development of the concept. These contain early formulations of the linkages between social systems and natural systems. Analysis of the cited articles in the papers using the term social-ecological supports this claim, with both monographs appearing in the top 10 most frequently cited references. The data shown in Table 4 is all the more significant, when it is understood that monographs are not well recorded for cocitation. Along with 8+ other publications they constitute an intellectual base within the knowledge domain.

Table 4. Publications most frequently cited in social-ecological articles.

Cited Reference	Frequency (2013)
Folke, C., T. Hahn, P. Olsson, and J. Norberg. 2005. Adaptive governance of social-ecological systems. *Annual Review of Environment and Resources* 30:441-473.	325
Folke, C. 2006. Resilience: the emergence of a perspective for social-ecological systems analyses. *Global Environmental Change* 16(3):253-267.	298
Gunderson, L. H., and C. S. Holling. 2002. *Panarchy: understanding transformations in human and natural systems.* Island Press, Washington, D.C., USA.	288
Walker, B., C. S. Holling, S. R. Carpenter. and A. Kinzig. 2004. Resilience, adaptability and transformability in social-ecological systems. *Ecology and Society* 9(2):5.	255
Berkes, F., J. Colding, and C. Folke. 2003. *Navigating social-ecological systems: building resilience for complexity and change.* Cambridge University Press, Cambridge, UK.	219
Holling, C. S. 1973. Resilience and stability of ecological systems. *Annual Review of Ecological Systems* 4:1-23.	208
Berkes, F. and C. Folke. 1998. *Linking social and ecological systems: management practices and social mechanisms for building resilience.* Cambridge University Press, Cambridge, UK.	200
Ostrom, E. 1990. *Governing the commons: the evolution of institutions for collective action.* Cambridge University Press, Cambridge, UK.	195
Olsson, P., C. Folke, and F. Berkes. 2004. Adaptive comanagement for building resilience in social-ecological systems. *Environmental Management* 34 (1):75-90.	175
Carpenter, S., B. Walker, J. M. Anderies, and N. Abel. 2001. From metaphor to measurement: resilience of what to what? *Ecosystems* 4(8):765-781.	171

Cluster analysis

Network analysis and visualization provide a complementary characterization of the literature. From the author network analysis, Carpenter, S. emerges as having the maximum "betweeness centrality" (0.29; a measure of the importance of a node) corroborating some evidence from the cited reference analysis above about authors bridging between different disciplines. The network analysis of document cocitations produces a visualization formed of 14 clusters. The clusters are formed from papers (nodes) and the links between them from cited references (edges). The overall network has a modularity Q of 0.6594 and a mean silhouette of 0.8378, indicating a relatively distinct and relatively homogenous set of clusters (Fig 3 and Table 1). Labels provide an indication of some of the key themes such as adaptive capacity, resilience, and adaptive governance. Some of the clusters, such as 8 Violence and 11 Action Research appear only loosely connected with the core SES literature.

In conclusion, the scientometric data shows how the term social-ecological has grown and evolved. It is used across a wide variety of disciplines. There are family resemblances between uses of this term. But more recently the term social-ecological systems has taken off and provided a framework for exploring key theories such as resilience, adaptation, and adaptive governance within a range of environment related disciplines. However, the scientometric analysis is not really able to get at the intentions behind the use of the term. For a more detailed examination, we turn to interpretation and use of language in practice, with a review of a major subset of the literature within one journal, *Ecology and Society.*

RESULTS (2): BECKER'S CLASSIFICATION OF SOCIAL-ECOLOGICAL SYSTEMS APPLIED TO *ECOLOGY AND SOCIETY* FINDINGS.

Becker (2012:44) defines SES as a concept that allows "an examination of the system interdependencies between natural and social processes occurring at different temporal and spatial scales." Becker further distinguishes between three ways the SES concept is applied in practice: (1) as a boundary object (Leigh Star 2010), which allows a common frame of reference between natural science and social science disciplines; (2) as an epistemic object, a device to structure research investigations through investigation of systemic qualities, where "system" goes beyond a metaphor for "a compound of things"; and (3) as a defined biogeophysical unit relative to an ecosystem. Becker suggests that the final definition is insufficient for providing system boundaries because other units such as resource systems are relevant for the social component. But perhaps it is implicit that these can be defined relative to a biogeophysical unit.

In the journal *Ecology and Society,* identified earlier as the leading journal using the term, 260 articles utilize the term social-ecological system as a keyword or within the title or abstract. These 260 articles make 5236 uses of the term social-ecological overall. Over 125 different terms are combined with social-ecological, i.e., social-ecological resilience, social-ecological dynamics, etc. Table 5 shows the top 10 coterms. In practice, some scholars use terms other than system such as assemblages, entities, mosaics, networks, inter-relationships, or units. For example, Apostolopoulou and Paloniemi (2012) write of social-ecological entities in biodiversity conservation and Michon (2011) writes of social-ecological units in forestry. Indeed there may be enough latitude in the common use of the term social-ecological system that it does not have systemic connotations.

Table 5. Keyword in context analysis of the term social-ecological.

Rank	Root Term	With	References
1	Social-Ecological	Systems	2569 (in 260 sources)
2	Social-Ecological	System	738 (in 180 sources)
3	Social-Ecological	Resilience	333 (in 94 sources)
4	Social-Ecological	Research	119 (in 22 sources)
5	Social-Ecological	Change	67 (in 33 sources)
6	Social-Ecological	Interactions	42 (in 20 sources)
7	Social-Ecological	Processes	38 (in 24 sources)
8	Social-Ecological	Factors	34 (in 11 sources)
9	Social-Ecological	Dynamics	33 (in 45 sources)
10	Social-Ecological	Networks	22 (in 6 sources)
-	Acronym SES		(in 75 sources);

Boundary object use

First, drawing on Becker's classificatory system (Becker 2012), our content analysis revealed that the majority of uses of the term SES are as a boundary object (> 60%; Table 6). In these cases, the term is being used to indicate a concomitant interest in analyzing both natural and social components of life on earth. Walker et al. (2012) highlight uses of the term SES that fail to articulate the concept of a system, neither identifying which components are included, nor where the boundary is drawn. However, this criticism can by no means be applied to all uses of a SES as a boundary object. For example, the treatment of the term may be less detailed simply because the goal of a study is to compare SES with some other concept or framework for explaining interactions, for example Gotts (2007) on world system theory, or Stokols et al. (2013) on social ecology.

Table 6. Content analysis of use of SES term in *Ecology and Society* articles.

Classification (Becker 2012)	Source Articles (n = 260)	Proportion of Source Articles (%)
Boundary object	159	61.2
Epistemic object	61	23.5
Defined biogeographical unit	27	10.4

Note: not mutually exclusive because one article may use the term in a variety of ways

Epistemic object use

Second, there are uses of the term that make a more formal definition of system. One indication of this, is the extent to which they employ systems terms. Some conceptual distinctions may be made about terms, with possible consideration of the methodological implications that arise (Becker 2012). For example, Anderies et al. (2004) delineate agents, interactions, and physical substance components of SES.

Defined system use

Third, there are uses of the term where it is applied to a biogeophysical unit with associated social components. This is challenging to confidently interpret from a journal manuscript alone, but a generous estimate is that ~10% of cases provided this level of definition. This is more than a simple invocation of a place-name or a case study. Some evidence of configuration in systems terms is required to qualify. For example, Atwell et al. (2008) conceptualize a U.S. Corn Belt agro-ecosystem through hierarchical systems of regional regulation, social networks, and farming practice within a county of the state of Iowa, relative to three watersheds.

Social components: patterns in the literature

Considering this literature overall, there is a marked emphasis on certain themes. Certain social components are commonly considered within these operationalizations of SES:

1. Focus on institutions, i.e., institutional-ecological systems such as resource systems or governance systems. Focus on governance, property, and access elements of social systems, including rules that resource harvesters use in practice.
2. Focus on economic incentives in ecosystems, e.g., payment for ecosystem services.
3. Focus on social interactions in social networks, at a scale below national societies, drawing on agent-based and systems dynamic modeling.
4. Focus on population or on landscape/land use as the biophysical infrastructure of society, and the role that humans play as living beings who remake the natural world.
5. Focus on hybrid ecological networks, e.g., irrigation systems or industrial agriculture.
6. Exploration of complex adaptive systems through Bayesian models, agent-based simulation, neural networks, fractal analysis, cellular automata, chaos theory, and fuzzy logic.
7. Focus on social learning, including learning as an emergent property, with some related work on the role of scenarios in social learning. (Arguably, this final aspect is an example of social-ecological systems drawing on social theory).

The patterns shown above align with the insights raised in the introduction and literature review. SES is strongest where (1) institutional/political administrative subsystem, or (2) economic subsystems or (3) social networks are the coupled social component under consideration. In addition, where the "material" component of society is under consideration, such as with (4) land use or (5) hybrid ecological networks. Thus in synthesis studies or when there is an attempt to explicitly look at the dynamics of coupled SES, a systems ontology seems to affect which components of society are under consideration.

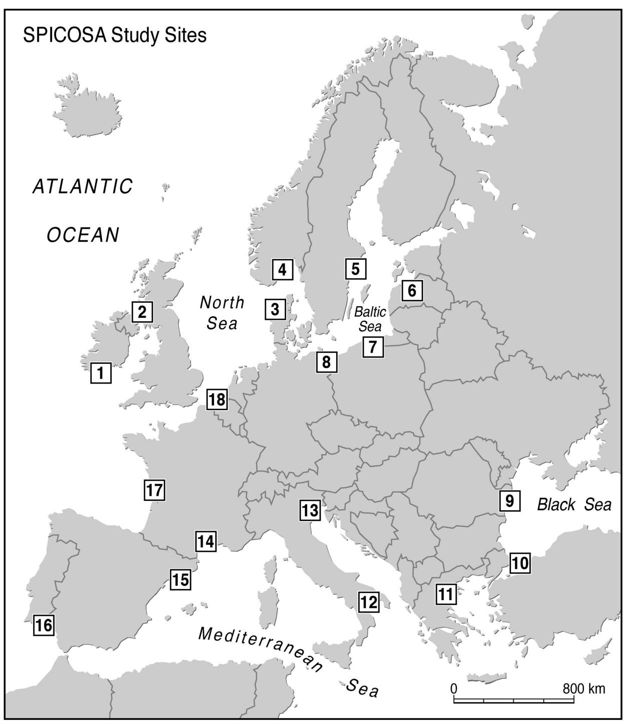
In contrast, there seems to be little evidence to support comprehensive representation of emergent features of culture and society. Thus, although such issues as trust, power, or deliberation can be considered within a systems dynamic framework (Janssen et al. 2012), behavioral experiments by definition bracket culture and society rather than make a deep exploration that would reveal emergent influences (Trosper 2005). Although there are many analyses that include culture, more often this is undertaken in a social-ecological perspective that departs from a systems ontology.

These apparent patterns within a corpus of literature are reviewed in the following results section at the level of a large-scale interdisciplinary research project. Analysis of an individual research project allows exploration of the implications of taking a systems approach for the practice of science. This is important for understanding not just which social themes dominate in SES research, but why and how they have become dominant.

RESULTS (3): META-ANALYSIS OF SYSTEMS APPROACHES IN A LARGE SCALE RESEARCH PROJECT ON COASTAL ZONES.

The EU FP6 SPICOSA research project applied a systems approach (Tett et al. 2011) to 18 case study coastal zones of Europe. These case study zones were selected for representativeness of major coastal regions of Europe: Baltic, North Sea, Atlantic coast, Mediterranean Sea, and Black Sea (Fig. 4). Two additional criteria were significant. Each case study area faced future scenarios with policy implications for sustainability (e.g., projected 50% expansion in recreational activity, Case Study #2), and it was a proviso of the research program that studies should consider economic, social, and environmental components of the coastal zone system. Findings are reported in special issues of *Ecology and Society* and *Marine Policy* (see Table 7). We focus on reviewing how "the social" was considered as part of an interdisciplinary research project, based on a systems approach.

Fig. 4. Science Policy Integration for Coastal Systems Assessment (SPICOSA) case study sites.



1. Cork Harbour	**7.** Gulf of Gdansk	**13.** Venice Lagoon
2. Clyde Sea	**8.** Oder Estuary	**14.** Thau Lagoon
3. Limfjorden	**9.** Danube Delta	**15.** Barcelona Coast
4. Sonderled	**10.** Izmit Bay	**16.** Guadiana Estuary
5. Himmerfjarden	**11.** Thermaikos Gulf	**17.** Pertuis Charentais
6. Gulf of Riga	**12.** Taranto Mare Piccolo	**18.** Scheldt Delta

Within SPICOSA, social components were included either within a single model, or as a separate subcomponent, integrated within a wider modeling structure. The identification of a key policy issue by scientists and stakeholders (see second column of Table 7) enabled the research to focus which components of the system were under consideration.

Conceptualizing the social

In practice, most of the social components included were either economic or easily quantifiable, such as employment, visitor numbers, or other measures of human activity (see third column of Table 7). An important influence was the need to link model components. For example, well-being was commonly expressed in economic terms, primarily because monetary units are compatible with numerical modeling. Thus a systems approach encouraged particular types of social investigation. Other reasons for the choice of social variables were influential, such as the level of involvement of stakeholders; the current expertise of scientists involved; and political setting of the research project (Tett et al. 2013). But although these influences could conceivably have pushed the research in the direction of considering more quantitative or qualitative social variables, none of these influences appear to overcome the challenge to dynamically link social and ecological components.

Therefore, the need to link ecological and social subsystems may tend to rule out those variables that are not easily quantified. In consequence, variables such as power, influence, rationality, and happiness are not commonly used. However, there are some notable exceptions within the case studies, and the approach captured more social variety than the critique outlined in the earlier literature review would allow. First, subjective perceptions of the environment, in terms of aesthetic benefits arising from outputs of ecological subsystems were considered in case studies #4 and #15. Second, levels of social conflict arising from different relative uses of ecological resources were considered in case studies #1 and #17. For example, case study #15 considered the recreational appeal of beaches, and case study #17 reviewed the interpretations of management solutions by fishers and farmers. Yet, in the cases where this did happen, validating the social variables involved recourse to research that was "interpretive" or "critical" rather than systems based. Such research involved (1) exploring the fundamental categorizations used, instead of testing for causal explanations; or (2) testing the plausibility or social significance of historical narratives or future scenarios, instead of validating differential equations that infer a rate of change. These findings reinforce aspects of the critique considered in the literature review.

Understanding social change

The modeling approach did encourage an understanding of the direction of social change in a number of cases, reinforcing the value of a dynamic approach (see fourth column, Table 7). Arguably, the most convincing explanations of the social component went beyond measures of human activity, to consider social drivers such as cultural identity. For example, case study #12 explored phenomena such as social deprivation and illegal fishing, whereas case study #4 explored the phenomena of second home ownership. In order for these cases to consider such social phenomena in a dynamic manner, this required a loosely coupled approach. This commonly entailed stakeholders discussing the

Table 7. Social components in a systems approach (SPICOSA).

Case Study Site	Policy Issue	Social Variables (economic variables not shown)	Social Dynamics	Journal Article
1. Cork Harbour	Marinas and N-loading	Physical infrastructure (marina) Access to harbour or coast. Level of conflict between harbor users	S→E→S Recreational opportunity driving infrastructure development causing water quality issues raising user conflicts	-
2. Clyde Firth/ Loch Fyne	Aquaculture and marinas	Boating (moorings and visiting vessels) Employment Tourism visits Land use	S→E Recreational boating pressure on nutrient loads	Tett et al. 2012
3. Limfjord	Mussels and N-loading	Fisher behavior Fishing effort Mussel farming effort	E→S Impacts of reduced nutrients on mussel competition and related human activities	Dinesen et al. 2011
4. Risor Fjord/ Søndeledfjorden	Cod and recreational fishing	Tourist visitors by type Boat Visitors Fishing effort Angling effort Second home development Landscape quality	S→E Second homes giving rise to increased angling activity exacerbating fishing pressure on stocks, plus conflict.	Moksness et al. 2011
5. Himmerfjarden	Water quality and sewage	Local population Levels of participation and collaboration with policy measures	S→E Impacts of sewage treatment and wetland creation on nitrogen loads.	Franzén et al. 2011
6. Gulf of Riga	Fishing	Fishing effort Recreational opportunities Cultural heritage and identity	E→S Impact of reduced fish stocks on recreational fishing activity	-
7. Gulf of Gdansk/Vistula Lagoon	Water quality and tourism	Tourism visits Tourism employment Beach user preferences	E→S Impacts of nutrient and pollutant loads on beach user preference	-
8. Oder-Szczecin	Aquaculture and N-Loading	Mussel farming activity Tourist numbers	S→E Impacts of mussel farming activity on nutrient loads and potential for tourism subsidy	Schernewski et al. 2012
9. Izmit Bay	Water quality and real estate	People's preference and satisfaction with water quality	S→E Impacts of urbanization and industrialization on water quality	Gamze Tolun et al. 2012
10. Varna Bay/ Danube Delta	Water quality and tourism	Tourist visits (overnight stays) Tourist perception of water quality Tourism employment	S→E Impacts of tourism development on water quality	Moncheva et al. 2012
11. Thermaikos Gulf	Mussels and fishery	Perceptions of aquaculture products Mussel production Local employment Access rights	S→E→S Impacts of mussel farming techniques on environmental quality and resultant mix of activities contribution to regional welfare	Konstantinou et al. 2012
12. Taranto Mar Piccolo	Mussels and waste discharge	Illegal fishing activity Public perceptions of mussel quality Aquaculture employment	S→E→S Social deprivation driving illegal mussel farming reducing mussel quality. Farming driving demand for mussels and impacting mussel farms..	Caroppo et al. 2012
13. Venice Lagoon	Clams and fishery	Employment Fishing effort (clams per day, area zoned for aquaculture)	S→E→S Sustainability of clam fishing in the face of natural cycles and competing uses	Melaku Canu and Solidoro 2014
14. Thau Lagoon	Seafood and pathogens	Land use Population Tourism activity Shellfish farm activity	E→S Impacts of microbial contamination on fish farms and tourism	Mongruel et al. 2013
15. Barcelona Coast	Discharges and beach quality	Beach occupancy Recreational appeal of beaches Beach visitors aesthetic perceptions	E→S Stormflow delivery of waste and litter to beach affecting tourist aesthetics	Tomlinson et al. 2011
16. Guadiana/Ria Formosa	*E. coli* and bathing	Tourism employment Population Social benefits (Blue Flag Status) Beach demand (number of visitors) Fish Landings	E→S Impacts of extraction and sewage discharge on water quality, beach users, and beach awards	Guimarães et al. 2012
17. Pertuis Charentais	Freshwater and agriculture	Agricultural activity Angling activity Water extraction (consumption and agricultural irrigation) Well-being Intergroup conflict	S→S→E Competition between human activities and land use, for space and freshwater extraction causing crisis events for water supply	Mongruel et al. 2011
18. Scheldt	Agriculture and N-Loading	Farming activity (area, numbers) Willingness to participate in environmental measures	S→E Agricultural pressure on nutrient loads	Vermaat et al. 2012

implications for social entities of the outcomes of dynamic models, rather than the social components being included within the systems analytical framework itself (Tett et al. 2013).

Patterns at the level of a systems-based research project

Conclusions at the level of a research project show the methodological implications of taking a systems perspective. Although from the scientometric and content analysis of the literature, patterns emerge that show an emphasis on key topics or certain social subsystems, at the level of an integrated research project it becomes methodologically apparent why certain social themes are dominant. These implications arise from the challenge of operationalizing SES in ways that can meaningfully represent systems dynamics. The consequence is similar in both cases: preference for certain social variables and undertheorization of the social. However, the inclusion of variables such as social perception of aesthetics hints at some ways in which these neglected social components might be loosely coupled with a systems approach.

CONCLUSION

This paper provides evidence that, from its growth in the 1970s, the term social-ecological and its coterms have become a dominant way of conceptualizing nature-society interactions. Scientometric and network analysis shows that the term social-ecological systems has relatively homogenous corpus of literature in a broad set of disciplines. Different terms are common in different disciplines. *Ecology and Society* is a leading journal. SES has some foundational texts from the late 1990s. A "take-off" period occurred late in the first decade of the 21st century. Meanwhile the content analysis delineates different uses of the term SES in practice. It provides evidence for wide use of the term as a boundary object, but less evidence of the term applied to a biogeophysical unit with associated social components. Key issues are being explored such as adaptive capacity, resilience, and adaptive governance. SES is proving a highly productive term to consider certain social components such as institutions, economic systems, social networks, land use, hybrid ecological networks, and social learning. Other social components are somewhat neglected within synthesis studies. This affirms the critique in the literature about adequacy of explanatory power and adequacy of scope of conceptualization of SES. On the other hand, findings from the content analysis and the review of case studies show that conceptualizations of SES do have a broader methodological base than most critiques allow. Analysis of 18 systems-based assessments from a multisite study of coastal sustainability shows some limitations in social investigation, but demonstrates the benefits of a dynamic approach and hints at possibilities of loose-coupling.

Now, to address the core question raised at the start. Walker et al. (2006) make the summary proposition that "The ecological and social domains of social-ecological systems can be addressed in a common conceptual, theoretical, and modeling framework." From the perspective of this research paper, it might be better to ask whether all components of the social domain can be addressed within a general systems framework. The findings of this research are mixed in this regard.

On the constructive side, conceiving of society and its components as a system enables a holistic approach that embraces complexity. It provides a framework for interdisciplinary research and heuristic devices for social learning. Furthermore, a number of components of society are particularly amenable to conceptualization as system, including economic systems, and functional subsystems such as institutions for administration and policy making. The potential for systems conceptualization of hybrid nature-culture spaces seems particularly promising, such as land use, land tenure, and ecological infrastructure. Here, SES as presently conceived, remains highly relevant and useful.

On the problematic side, the social-ecological systems concept neglects critique in the social sciences that certain elements of society are less amenable to conceptualization as systems, and therefore undertheorizes social entities and processes. People's intentions, as reflected by their interpretation of worldviews and traditions, cultural norms and relations, power dynamics within civil and political spheres, role formation, and personality, have a strong bearing on the development of society and its components, i.e., the reasons why humans pursue life in a collective. The implications of neglecting their analysis will be most seriously felt in the transition from research and theory to action, when particular solutions become privileged. Although the presentation of dynamic modeling in participatory context (Lynam et al. 2002, Jones et al. 2009) might go some way toward ameliorating these issues, it evades major traditions in social research that might contribute to this understanding.

DISCUSSION AND GROUNDED SPECULATION

We conclude with some alternative options for future research directions:

- Let SES function as a productive boundary object (or simple heuristic). In line with the claim of Binder et al. (2013) at the beginning of this paper, social-ecological systems may well be considered the most useful term for sustainability research that recognizes dynamic linkages. This allows for systems to function as a loose metaphor, without worrying about precise definitions, but ignores the critique above.
- Be explicit about SES linking to certain social domains. This would clarify the core social subcomponents under consideration, and might entail more precise use of terminology, e.g., institutional-ecological systems.
- Reformulate SES as S^2ES, depending on the goals and context of the research. Here S^2 refers to both systems-based approaches, and social research that departs from a systems ontology but can be integrated into interdisciplinary understandings. This would highlight the benefits of combining both systems and critical approaches in the social domain. It could draw on the variety of frameworks that human sciences have used, without adherence to a systems-based perspective, to explore the relationships between human societies and the biophysical environment. Such methodological variety is already commonplace within journals such as *Ecology and Society*. However, its synthesis is not a trivial matter. It would entail using a variety of diagnostic approaches that draw on both social theory and dynamic ecological theory, and coupling of approaches that have different foundational assumptions. Evidence from the content analysis in this paper shows that the nature of these loose couplings remains a major question for interdisciplinary research.

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[1] Although social systems remain subject to the same thermodynamics and most of the ecological principles that govern ecosystems, not least because they involve human bodies, it would be a philosophical assumption to state that social processes are structured by bottom-up rather than top-down mechanisms. Bottom-up assumptions tend to render social processes as primarily subject to the fluctuations of physical and biological processes.
[2] Methodologically there is currently an emphasis in social science on measuring values, motives, and opinions of individuals and groups, at basic levels of social interaction (Bauman 2004).
[3] Other core insights from the philosophy of social science include the relatively enduring nature of social phenomena in time and space, which become sealed in history and gain a certain form of intransivity (Bhaskar 1978); the dependence of social interactions on media such as money, cultural values, or social influence rather than simply throughputs such as energy or material (Habermas 1984); and the self-reflexivity of the human species whereby actors interpret their actions according to the meanings that they subscribe to them, and the motivations that attend their actions (Bourdieu and Wacquant 1992, Giddens 1993).
[4] Critical theory is used here to describe a range of approaches to scholarship, where social theory is used to study aspects of society, whereby these are studied along with critical theories that are used as a way of making value judgements on cultural phenomenon themselves. Examples of critical theories might include Marxism, feminism, or poststructuralism. These approaches are common in subdisciplines such as political ecology or cultural geography.
[5] Naturalism is used here to describe a position in the philosophy of science that sees a fundamental unity in the principles of natural and social sciences. In contradistinction, antinaturalism posits fundamental differences between natural and social sciences based on the differentiation of their subject matters.
[6] Web of Science has a preponderance of journal publications and therefore favors the sciences over the social sciences/arts and humanities. But Web of Science has very good coverage of English language journals and international publications over a long time period, and so is suitable for our analysis.

Responses to this article can be read online at:
http://www.ecologyandsociety.org/issues/responses.php/8633

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Appendix 1. Visualization: detailed methodologies.

What is the goal of the visualization and analysis?

- The visualization and accompanying metrics allow an overview of the major areas of research of those articles classified with the term 'social-ecological systems.' The input dataset was sourced from Web of Science. For the author-network, the metric 'betweeness centrality' gives an indication of the importance of key nodes. For the cited reference network, 'modularity Q' and 'mean silhouette' metrics provide an indication of the overall structural properties of the network.

How was the visualization conducted?

- The analysis and visualization were conducted using the software Citespace, version 3.8R1 (Dated 6 January 2014).

Which assumptions and methods have been used in generating the visualization?

- Clustering- identification of prominent groupings- is performed using a smart local moving algorithm (Waltman & Van Eck 2013).
- The clusters allow the identification of core themes within the literature. Time slicing was set at one year intervals.
- Labels for the clusters were based on 'noun-phrases' taken from the titles of co-cited papers.

How were the metrics selected and can they be justified?

- Table A1.3 below shows the outputs of three approaches to automatically generating labels for the clusters, drawing on terms found the titles of all the co-cited papers in each cluster. Term Frequency Inverse Document Frequency (TFIDF), Log Likelihood Ratio (LLR) and Mutual Interactions (MI).
- In our judgement the labels do not show strong dissimilarities, and Log Likelihood Ratio provides the best combination of unique aspects related to each cluster, whilst also providing a breadth of indication of topics within the theme. Hence our choice to include LLR in Figure 3.

Table A1.1 Analytical strategies for scientometric analysis

Issue	Strategy
Hyphenated words:	Both databases treat searches for hyphenated words similarly: social-ecological will find both social-ecological and social ecological
Boolean searching	Terms were combined with the OR operator to ensure all forms of the word were accounted for e.g. socialecological OR social-ecological
Variant endings	Truncation was used to find variant endings e.g. ecolog
Publication types:	Search was refined in both databases to only include the document type (journal) 'articles'
Phrase Searching	Used for "Social-ecological systems"
Fields Searched	Topic search in Web of Science which equates to the Title, Abstract and Keyword search available in Scopus
Time period	From the earliest record in the index to end of 2013
Analysis options	By publication year, by source (journal title) by subject category (discipline of journal)

Table A1.2 Broad categories of the use of the terms socioecological and socialecological

Fields	Meaning
Public health and psychology	Health of individuals within wider contexts
Ecology	Interactions of species within their environment
Human Ecology/ Resilience Theory/ Complex Adaptive Systems	With '-system' to conceptualise an entity made up of interacting biogeographical and social components

Table A1.3 Comparison of output metrics for Labelling Clusters: Term Frequency Inverse Document Frequency (TFIDF), Log Likelihood Radio (LLR) and Mutual Interactions (MI)

ClusterID	Size	Silhouette	mean(Year)	Label (TFIDF)	Label (LLR)	Label (MI)
0	65	0.458	2004	(12.68) multi-level connection; (10.72) collaborative design; (10.72) management system; (10.72) rhine basin; (10.72) informal participatory platform	**adaptive capacity** (68.49, 1.0E-4); multi-level connection (29.47, 1.0E-4); research framework (25.92, 1.0E-4);	complex adaptive network
1	49	0.458	2000	(9.48) catastrophic threshold; (8.11) synthesis; (8.04) forest; (8.02) multi-use boreal forest; (8.02) interlocking panarchies	**catastrophic threshold** (35.2, 1.0E-4); concept (38.73, 1.0E-4); multi-use boreal forest (21.1, 1.0E-4);	british columbia
2	43	0.803	1997	(12.68) pre-contact pacific; (9.5) history; (9.5) urban cultural landscape; (9.5) biodiversity-rich; (8.68) rural people	**pre-contact pacific** (59.41, 1.0E-4); social ecological system (59.41, 1.0E-4); history (24.68, 1.0E-4);	building resilient social-ecological system
3	41	0.942	1996	(12.68) atoll countries; (7.21) pacific island countries; (7.21) uncertainty; (6.52) countries; (3.69) problem	**pacific island countries** (186.26, 1.0E-4); uncertainty (186.26, 1.0E-4); problem (177.19, 1.0E-4);	urban delta
4	34	0.841	1993	(10.72) resilience management; (10.72) working hypothesis; (10.72) participatory approach; (7.64) understanding complex eco-social interaction; (7.64) diagrammatic approach	**resilience management** (39.41, 1.0E-4); working hypothesis (39.41, 1.0E-4); participatory approach (39.41, 1.0E-4);	building resilient social-ecological system
5	28	0.762	2003	(8.68) global collaboration; (8.68) open source; (8.68) social-ecological research; (8.68) open content; (7.03) interplay	**social-ecological analysis** (33.21, 1.0E-4); biodiversity (26.09, 1.0E-4); multilevel water (26.09, 1.0E-4);	collaborative focus
6	17	0.967	1994	(10.45) canadian western arctic community; (4.12) social-ecological resilience; (2.87) migration;	**canadian western arctic community** (135.77, 1.0E-4); social-ecological resilience (72.77, 1.0E-4); migration (14.96, 0.001);	resilience

7	15	0.92	1992	(4.2) local ecological knowledge; (4.2) dynamic; (4.2) sweden; (4.2) racken watershed; (4.2) ecosystem	**local ecological knowledge** (65.86, 1.0E-4); racken watershed (70.19, 1.0E-4); lake (65.86, 1.0E-4);	racken watershed
8	9	1	2001	(11.63) violence; (11.63) youth; (11.63) building community connection; (1.9) building;	**violence** (95.69, 1.0E-4); youth (95.69, 1.0E-4); building community connection (95.69, 1.0E-4);	...
9	5	0.938	2001	(4.04) marine governance; (3.41) planning; (3.35) fisher; (2.38) communities; (2.38) fisheries	**adaptive marine governance** (9.35, 0.005); patron-client relation (9.35, 0.005); southern kenya (9.35, 0.005);	resilience
10	4	0.979	1997	(8.68) sustainable development; (4.04) transformation; (3.35) development; (3.35) world; (2.7) adaptive capacity	**sustainable development** (42.67, 1.0E-4); world (42.67, 1.0E-4); transformation (21.22, 1.0E-4);	resilience
11	3	1	1999	(7.64) support; (7.64) theoretical framework; (7.64) school; (4.22) action research; (2.95) framework	**action research** (36.43, 1.0E-4); support (36.43, 1.0E-4); theoretical framework (36.43, 1.0E-4);	...
12	3	0.996	1998	(7.64) strategic adaptation; (7.64) social conflict; (7.64) swedish water management; (2.95) conflict; (2.38) social-ecological resilience	**swedish water management** (34.92, 1.0E-4);strategic adaptation (34.92, 1.0E-4); social conflict (34.92, 1.0E-4);	social-ecological resilience
13	2	1	1999	(2.38) social-ecological system; (1.01) system;	**marine social-ecological system** (13.1, 0.001); introduction (13.1, 0.001); lagoon (10.33, 0.005);	social-ecological system