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Socio-Environmental Systems (SES) Research: what have we learned and how can we use this information in future research programs

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The call for integrated social–environmental science, complete with outreach to applications and solutions, is escalating worldwide. Drawing on several decades of experience, researchers engaged in such science, completed an assessment of the design and management attributes and impact pathways that lead to successful projects and programs and to understand key impediments to success. These characteristics are delineated and discussed using examples from individual projects and programs. From this, three principal lessons leading to successful efforts emerge that address co-design, adaptive or flexible management, and diversity of knowledge. In addition, five challenges for this science are identified: accounting for change, addressing sponsorship and timelines, appreciating different knowledge systems, adaptively communicating, and improving linkages to policy.

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Introduction

Social–environmental change is explosively accelerating worldwide. This change holds significant implications for the sustainability of the earth system and its inhabitants.

Over the last decades, repeated calls have been made for a new paradigm for environmental research to address the sustainability challenge [1–3]. This new paradigm involves greater responsiveness to societal needs in choosing priorities for research; setting explicit goals for producing 'usable' knowledge; implementing integrative social–environment systems (SES; aka social–ecological systems) research approaches; coordination with policy makers and agencies to promote the integration of evidence into policy processes; and more emphasis on long-term, place-based monitoring and analysis of SES.

Embedded within this grand challenge, accelerated efforts are underway to assemble and deploy teams of investigators from diverse disciplines to address issues related to protecting our natural resources while provisioning humankind, now and in the future, in a changing world [4,5]. The integrated science directed to these efforts, often labeled sustainability science, is championed by various international programs, such as Future Earth [6]. This science frames problems in terms of SES and involves experts grounded in diverse disciplines and praxes collaborating to understand the operation these systems and the impacts associated with their change. A substantial history of such research efforts has emerged over the past decades, expanding beyond science-based understanding of SES to more solutions-oriented research and action [7–9].

As more resources are devoted to such work, examining the lessons learned from existing efforts is useful to inform the crafting of future efforts. What follows is a review of a sample of cases of SES projects undertaken over the last few decades, including recent and ongoing efforts, which are probed and analyzed for the elements that led to their success as well as the pitfalls that hindered their progress. Our sample includes analyses of programs focused on some combination of understanding a SES problem, developing and implementing a solution to an environmental problem, and funding integrated social–environmental science efforts. These case studies appear as a collection in this special feature of *Current Opinion in Environmental Sustainability*.

To undertake this review, authors involved in the case study analyses of the various projects and programs came together in Annapolis, MD at the National Socio-Environmental Synthesis Center (SESYNC) to hear the results of all cases from those who produced them. Researchers involved with each case were asked to address the conceptual design, management, and impact or consequences of their projects. Group discussions by the SESYNC participants (the authors of this paper) probed each of the cases for the lessons learned, seeking to identify general lessons crossing the cases and serving as insights for any future efforts of these kinds. From this, broader discussions of the factors that facilitate team collaborations for socio-environmental research ensued, which also drew from projects facilitated by SESYNC [10].

The outcomes of this effort follow. First, the major characteristics of project design, management, and impact emanating from the case studies and SESYNEC projects are reported. On the basis of this foundation, the cross-cutting lessons learned and challenges remaining for integrated social–environmental science projects, especially directed at sustainability issues, are identified and briefly discussed.

Project design, management, and impact

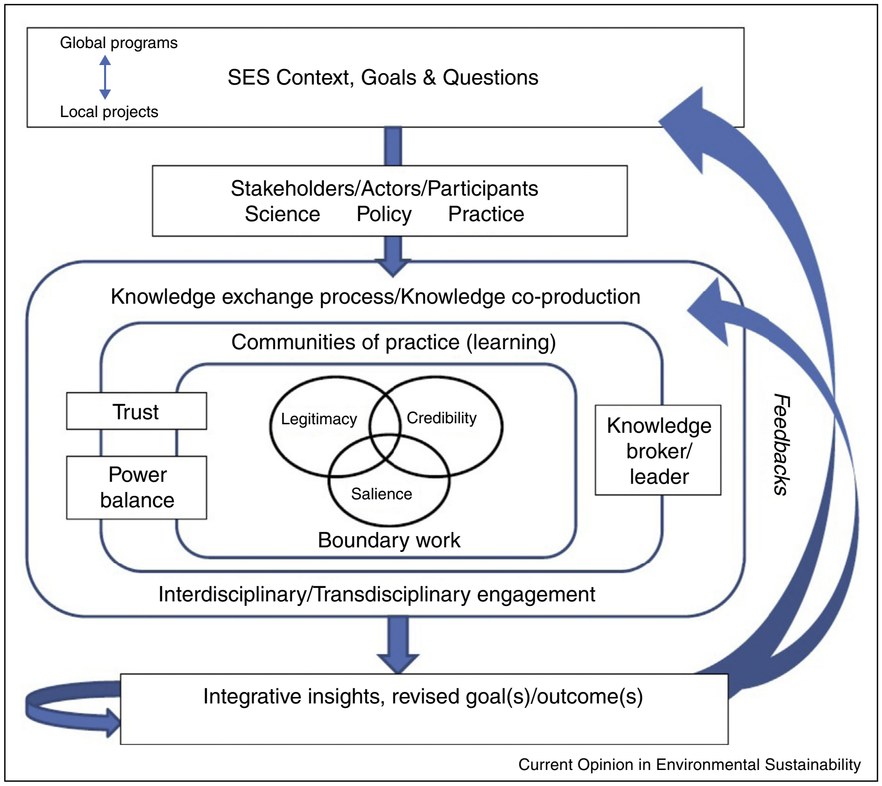
Integrative SES research projects, both science and outreach driven, and programs supporting them maintain somewhat common frameworks captured in Figure 1 and Box 1. A number of foundational issues, consistent with the framework (Figure 1) were apparent during the initiation of the integrated projects. These issues can be divided into three broad groups: first, those relating to the conceptual design of the project, including formulating the goals of the project and the different disciplines and stakeholders necessary for achieving these goals; second, those relating to the management of the project, including planning for overcoming common obstacles and flexibility to accommodate unforeseen developments; and third, those relating to ensuring that the project has impact consistent with its goals.

Conceptual design

Different disciplinary lenses and stakeholder objectives shaped different views about the problem in hand and means to address it. The shared interest in the SES approach, however, required attention to accounting for and integrating these differences in the design phase [20]. The cases examined demonstrated the benefits associated with broadly engaging the natural and social sciences to understand environmental phenomena, their SES consequences, and identifying solutions. Attention was paid to project (co)design, leadership, and facilitation of dialogue among project participants, since differences in terminology, worldviews, and goals existed among the researchers and between them and stakeholders [21,22]. Different disciplinary lenses shaped the design and implementation of the projects, as did different stakeholder objectives in cases of projects with outreach to practice. This inclusiveness added complexity to program management (below) but generated novel insights, findings, and solutions.

Clear program goals, questions and frameworks underpinned information collection, analysis, and stakeholder involvement in the cases [7]. In some cases, designing broad questions at the start of a project allowed the appearance of lower-level objectives [20,23,24], or initial goals evolved or enlarged through time, with the greater

Figure 1



A framework for integrated SES research projects.
Modified from N Sitas, PhD thesis, Stellenbosch University, 2014.

acquisition of data/knowledge and application of new analytical tools and technologies [10,25,26]. Funding constraints and/or unanticipated external influences (e.g., new laws or environmental regulations), however, changed goals or their relative importance in at least one project [27].

Implementation and management

The ways in which the projects' conceptual design were operationalized — managed and governed — profoundly influenced the success of the programs. For the most part, management and governance were inclusive in order to account for differences in culture, epistemology, and motivation among the research units and between those units and partners in other sectors of society, even though transaction costs often increased as these differences increased. The perceived legitimacy of different partners within key decision processes (e.g., project design, choices in methodology, research collection and analysis, data interpretation, and information products) had significant impacts on the evolution of the project and the impact of project goals. These differences, which often were linked to the dynamics of power and control within the project, influenced everything, including how (and what kinds of) data and related information were produced, exchanged, analyzed, synthesized, and validated over the course of the project.

Legitimacy anchored in trust-building and power-sharing both between researchers within a project as well as between researchers and stakeholders is well known to contribute to successful interdisciplinary and transdisciplinary collaborations (e.g., [19•]) and was evident in a number of the case studies in this issue [28,29]. Trust building began during project development, in some cases starting from low levels of trust [30], often linked to senior–junior researcher or interunit power differentials [24], and was maintained or improved throughout project implementation through cooperative activities [22,31]. The ability and willingness to listen to different interests and perspectives, shape the research to incorporate the differences into a coherent whole, and in some cases compromising to reach common outreach goals proved to be central. In most cases, no single group's goals or agenda took full precedence over those of other groups [23,28], and in a few cases the benefits gained by legitimacy changed the preconceived experimental design or planned intervention [32,33].

Box 1 A framework for integrated SES research projects

The framework presented in Figure 1 is applicable to integrated social–environmental science research and programs. It outlines the general factors and processes that the studies within this special feature found to be critical for the success of such activities. It provides a conceptual and practical approach to co-designing and undertaking interdisciplinary and transdisciplinary and action-oriented science.

Project outcomes result from extensive co-production of knowledge, and knowledge exchange processes mediated through interdisciplinary and transdisciplinary engagement. The knowledge-exchange processes recognize the perspectives of various stakeholders within a specific social–ecological context or problem-framing, integrating knowledge originating from science, policy and practice. Extensive research from the fields such as cognitive psychology, learning science, interdisciplinary studies, and the science of team science has contributed significantly to understanding when and why interdisciplinary and transdisciplinary teams productively collaborate (e.g., [11,12•,13]). The co-production and exchange of knowledge, which we view as 'the collaborative process of bringing a plurality of knowledge sources and types together to address a defined problem and build an integrated or systems-oriented understanding of that problem' [14,15], is facilitated by knowledge brokers or leaders (organizations or individuals) who link different stakeholders and assist with interaction and engagement across disciplinary or institutional boundaries [16]. Such boundary work is facilitated by careful attention to issues relating to credibility, legitimacy and salience [17]. A communities-of-practice model of engagement, which is comprised of communities of practitioners with a shared domain of interest, greatly assists with ongoing problem solving and knowledge sharing through the building of trust [18•]. The role of power inherent in such knowledge exchange processes — where different knowledge holders can influence both the ways in which knowledge is produced and exchanged — and the results that are possible, are acknowledged and carefully balanced [19•].

While presented linearly, the processes illustrated in Figure 1 are ongoing and nonlinear, with feedbacks between the knowledge-exchange processes, social–ecological context and outcomes of such processes.

Definitions:

Interdisciplinary: synthesis that integrates knowledge and methods from different disciplines.

Transdisciplinary: unity of intellectual frameworks that transcend disciplines and involves stakeholders.

Projects and programs in this collection of case studies all employed a thoughtful and respectful process of flexible management and trust building to meet project objectives and navigate various problems (Box 1). Considerable energy was expended on timely, high quality, multi-directional communication among project components and teams, often involving face-to-face interactions [7,10,27], giving project members the autonomy and authority to contribute and generating transparency in project operations [22,25,32]. For example, an Alaskan project [28] promoted engagement of leaders within the stakeholder communities (Native American communities) that was critical in building legitimacy and trust. A project in South Africa was confronted by issues of focus, as some members were attentive only to their subset of the larger project [33]. In contrast, a southern Yucatán case [24] involved clear delineations of responsibilities around distinct project tasks (e.g., remote sensing, nutrient cycling and farmer decision-making). These tasks, however, were co-located such that individual unit products were linked to one another, thereby facilitating disciplinary integration and the detection of emergent properties (e.g., the role of fire in agricultural management and landscape change). In yet another case [23], a research network designed for flexible and decentralize collaboration encouraged self-organization around topics of mutual interest.

Management was often affected by funding, and funding models for the projects and programs were highly variable, reflecting a collection of experiences that encompassed different scales of time and space [7] (see Challenge 2 below). In some cases, the funding units broadened the goals of the project and expanded expectations of outcomes [33]. In others, funding shortages and shortfalls were common, as were mix-and-match funding models and opportunistic pursuit of support from multiple sources. It was generally agreed, however, that some funding organizations played a key role in facilitating interdisciplinary research. The persistence and leadership of key individuals was essential, given the high transaction costs involved in acquiring sufficient funds to tackle the full range of these SES problems. The most successful leaders articulated a shared vision of success, built and maintained trust among participants and stakeholders, and pursued cooperative leveraging and co-ownership throughout. These same skills typically fostered the generation of creative ideas among members as well as shared learning [34,35].

Impacts

Despite various calls for rigorous project assessments, only one project [22] employed an effective assessment framework [36] to determine the extent to which the project generated new knowledge, new perceptions, new actions and new outcomes. The paucity of such assessments reflected, in part, the challenges incurred in attempting to implement them. The majority of the projects assessed outcomes through evidence of publications and/or outreach products.

Project impacts were partly contingent on the structures set in place during the design phase, and implemented throughout the project. In many cases, the project design itself had a major impact, as it established among researchers and stakeholders a framework for future activities, as in the case of the case of a delta project [23], leading to an ICSU sanctioned research initiatives on sustainable deltas (http://www.icsu.org/news-centre/news/icsu-endorsed-initiative-sustainable-deltas-2015-launches-in-rotterdam). In almost all research-focused projects, this impact was linked to processes in which project leaders identified primary participants and involved them in project development. For projects with applied goals, stakeholder and constituent involvement in co-design proved critical. Important stakeholders included policy and decision makers, community members, resource users, and industry. Such inclusiveness built trust, an essential element of project impact.

Strong responsiveness to the dynamic nature of interdisciplinary and transdisciplinary projects and changing contextual conditions (e.g., changes in constituents' priorities, ability to collect necessary data, disruptive ecological events) proved important for goal achievement and impact. In at least one case [32], external forces derailed progress toward the original project goals. Another project was required to shift aims [28], owing to changing political conditions in the partner community. The ability to shift in this way, however, was limited in other cases by various constraints (e.g., budgetary or timeframe). Budgetary and staffing inadequacies were identified throughout the cases as impediments to full project impact, be it involving the research or outreach components. In regard to outreach, insufficient funds for technology transfer, capacity development, and outreach awareness campaigns [30] and linkages to NGO and donor partners [22] were identified as particularly important constraints. Overall, the cases revealed that interfering external forces and changing contextual conditions should be expected, and successful projects maintained sufficient flexibility to achieve their goals, even if altered owing to the dynamics encountered.

The integrated science projects and programs examined here have already produced knowledge and new understanding of the functioning of environmental systems, including insights into the ecosystem services and the societal implications of their change [10,27,29], ecosystem based response strategies [22], and integrative theory across disciplines [28]. These projects have also assisted in the innovative adaptation of tools and methods, and the development of new ones that cross research fields and are applied to SES problems (e.g., [23,24]). In addition, they have engaged multiple stakeholders in the development and implementation of new, alternative practices and strategies for sustainable development (e.g., [20,28,33]). Our explorations of them, therefore, provide insights for future activities of this kind.

Lessons learned and challenges for the future

Integrated SES research and practice as exemplified in the case studies of this special feature, applied organizational processes designed to engage a diversity of actors and/or stakeholders effectively in collaborative processes, leading to integrative knowledge likely to succeed in generating strong science outcomes, effective management interventions, and/or innovative governance structures. Our review and synthesis of them provides several important lessons that, if properly addressed, promote integrated project success and reveals several challenges on which these kinds of projects and the programs supporting them require improvement. On the basis of the case studies in this special feature, we identify several common lessons that have made these programs and projects successful, and point to challenges that need to be addressed to enhance SES contributions to science and practice.

Lessons

Lesson 1: Co-design and co-learning. Research integration on SES problems requires the establishment of co-designed frameworks in the development and planning process [12•,20]. Co-design for activities directed at basic-science research involves shared problem-framing and problem-definition among natural and social scientists (e.g., [32,37]), and with cross-cutting specialists, such as modelers and remote sensors (e.g., [24]). Indeed, the historically low levels of engagement of the social sciences in social–environmental research at large — be it global environmental change or sustainability — reflects insufficient attention to co-design of research questions and agendas (e.g., [33]). In addition, providers of funding increasingly expect or require explicit attention to outreach and to solutions that make a difference in the real world [10,37]. In these cases, relevant stakeholders must be part of the co-design in order to insure that the research questions are pertinent, as well as to promote stakeholder ownership of the findings and solutions [23,28,38]. A caveat is warranted, however. The experience of some projects [27] suggests a diminution of basic science concerns as stakeholder and decision-maker involvement increases, perhaps leading to inadequate understanding of the operation of the SES problem. In such cases, broker organizations (i.e., those addressing the facilitation of, in this case, partnerships between researchers and stakeholders) may be invaluable in reaching an appropriate balance between research and outreach needs as well as minimizing time-consuming aspects of collaborative interdisciplinary programs (e.g., [31]).

All of our case studies recognized the value of co-design and co-learning, although various constraints inhibited full use of them by some projects. Of those projects not so inhibited, various means were employed to undertake the process. Some projects relied on leaders and members predisposed to interdisciplinary research or with an inclination to extend beyond their disciplines. 'Tweeners' or boundary-spanners were not only essential but also catalytic for the development of shared learning [22,24,31]. In these and other cases, interdisciplinary learning was fostered through formal (e.g., multiple workshops, jointly authored publications) or informal (e.g., joint fieldwork, social gatherings) interactions. Projects relied on processes designed to build interdisciplinary learning as an explicit component of the program [10,31,37]. The development of shared conceptual frameworks (boundary concepts, objects and settings *sensu*: [39]) were essential as were processes to facilitate dialogue [29,37], as demonstrated in the Millennium Ecosystem Assessment [40]. Many projects built-in distinct opportunities for graduate training in interdisciplinary and transdisciplinary research [7] complete with cross-disciplinary dissertation committees [24].

Lesson 2: Comprehensive planning and adaptive management. Comprehensive planning is important to all research and implementation projects, but it is critical in interdisciplinary efforts in order to clearly articulate responsibilities, timelines, and linkages between project components [10]. Plans must be clearly set out at the beginning, but must also allow for flexibility, creating the potential for adaptive management (e.g., [22,31]). This style facilitates the handling of surprises or discoveries invariably found in the interactions and outcomes of complex SES and different opinions among project members about–the relative importance of these issues or how to deal with them. An adaptive management approach inevitably requires extra investment in communication and team-attention to the state of the project and its emergent properties [19•]. The researchers in this special feature, however, agree that this investment is not only worthwhile, but essential for project and program success (e.g., [22,28,41]). This reflexive approach requires that the internal politics of large team-based research be addressed early and continuously throughout the course of a project [10,24,31].

Lesson 3: Accounting for knowledge diversity. SES research must take stock of diversity in the knowledge realms of the research effort and in the consequences of applied practices. In many cases, information and understanding of integrative research efforts can be enhanced by the use of multiple or mixed methods (e.g., quantitative and qualitative analytical approaches) and of understanding gained from different explanatory perspectives and local knowledge systems, potentially enlarging the array of expertise engaged in the activities [24,42•]. Learning networks have proven useful in this regard [25,30,31]. Research products with direct policy implications or applied solutions rarely align perfectly with the interests of diverse stakeholders [30,32], and accounting for this diversity enhances the salience, credibility and legitimacy of the science among stakeholders [17,38]. This alignment issue also involves the recognition that different stakeholder groups have differential power or capacities to facilitate or impede policies and solutions [22,32,43].

Challenges

Integrated social–environmental science continues to improve by drawing from these broad but salient lessons. Such improvements notwithstanding, an array of challenges confront this science, including some which emerge from cases described in this special feature.

Challenge 1: Accounting for change. Social–environmental systems typically change rapidly, often in unpredictable and surprising ways due to the complexity of the systems in question (e.g., [44]). Inasmuch as integrated social–environmental research, especially under the rubric of sustainability, seeks to inform decision-making and to advance solutions, attention must be given to the robustness and suitability of its products as changes in SESs take place [27]. This attention involves more than adaptive management *per se*. Ideally, it involves long-term monitoring of the SES and regular assessments of the effectiveness and consequences of the policies or practices emanating from programs and projects [25]. Additionally, the methods used to assess those 'consequences' and more generally identify when 'change' has occurred must be carefully considered. Change is not merely an empirical variable that is good or bad but can be measured along many dimensions (e.g., political, economic, environmental) and from diverse perspectives depending on how it was experienced and perceived [45]. Monitoring and assessments management remains a work in progress for most SES efforts, as it does for disciplinary projects.

Challenge 2: Sponsorship and timelines. The need for increased funding is an age-old refrain among virtually all research communities. By definition, integrated science adds layers of information and may thus increase complexity [7]. Complexity, in turn, may add costs, though this depends on the scale and location of the research, the size of the research team, and the kinds of questions being asked. In many cases, interdisciplinary science demands that a larger proportion of financial and/or time budgets be devoted to 'boundary work' and transaction costs, the 'glue' or 'matrix' that holds research activities, structures, and people together. It may also require piecing together multiple sources of funding and sponsorship, which often entails enlarging the scope of the project to identify products wanted from different sponsors [24]. In some cases, however, significant interdisciplinary knowledge has been produced with modest means and simple technologies [41].

Soliciting the active involvement of stakeholders other than scientists and paying attention to communications, outreach, and long-term monitoring may point to the need for longer lifespans for projects [25], especially for projects with negotiated implementation goals that may change as context changes. Assessment, evaluation, and adjustment to changing conditions, as noted in Challenge 1, may often require the continuous or periodic presence of researchers for considerably longer periods than the conventional three to five years of many sponsored projects. Programs and projects have tackled this challenge in a variety of ways but usually involve long-term commitment by key project personnel [7,10,24,25,41]. In the long run, capacity building of on-site civil society or community organizations to participate actively in monitoring aspects of environmental change can simplify these challenges [22]. It is noteworthy, however, that projects with research and implementation goals may confront the challenge of delivering short-term societal products in the face of longer-term science challenges [33].

Challenge 3: Appreciating different knowledge systems. As noted in Lesson 3, much progress has been made over the past quarter century in enlarging the range of explanatory perspectives directed to integrated social–environmental science. Nevertheless, the level of coordination and integration between the natural and social sciences commonly remains inadequate [42•]. Venues that build new and innovative relationships between these sciences — bridging boundaries — remain urgently needed to accomplish a range of goals, from international agenda-setting to specific outreach efforts and opportunities to build social networks across disciplines [46•]. These relationships demand heightened awareness and appreciation of different ways of problem-framing, and of the range of methodologies that can shed light on complex multi-dimensional problems (e.g., beyond mainstream science, see [47•]). While it may not be possible or desirable to fuse the fundamental explanatory perspectives (i.e., the variants of ontologies, epistemologies, and methods) which are particularly diverse in the social sciences, it is possible to appreciate the understanding gained from different problem-framings and use them to inform the base science [10,24]. Likewise, knowledge gained from stakeholders operating beyond the academic-research realm can inform the base science as well. This appreciation and integration of problem-framing and analytics is gaining traction among junior researchers, but it is not yet clear how they resonate among the sponsors of integrated research.

Challenge 4: Adaptive communication. Virtually all SES research programs within sustainability science contribute to basic science but also seek to inform decision-making or provide solutions to various problems. In most cases, such efforts require outputs for diverse research and outreach purposes. The larger and more complex the project, the more difficult it may be to foster appropriate levels of communication among the researchers, and projects must weigh the pros and cons alternative means of communication [23]. The level of detail in outreach communications among diverse stakeholders varies in terms of its usefulness. As such, these kinds of projects increasingly recognize the need for multiple resolutions or grains of communication [22,27], including policy briefs, and the search is on to identify the appropriate mechanisms to translate findings and output to meet the needs of different communities of users while maintaining the essential attributes (above) that enhance the receptivity to communications [17,38].

Challenge 5: Improving linkages to policy. SES solutions often involve more than new or alternative technologies or methods but also require attention to policies of various kinds that facilitate the solution. Effective policy implementation is influenced by many factors, including but not limited to the complementarity of science with stakeholder interests, the political context underlying governmental decision-taking, and the political environments in funding and formal academic institutions [38]. Our case studies were replete with explicit policy linkages. For example, Sitas [22] demonstrates substantial policy shifts in which disasters are managed, resulting in a move toward more proactive, ecosystem-based initiatives for natural disaster risk-reduction. Bridgewater [27] points out the establishment of a global network of biosphere reserves and in-country development of biosphere reserves as a concrete policy achievement, while Reid and Mooney [29] describe the evolution of IPBES in part arising from the success of the Millennium Ecosystem Assessment [40] demonstrates that useful space remains available in many developing countries for environmental 'think-tanks' with combined research and policy objectives — though again, establishing such units does not guarantee uptake on the part of political powers. Cáceres [32] reports on a project which produced highly relevant to policy makers yet failed to influence policy, although subsequent work may produce a more favorable outcome. Chapin [28] notes that while no new formal policy initiatives occurred in project implementation, some informal pathways (termed soft policy) were developed in which some community goals could be met. Leemans [20], finally, stresses the importance of an appropriate governance system to connect to policy makers and other stakeholders. These examples notwithstanding, much, if not most, SES research lacks explicit expertise devoted to policy formation or implementation. Means by which to improve this lacuna require investigation.

Concluding remarks

The case studies presented in this special feature indicate that imaginative and resourceful interdisciplinary research projects and programs are making progress toward the broad objectives of the 'useful science' paradigm [3] addressing environmental concerns through the lens of SES. They have rendered important contributions to basic science while informing and developing solutions for a varied set of issues and problems. Overall, these case studies demonstrate the successes of co-designed, flexible management projects informed by diverse knowledge sets, and provide insights about required attributes such as trust building. At the same time, the case studies indicate that much work remains to realize the full potential of environmental and sustainability science to confront the urgent challenges now facing the planet.

These challenges range from finding ways to match research and monitoring programs to the rapid pace of change now affecting SES's everywhere, to improving the capacity of science to inform solutions, and in some cases, implement them.

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This commentary argues for a more inclusive, integrated science, one that is open to the social sciences operating beyond mainstream science and to the humanities.