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Synthesis, part of a Special Feature on Social Learning in Water Resources Management

Sustainability Learning in Natural Resource Use and Management

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ABSTRACT. We contribute to the normative discussion on sustainability learning and provide a theoretical integrative framework intended to underlie the main components and interrelations of what learning is required for social learning to become sustainability learning. We demonstrate how this framework has been operationalized in a participatory modeling interface to support processes of natural resource integrated assessment and management. The key modeling components of our view are: structure (S), energy and resources (E), information and knowledge (I), social-ecological change (C), and the size, thresholds, and connections of different social-ecological systems. Our approach attempts to overcome many of the cultural dualisms that exist in the way social and ecological systems are perceived and affect many of the most common definitions of sustainability. Our approach also emphasizes the issue of limits within a total social-ecological system and takes a multiscale, agent-based perspective. Sustainability learning is different from social learning insofar as not all of the outcomes of social learning processes necessarily improve what we consider as essential for the long-term sustainability of social-ecological systems, namely, the co-adaptive systemic capacity of agents to anticipate and deal with the unintended, undesired, and irreversible negative effects of development. Hence, the main difference of sustainability learning from social learning is the content of what is learned and the criteria used to assess such content; these are necessarily related to increasing the capacity of agents to manage, in an integrative and organic way, the total social–ecological system of which they form a part. The concept of sustainability learning and the SEIC social-ecological framework can be useful to assess and communicate the effectiveness of multiple agents to halt or reverse the destructive trends affecting the life-support systems upon which all humans depend.

Key Words: *modelling social-ecological systems; social learning; sustainability*

INTRODUCTION

During the last two decades, the discussion on sustainability has increasingly shifted from being goal oriented to understanding sustainability as a learning process. Indeed, the notion of sustainability as a social learning process is now pervasive in environmental and natural resource literature. However, this particular interpretation of sustainability is relatively new and still subject to many ambiguities. Here, we draw from the insights of human ecology, studies of the adaptation of social-ecological systems, and the emergent ecological sociology to provide a theoretical and normative framework aimed at defining and making operational the concept of sustainability learning. This approach, which takes the form of a model, is supported by the findings of the European Union (EU) project Harmonising Collaborative Planning (HarmoniCOP) and is being further developed in the EU project Methods and Tools for Integrated Sustainability Assessment (MATISSE). Our goal is to provide an innovative systems approach to understand the links between sustainability and learning and to explore to what extent the approach can contribute to improved understanding and assessment of and decision making for natural resource systems.

This paper is organized as follows. In the first section, we examine the concept of social learning and the main factors that stimulate or constrain social learning within river basins and national scales, as identified by the HarmoniCOP findings. In the second section, we examine how theories of social learning have incorporated issues of sustainability by drawing mostly from the original work of Lester W. Milbrath (1989). In the third

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section, we propose a simple model aimed at synthesizing and representing the main components and interrelations upon which the sustainability of social-ecological systems depends and at supporting the integrated assessment and management of natural resources. This model is derived from the insights provided by human ecology, ecological sociology, and studies of the adaptation and resilience of social-ecological systems and is now currently being implemented within the MATISSE project. In the conclusion, we defend the potential of our approach, acknowledge its drawbacks, and relate it to the ideas of cultural development and the enhancement of a self-aware society.

SOCIAL LEARNING IN RESOURCE MANAGEMENT

Social learning as an approach for the understanding and management of environmental issues has become a prominent interpretative framework in the assessment and management of natural resources (Worcester and Barnes 1991, Wynne 1992, Parson and Clark 1995, Webler et al. 1995, Daniels and Walter 1996, Social Learning Group 2001, Craps 2003, Folke et al. 2003, Schusler et al. 2003, Ison et al. 2004, Pahl-Wostl and Hare 2004, Keen et al. 2005, Pahl-Wostl 2006). Beginning in the 1970s, the notion of social learning gained attention in many disciplines such as political science in which the role played by advocacy coalitions in processes of societal change and learning was underlined (Sabatier 1988, Bennett and Howlett 1992, Minsch et al. 1998). In resource assessment and management, the notion of social learning coincided with the thrust for public participation and the growing importance given to sustainable development. New methodological approaches such as participatory integrated assessment (Rotmans 1998) and sustainability science (Kasemir et al. 2003) involved the consideration that public participation is necessary in any attempt to build robust knowledge capable of dealing with the challenges, complexities, and uncertainties of sustainable development. In this respect, the approach of civic science (Lee 1993, Irwin 1995) underscored the need to reshape the usual roles taken by scientists, policy makers, and citizens in the governance of sustainability, although it has been criticized for not providing clear guidelines on how to do so. In particular, the emphasis of sustainability science and civic science has not been so much on attempting to change the rules and practices of the production of scientific knowledge, but simply on promoting wider participation in the process (Bäckstrand 2004).

In this regard, Lee (1993) distinguished nine types of learning according to whether the learner is an individual or a group and with regard to how the decision processes function to produce results from which to learn. In addition to individual learners, if the learners form a group that has a single purpose, they are considered “purposive” learners, whereas if the group has multiple objectives, they are considered “collective” learners. Decision making based on rational choice, bounded rationality, or biased cognition also yields different types of learning. Of these different types of learning, “single-loop” learning refers to purposive learners who operate under bounded rationality, whereas “organized anarchy” refers to collective learners who operate under conditions of biased cognition. “Double-loop” learning refers to purposive learners who are capable of rethinking their purposes and rules of operation in a way that reveals the limitations of their assumptions and theories, in turn driving the resolution of practical problems. For Lee (1993), adaptive management can be understood as a way to incorporate double-loop learning into the routines of organizations in charge of the management of social-ecological systems, giving double-loop learning some of the strengths of bounded rationality.

Therefore, learning has different meanings depending on whether it refers to processes involving individuals, collective agents, or wider social systems. The work of Bandura (1977) refers to individual learning as based on the observation of the behaviors of others, which results from social interaction within a group, e.g., through the imitation of role models. Individual learning assumes an iterative feedback between the learner and his/her environment, with the learner changing the environment and the environmental changes affecting the learner. However, this approach has been regarded as too narrow and much too focused on the personal aspects of learning to embrace the complexity of learning processes that occur in the governance of social-ecological systems. According to Folke et al. (2005), the adaptation of social-ecological systems can be seen as a type of learning in which multiple processes interact at different scales of action. These processes include establishing the roles of leaders and networks, managing systems of knowledge, building trust and social capital, and making sense of information, as well as determining the extent to which boundary and bridging organizations are able to collaborate to incorporate their particular experiences and create collective action to build the capacity to adapt to change. This demands the design of specific mechanisms that institutions can use to incorporate lessons from disturbances of social-ecological systems and, in particular, the design of institutional structures capable of functioning over a range of domains and scales of action. Learning to create resource institutions based on redundancy, policentricity, and diversity is viewed as fundamental to coping with the risks associated with unsustainability (Becker and Ostrom 1995, Dietz et al. 2003, Moberg and Galaz 2005).

Such a broad interpretation of social learning was also followed in the Harmonising Collaborative Planning (HarmoniCOP) project (www.harmonicop.info). The approach developed for social learning in the context of river basin management was influenced by authors such as Wenger (1998) who focused on the role played by communities of practice. Social learning, as understood by the HarmoniCOP project, results from an interplay among the following three elements (Craps 2003, Pahl-Wostl et al. 2007): a context formed by a given governance and physical system, a process formed by a set of relational practices, and a series of outcomes that feed back into the original context as changes in the institutional and environmental systems. It is by sharing different points of view and types of knowledge that the actors involved in river-basin management planning can build a social learning process in an emerging community of practice (Craps 2003, Bouwen and Tailleu 2004). Social learning can be induced by promoting public participation. In this regard, social learning processes are affected by the framing and reframing of the problems at stake, the management of boundaries to determine who is and who is not involved in the process, the type of negotiation strategies used, the ground rules established to facilitate interactions, the leadership required to steer and coordinate the process, and the facilitation and allocation of resources (Pahl-Wostl et al. 2007).

The HarmoniCOP project identified the key factors that affect social learning in river basin management. Among those of importance were the role of the motivation and skills of leaders and facilitators, clarity about the role and purpose of stakeholder involvement, the internal structure and the lattitude given to democratic debate about regulatory institutions, the structural capacity for interactions among social networks, and the influence exerted by the existing culture on the framing and definition of the issues at stake. More specifically, and in the context of the management and planning of river basins, the HarmoniCOP project revealed that, according to Patel and Stel (2004), Tàbara et al. (2005), and Mostert et al. (2007), social learning processes require:

- opportunities for critical mutual reflection and the awareness and modification of assumptions and cultural frameworks that are taken for granted;
- the development of participatory, multiscale, democratic decision-making processes;
- reflexive capabilities of individuals and societies for the development of polycentric forms of resource assessment and management;
- the empowerment of social movements and actors to shape the political and economic boundary conditions that determine their opportunities to become involved in the processes aimed at improving the existing situation;
- the recognition of mutual interdependencies and interactions in the existing networks of action;
- an increase in the capacity to reflect on assumptions about the dynamics and cause-and-effect relationships in the system to be managed and on the subjective valuation schemes; and
- the active engagement of individuals in collective decision processes. This may include the development of new management strategies and the introduction of new formal and informal rules.

In this way, processes of social learning can be improved by facilitating processes toward:

- recognizing the diversity and complexity of the different types of mental models and cultural frames that influence problem definition and decision making;

- building a shared representation of the issues at stake. Participatory modeling can help to achieve a common ground for problem perception among a diverse group of actors, particularly when the problem is largely ill-defined, although this does not imply consensus building; and

- building trust among the main stakeholders and institutions as a base for critical mutual and self-reflection.

SOCIAL LEARNING AND SUSTAINABILITY

Social learning, particularly at the level of the whole society, has been associated with the concept of sustainability. One of the earliest reflections from environmental sociology to link these concepts was provided by Milbrath (1989) in his work *Envisioning a Sustainable Society: Learning Our Way Out.* In his view, social learning occurs when a dominant institution is replaced by another; therefore, it refers to changes in societal practices and norms that are shared by a large number of actors. He used the framework provided by Argyris and Schon (1978) and Trist (1980), which distinguished between single-loop learning in which learning is incremental and experimentally based and double-loop learning in which the learner becomes aware of the assumptions and values that he or she holds and is capable of major shifts within the frames of reference. Because society is increasingly moving into a turbulent environment that requires the improvement of its adaptive capacity and not merely learning about how to do the same things in a better way, society needs to develop its capability for double-loop learning at both the personal and societal levels. Social learning in the domain of sustainability entails a completely new way of thinking and a radical change in values. Milbrath (1989:85–87, adapted) understood that, for social learning to move towards sustainability, people must learn:

- to become conscious of their ways of knowing;

- to understand the critical roles played by values and beliefs in the shaping of reality, and that science is not value free;

- to reason together in public debate about their values to redirect scientific and societal development;

- to appreciate the complexity and interconnectivity of ecosystems and their implications for social action;

- to think holistically, systemically, and integratively;

- not to separate human societies from nature, but to live in harmony with nature, rather than dominate it;

- to avoid interfering with nature’s systems and cycles and recognize the limits to growth; and

- to empathize with and extend our compassion to people of other lands, other species, and future generations to preserve the integrity of the ecosphere and the survival of all.

In particular, according to Milbrath (1989), a learning society moving towards sustainability would:

- use a wealth of information and overcome the legal, social, and financial barriers to the easy sharing of such information;

- find better ways to disseminate and use information, e.g., by means of a world electronic library aimed at helping to understand ecosystem processes, resource stocks, and depletion rates and to anticipate consequences;

- emphasize integrative and probabilistic thinking, starting from basic education, by learning to think holistically and in long-term and large-scale frames of reference;

- emphasize values as much as facts by learning how to learn from the values of others and how values relate to the interpretation of facts;

- be critical of science and technology in a constructive way to develop procedures to evaluate and control the role of science and technology in society;

- combine theory with practice because scientific understanding alone is insufficient, and change must be obtained by purposive action;

- be consciously anticipatory by learning to anticipate unintended consequences that arise in response to almost every policy on current complex and interactive systems. We should always ask, “And then what?” and think, “We can never do merely one thing”;

- think that change is possible because people need to be empowered to believe that change is possible and that they can participate in its direction;

- examine outcomes to learn from them because the systematic evaluation of feedback is necessary to assess the outcomes of learning and support social learning;

- develop institutions to foster systemic and future thinking in government, business, and other major organizations;

- institutionalize the practice of analyzing future impacts to try to follow the basic principle of “looking before leaping” in making major societal decisions and developing methods of value impact analysis;

- reorient education toward social learning by incorporating principles such as systemic, future, and integrative thinking and moral reasoning into the lessons of educational institutions;

- support interdisciplinary research and encourage the reframing of research toward a more harmonious relationship with nature. The goal of universities is to encourage social learning; when they place obstacles to such research, they become obstacles to social learning; and

- maintain openness and encourage citizen participation to foster learning and counterbalance excessive bureaucratic policy making.

Of course, the above discussion still leaves many questions about the actual meaning of sustainability unanswered. With now dozens of definitions of sustainable development, numerous distinct ways to measure it, and millions of Web pages featuring it, the ambiguities of what has been called an oxymoron seem to be prevalent in even the most commonly used interpretations of the concept. Indeed, it is difficult to agree upon one sole definition of sustainable development, i.e., on what is to be sustained, for how long, and what is to be developed (Kates et al. 2005). On one hand, the understanding mainly influenced by social sciences tends to focus on the key concept of needs, as primarily understood by the World Commission on Environment and Development (1987). On the other hand, the natural sciences tend to emphasize the roles played by the carrying capacities of ecological systems, the limits to the use of nonrenewable resources, and the ability of ecological systems to assimilate pollution and negative effects caused by human development. There are some attempts at systemic integration between the two extremes, but the difficulties in bringing them together create the clash between the understandings and accelerate the growth of new interpretations.

One of the main reasons that there are so many definitions of sustainability must be found in the way that different cultural world views conceive the relationships between humans and natural systems. What most widespread notions of sustainability have in common is their insistence on maintaining and reproducing dualistic or even antagonistic views between natural and social systems, which sustainable development must then resolve. For instance, Barbier (1987) states that sustainable economic development entails the integration of goals assigned to economic, social, and ecological systems. Authors arguing for either strong or weak sustainability often depart from the assumption that there are different types of capital that can or cannot be interchanged (Pezzey 1992, McKenzie-Mohr and Marien 1994, Pezzoli 1997*a,b*, Mebratu 1998). However, sustainable development simply cannot resolve a problem that is culturally rooted in the way that science and policy view and interpret the relationships between natural and social systems and the role of knowledge production. Sustainability demands, above all, a cultural transition in the form of an emerging sustainability culture that views humans as an inextricable part of the making of their own social-ecological system (Tàbara 2002, Berkes et al. 2003). Some of the new tools and methods aimed at contributing to this transition, e.g., those of the emerging field of integrated sustainability assessment (Weaver et al. 2005), also depart from this perspective.

SUPPORTING SUSTAINABILITY LEARNING: A MODELING SYNTHESIS

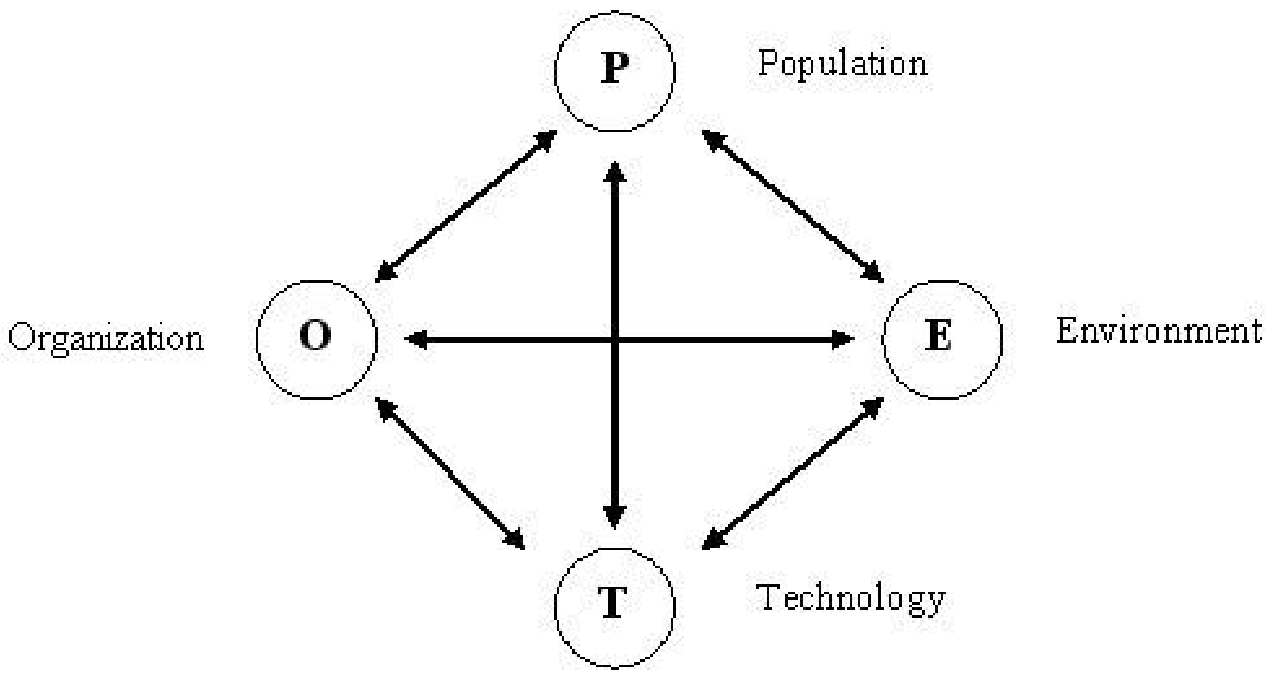
The above discussion of social learning and sustainability makes it clear that we are faced with an increasing number of definitions and interpretations of the two concepts. Although these definitions and interpretations seem to be expanding by the minute, very little has been done to integrate them in an operational manner. A synthesis that can be used in sustainability science and policy is needed. The concept of sustainability learning (Tàbara 2002) attempts this synthesis, and we have begun to explore its validity for the case of water systems management at river-basin and national scales (Tàbara et al. 2005). For instance, we have identified a process of sustainability learning in the change in the Spanish water policy that occurred during the decade 1998–2007, which resulted in a series of important changes in the use of natural resources and in the way that water systems were understood and eventually managed by the governing institutions of the country. These changes were stimulated not solely by biophysical constraints or by the role of advocacy coalitions, but also by a set of complex hybrid processes between natural and social forces that stimulated a distinctive type of learning. It was the outcome of pressures that operated from both within and outside of Spain and of changes that occurred simultaneously in the symbolic, institutional, and natural systems (Tàbara and Ilhan 2007).

Nevertheless, a main difficulty in the delimitation of the concept of sustainability learning lies in providing a specific content about what is to be learned, so as to transform and orient general social learning processes into sustainability learning processes. So far, most of the debates on social learning (Pahl-Wostl et al. 2007) have largely left this question untouched. Therefore, it is often impossible to assess how, under what criteria, and to what extent participatory and collaborative processes actually contribute to the improvement of sustainability. We attempt to provide a theoretical and normative framework in the form of an integrative model to help highlight the key components that should be taken into account when assessing the effects on sustainability of processes of social learning in the management of social-ecological systems. Our approach departs from a hybrid, co-evolutionary, and organic standpoint; this is critical because of the prevalent dualisms such as those between nature and culture or between social and ecological systems. Although we are sympathetic to their perspective, we do not fully embrace the post-modern interpretation of social-natural relations provided by authors such as Latour (1993, 2004), Freundenburg et al. (1995), and Callon (1999), who suggest that associations between humans and “actants,” i.e., nonhuman entities with a social-ecological nature, should be the focus of ecology, and not abstract and detached notions of nature.

To provide the background to understand the origins of our approach, we first discuss the insights provided by human ecology and, in particular, Duncan’s (1961, 1964) notions of the “ecological complex” and the POET model (Fig. 1). For Duncan (1961, 1964), human ecosystems consist of four key components or properties that are closely interrelated: population(P), organization (O), environment (E), and technology (T). The POET model, like many attempts at metamodeling in socioenvironmental sciences, has been criticized as oversimplified. Nevertheless, it stimulated a considerable amount of research and proved useful for the emergence of environmental sociology (Humphrey and Buttel 1982, Dunlap et al. 1994, Buttel and Humphrey 2002). Mostly, it suggested that the adaptation of human populations to environmental changes occurs in many ways and may not entail simply a reduction in population. Changes in many other components, technologies, or organizations may take place. In turn, transformations in any of the other P, O, and T components have co-evolutionary effects on the natural environment.

The POET model has some obvious limitations such as the lack of scale considerations; the way it deals with the effects of growth on the size of the ecosystem at stake, including its relationship with carrying capacity; and the roles played by culture,

Fig. 1. Duncan's POET model of the ecological complex (Duncan 1961, 1964).



power, and individual agencies. In addition, it was embedded in a dualistic vision between the natural environment, i.e., E, and human environment components, i.e., P, O, and T, and was thus labeled as anthropocentric (Dunlap et al. 1994). All of this made it difficult to address issues such as the role played in sustainability by the existing stocks and flows of information, biodiversity, and pollution from different scales of human action. For instance, the loss of biodiversity is not only a loss of a natural resource, but also a loss of information, which affects the way human-natural communities organize themselves, create co-adaptive institutions, and construct natural-human hybrid associations. Hence, a more hybrid relational co-evolutionary synthesis of social-ecological systems is needed (Freese 1997).

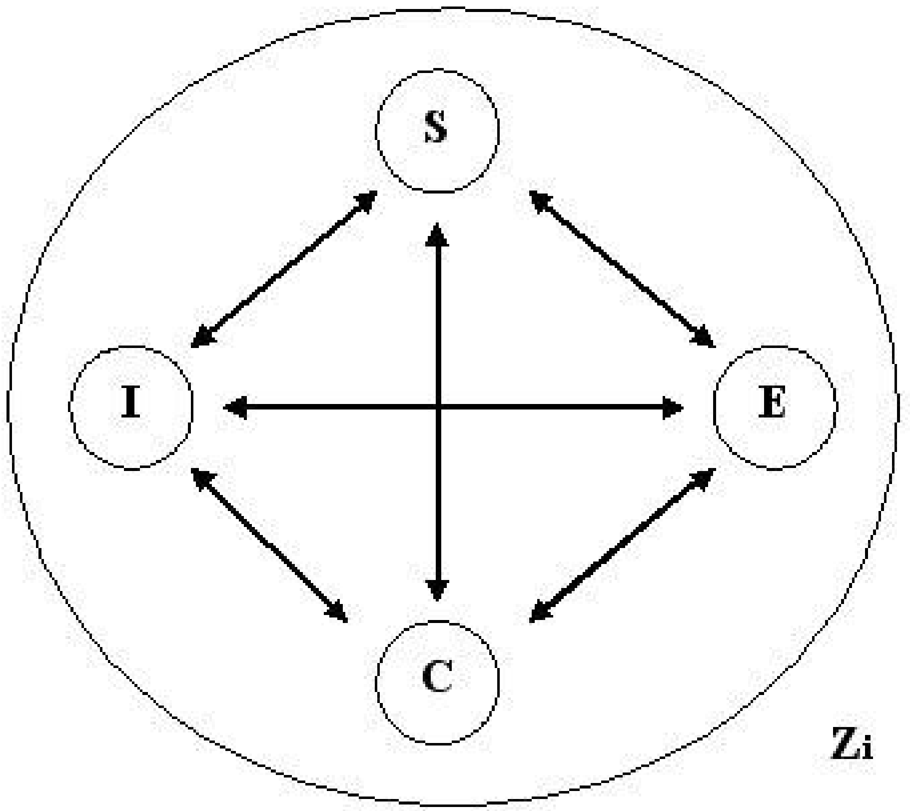
To deal with such challenges and avoid oversimplification, we suggest a more elaborate model for the synthesis of and communication and learning about sustainability (Fig. 2). Emerging from the reflections of the new ecological sociology, the social-ecological system (Tàbara 2003) can be understood as consisting of four main components: structure (S), energy and resources (E), information and knowledge (I), and social-ecological change (C). Structure includes the stable set of system-governing rules and conditions that a particular set of social-ecological relationships or agents use to arrange their behavior and adapt to the changing environment. These rules and conditions are conscious or unconscious, formal or informal, and human created or not human created. Energy comprises the whole set of resources, including biodiversity, that is needed by the agents or the social-ecological system of reference to pursue their goals and/or perform their functions. Information and knowledge encompass not only those types of information that are represented, stored, and communicated in human languages and artifacts, but also those stocks of information and knowledge embedded in natural systems and biodiversity that have been acquired by evolution. Change encompasses those stocks and flows of driving forces and conditions that transform the whole social-ecological system and that emerge from the accumulation of the effects of the agents. Change is not only the result of transformations within the natural environment, e.g., by the use of energy, but also that of changes in the use of social and information systems, e.g., the loss of local knowledge as a result of the expansion of computer-based information tools. Whenever the change in the social-ecological system is too fast or too large for the purposeful agents of the system to adapt to it, the system can enter into an irreversible situation of unsustainability. The sustainability of the total social-ecological system is only possible if a certain degree of complexity and diversity is ensured to allow it to adapt to changes and provide the multiple services that agents of different scales and natures need to maintain their functioning. In a social-ecological system, change must always navigate between thresholds that are often given by the quantitative and qualitative carrying capacities of the system in relation to its knowledge systems, resource availability, and institutions to ensure the system's sustainability. Thus, if institutions grow beyond a certain threshold, they may also become dysfunctional in terms of sustainability.

Therefore, our approach does not assume co-adaptive equilibrium or the spontaneous emergence of self-regulation of the different parts of the social-ecological system. Collapse can also occur whenever the growth of a system surpasses certain limits or whenever the type, intensity, or scale of change create risks and system conditions that are impossible to tackle with the available information systems, resources, or governing institutions (see Abel et al. 2006). The SEIC model also contains a characterization of the size, Z_i, of the social-ecological system that helps to integrate the interrelationships between different social-ecological systems at different scales and relate them to the concepts of system limits and system assimilation, e.g., the incorporation and control of the dynamics of a social-ecological system by another, larger system (Fig. 3).

This framework has already been operationalized, using the concept of the World Cellular Model, in a computer environment for integrated, multiscale, agent-based modeling (Tàbara et al. 2006) that can be used in participatory settings with stakeholders to enhance a learning reflection on sustainability issues. In this model framework, the total social-ecological system consists of numerous subsystems represented by agents or "cells." Each cell can be categorized as human agents, a patch of soil, or a hybrid actant, either individual or collective, and the cells interact within in a global network of social-ecological systems (Boulding 1985). For instance, size can be operationalized according to the system of reference that is to be assessed and managed. In the case of water, a simple measure of size can be the total water stocks and flows used by the agents of the social-ecological system, which can then be compared with the total water available in the system. The participative use of this approach helps to anchor such a general and abstract framework to a more concrete context and to include other issues in the discussion, such as the role of culture and power in the management of a particular social-ecological system such as a river basin. Scale issues and interrelations among systems can also be represented and modeled in a simple way, e.g., by showing the relationships that occur when larger systems of information or governing rules affect other systems of information or governing rules that belong to smaller social-ecological systems. This perspective is in agreement with and complements the interpretations expressed in Gunderson et al. (1995), Holling et al. (1998), and Berkes et al. (2003), in which the management of information and institutional systems for the improvement of the co-adaptative and resilience capacities of social-ecological systems plays a central role (see also Cash et al. 2003).

The extended version of the SEIC model for the total social-ecological system can be used to summarize the key components upon which, in our view, sustainability, and in particular sustainability learning, depend. Although several interpretations may be derived from this framework, we can simply state that, in general, the improvement of the sustainability of a given social-ecological system entails learning to design and implement hybrid adaptive governing institutions (S) capable of ensuring the following three factors over the long term. First, the use of the stocks and flows of energy and natural resources (E) by the agents of the system must be compatible with the agents' long-term goals and activities. In some cases, this may imply a reduction in the use of nonrenewable sources of energy or the use of the same level of energy to carry out activities, or else the generation of adaptive changes in activities and behaviors to meet different goals. Second, the existing stocks and flows of information and knowledge (I) must be preserved and enhanced to guarantee the necessary level of system complexity and diversity upon which its learning potential depends. Agents of the system must generate and use their knowledge of the social-ecological system to increase their total awareness of the system, anticipate change, and orient their

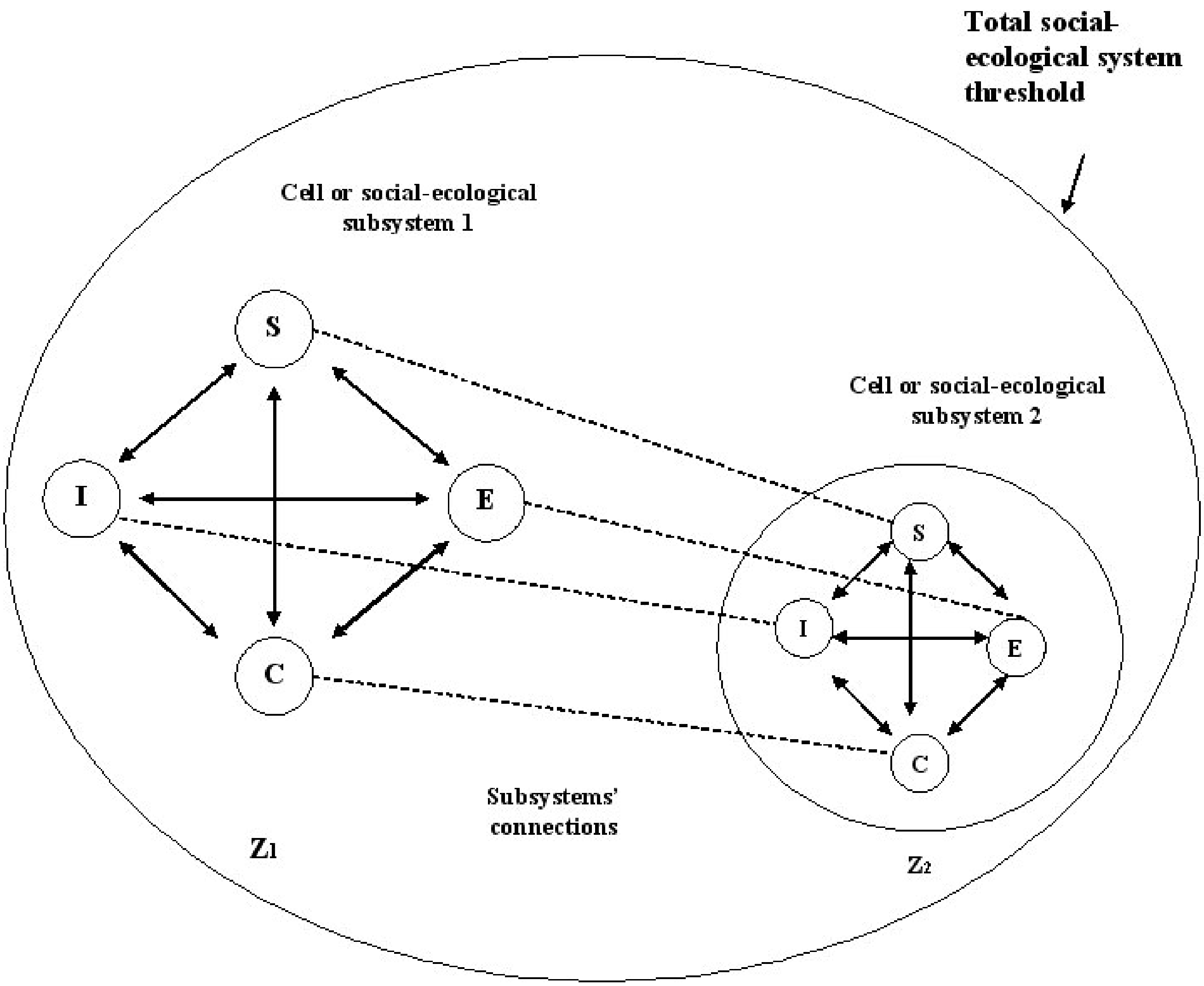
Fig. 2. The social-ecological system as represented by the SEIC model (Tàbara 2003). S = structure and ruling institutions, E = energy and resources, I = information and knowledge, C = social-environmental change, and Z_i = size of social-ecological system *i*.



behavior to adapt their governing institutions accordingly. Preserving redundancy in function to sustain resilience and adaptive capacity may be more desirable than the short-term optimization of a functional trait. Third, change (C) must be managed so that the growth in size, Z_i, of the social-ecological system and the type of qualitative impacts derived from the use of resources and information in the present stage of development do not trespass certain thresholds that make the adaptation of the system agents impossible in the next stage of development.

For sustainability learning to occur, institutions must develop the capacity to prevent and cope with the unintended, negative, and often unexpected effects of the actions of the agents that compose the system and do so from a wholly integrative organic perspective. It must be noted, however, that our approach is an open-ended one and that it does try to impose a particular universal definition of sustainability that is valid for all contexts. Thus, our proposed model only provides a general framework of reflection that agents of a selected context of action in a particular situation may use to reflect about the constraints, as well as the opportunities, for sustainability learning. Our contention is that it is better to provide a tool for learning than a concept to learn. In this regard, the identification and selection of the agents, boundaries, and dynamics of the system is a learning process in itself (Tàbara 2005).

Fig. 3. Interrelationships between two social-ecological systems of reference with two different sizes, Z_1 and Z_2, and their relation to their total system growth limits. In the World Cellular Model computer interface that was applied to the Ebro River basin in Spain, each subsystem is related to an agent with a differentiated capacity to use water resources, process information, generate rules of behavior, and create social-ecological change in a co-evolutionary fashion (Tàbara 2003, Tàbara et al. 2006). S = structure and ruling institutions, E = energy and resources, I = information and knowledge, and C = social-environmental change.



CONCLUSION

In contrast to the notion of social learning in general, sustainability learning focuses on the process of generating and applying a specific type of content of what is learned. In particular, sustainability learning relates to learning to develop the capacity to manage options for the adaptation of human societies to the limits and changing conditions that are imposed by their own social-ecological systems. Sustainability learning entails becoming increasingly aware of the limits and of the unintended negative consequences of collective action upon life-support systems and being capable of anticipating and managing those effects. It also requires overcoming many cultural dualistic perceptions that are still embedded in the way humans interpret their coevolutionary connections with the larger ecosystems and with other agents. To a large extent, sustainability learning can be understood as a search for a collective truth that, although it will necessarily be contextual, will not be totally random. In this regard, learning is a search for truth that can be applied to learning about social-ecological systems. Lee (1993:160) stated that " ... sustainable development must be both true in the sense that it should preserve the productivity capability of the environment, and just in the sense that people should consent to the governance needed to maintain sustainability."

We have provided a general framework with which to interpret sustainability and a conceptual model that can be used to support sustainability learning in natural resource management. We claim that sustainability learning occurs whenever a social-ecological system is able to keep its dynamics of change (C) between some feasible thresholds by creating adaptive changes in the governing structures (S) and efficiently manage its stocks and flows of information (I) so that it is possible to reduce its pressures on the natural resources and the use of energy (E). Pathological systems of information and knowledge prevent agents of the social-ecological system from becoming aware of the critical changes in their own system that can jeopardize their own survival. Conducive systems of information and knowledge generation tend to support the creation of communities of learning and action and help the making of collective understanding and adaptive transformation. Sustainability learning involves both cultural and institutional development. What distinguishes social learning from sustainability learning is therefore the substance, i.e., the type of social process and direction, and the final effects of what is learned. Changes in perceptions, values, and cultural beliefs related to overcoming the dualistic interpretations of social-ecological interrelationships need to affect both collective behaviors and individual norms. In this regard, sustainability learning depends largely on the investment in and reorientation of public education, an undervalued component of participatory environmental assessment (Sinclair and Diduck 1995). Recognizing the role of public education and implementing a new integrative nondualistic vision of knowledge and social-ecological systems in resource management will entail the integration of an ecosystemic precautionary approach within the domains of governance and science (Orr 1994, 2002, Huckle and Sterling 1996).

To conclude, sustainability learning entails overcoming many of the prevalent dualisms that now inform assessment and decision making with regard to the perception and use of social-ecological systems. These include dualisms between the individual and the collective, between human and natural systems, between structure and change, between internal and external system properties, and between human agency and natural conditions. A more hybrid, relational, and co-evolutionary holistic understanding of human-natural interactions is needed. In the final reflection on the HarmoniCOP project (Tàbara et al. 2005), we argued that sustainability learning should open spaces for the hybrid self-organization of natural-social systems. This means that the agents of the systems should be able to manage and unleash the restoring and life-enhancing forces embedded in both natural and social systems whenever these forces are capable of interacting in a harmonious way, e.g., allowing for mutual self-organization and resilience. New tools and methods for the Integrated Sustainability Assessment of water such as those provided by the World Cellular Model and the SEIC social-ecological system analysis in the MATISSE project attempt to move in this direction. We do not claim that we have already solved and overcome all of the theoretical and methodological challenges that such a new vision implies for the evaluation and management of social-ecological systems. We have only provided a possible way forward in the form of a model and a concept to support a process that could be useful for science and policy to conceptualize and communicate in a simple way the complex hybrid processes upon which sustainability and sustainability learning may depend. As noted by O'Riordan (2004:245), sustainability calls for the construction of a "self-aware society" that transcends existing dualisms and in which the notion of citizenship needs "to encompass transcendence of the human spirit into a common bond for a self-sustaining humanity on a life-supporting planet."

Responses to this article can be read online at:
http://www.ecologyandsociety.org/vol12/iss2/art3/responses/

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