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Experience With a Hard and Soft Participatory Modeling Framework for Social-ecological System Management in Mount Everest (Nepal) and K2 (Pakistan) Protected Areas

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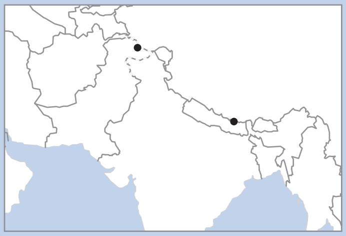

High mountains have sensitive social-ecological systems (SESs) characterized by fragility, complexity, and marginality. The local economies of these environments mainly rely on primary production, tourism, and leisure activities; thus human–ecosystem interactions are intricately linked. Many authors stress that this strict relationship must be assisted with a participatory approach involving interested stakeholders in the conceptualization, specification, and synthesis of knowledge and experience into useable information for the express purpose of addressing a problem complex. This paper presents experience garnered with a participatory modeling framework combining hard and soft methodology in 2 case studies: the Sagarmatha National Park and Buffer Zone (Nepal) and the Central Karakoram National Park (Pakistan). The modeling framework was developed based on local stakeholders' demands and needs; it consists of 5 modules, briefly presented here along with their conceptual background. In developing the framework, particular emphasis was given to considering the needs of decision-makers at the local level, rather than simply providing technical solutions to abstract problems. From the development of this modeling process, a need emerged to structure a management-oriented research module in order to generate management knowledge that is both stakeholder-relevant and evidence-based. The application of the framework in the 2 cases studies showed that the modeling can trigger valuable discussion among stakeholders as well as guidance for management-oriented research and feedback loops ensuring validation of knowledge. In addition, the resulting scenarios can help decision-makers in defining pathways for sustainable development in mountain areas, where people's livelihoods are closely dependent on ecosystems. The framework was developed in such a way that it can be replicated in other mountain areas with similar challenges.

Keywords: *System dynamics; management-oriented research; quantitative modeling; social-ecological systems; qualitative modeling; adaptive management; modeling scenarios.*

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Introduction

The concept of *social-ecological system* (SES) is based on an integrated approach that aims to avoid a conceptual division between humans and nature. Social and ecological systems constantly change; consequently, taking account of change is critically important to their management (Pirot et al 2000). Although the complexity of SESs has been widely discussed, some authors have formalized long-term intervention methodologies using modeling techniques dedicated to supporting stakeholders in implementing adaptive management of their system (Hagmann et al 2002; Walker et al 2002). *Protected areas*, the main objective of which is usually to reduce human use of resources within their boundaries, are a typical example of an SES requiring participatory management (Galvin and Haller 2008). The aims of management shift from letting pristine wilderness take its

FIGURE 1 Stakeholders identified the current expansion of tourism infrastructure and improper disposal of solid waste in the SNPBZ as some of the major issues to be dealt with in future. (Left) Heavy construction activity due to tourism demand in Namche Bazar in 2008. (Photo by Rodney Garrard.) (Right) Garbage left on the banks of Dudh Koshi River at Phakding: improper disposal of solid waste along trekking itineraries causes deterioration and pollution of the environment. (Photo by Pramod Kumar Jha)

course to allowing the rightful inhabitants to use resources more sustainably than under current conditions, where anthropogenic pressure comes from multiple sources. *Mountain areas* are environments in which SES analysis is particularly important. Indeed, here local economies mainly rely on primary production, tourism, and leisure activities; thus the link between society and ecosystem goods and services is closer than in other environments. Highlands are characterized by fragility, complexity, and marginality (Beniston 2003; Wymann et al 2006), as well as limited resilience to both environmental and anthropogenic pressures that weaken the delicate balance between humans and nature (Jansky and Pachova 2006). Ramakrishnan at al (2003) provide a detailed analysis and evaluation of methodological issues implied in linking biophysical and human dimensions of ecosystems, underlining that this linking is a critical requirement in many mountain areas.

Many authors have emphasized that mountain SES management needs to be assisted by a *participatory approach* (Curt and Terrasson 1999; UNEP 2004; Jansky and Pachova 2006). Pirot et al (2000) give 4 justifications for stakeholder participation: (1) local stakeholders have a strong interest in the management process, being dependent on the services that ecosystems provide; (2) they often have considerable, relevant knowledge of the ecosystem and the ways in which it can be managed; (3) in some cases, the cultural, ethical, and spiritual values of local stakeholders have developed on the basis of a long-standing interaction with an ecosystem, so their interest goes beyond simply deriving material benefits from the system; and (4) in many cases, they have developed local use or tenure systems that can be adapted to the aims and objectives of an ecosystem management program (see also Rist et al 2003).

Emergent forms of direct participation with stakeholders involved in processes of collective decision-making aim at reducing the distance between governmental and local problems. The use of *models* in open decision-making processes is not a new concept: case studies date back to at least 1961 (Rouwette et al 2002). The basic idea remains the same: the use of models involves stakeholders in the conceptualization, specification, and synthesis of knowledge and experience into useable information (ie models) for the purpose of addressing a complex problem. Advantages reported in support of participatory modeling include providing stakeholders with systems insight, scoping analyses, and education toward a common understanding of the issues (Palmer et al 1993; Rouwette et al 2002; van den Belt 2004).

In this context our objective was to identify key considerations in designing and implementing a participatory modeling framework specifically developed in the context of mountain SESs, within the framework of a 3-year partnership project in the Hindu Kush–Karakoram–Himalaya (HKKH). Various participatory modeling exercises with different purposes were implemented in the Sagarmatha National Park and Buffer Zone (SNPBZ; Nepal) and the Central Karakoram National Park (CKNP; Pakistan), according to an integrative approach linking research and management, and focusing explicitly on local needs (Figure 1). Given the breadth of this subject, in this paper we focus on experience garnered in the SNPBZ and CKNP, where our modeling approach was implemented. First, however, we

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offer a systematic presentation of the *conceptual rationale* behind our approach and choice of tools. We begin by providing an overview of hard and soft systems methodology, with the aim of presenting the general approach. We then describe the framework consisting of 5 stand-alone modules, with explicit references to the relevant literature. For each module we present a review of well-known tools currently available in the literature. We then provide insights into the 2 case studies and finally discuss lessons learned regarding the application of the adopted participatory modeling framework in our mountain SESs.

An overview of hard and soft systems methodologies

Agent-based and System Dynamics

Hard and soft systems methodology has a rich history. Over time, 2 major nonlinear modeling techniques emerged: agent-based (AB) modeling (Bousquet and Le Page 2004) and System Dynamics (SD) modeling (Forrester 1994). Both techniques aim at understanding complex systems, but whereas AB modeling looks at global consequences of individual interactions in a given space, SD helps trace the behavior patterns of a dynamic system to its feedback structure, seen as intrinsic in real systems (Scholl 2001). The AB modeler defines behavior at individual level, with the global behavior emerging as a result of many individuals. By comparison, SD abstracts from single events and entities and takes an aggregate view, concentrating relationships among different system entities (Borshchev and Filippov 2004). Therefore, the 2 modeling techniques can be considered complementary, and both could be applied in participatory modeling for analyzing the complexity of SESs (Janssen and Ostrom 2006). SD is more demanding, requiring a wide knowledge of SES dynamics. At the same time, starting from a deductive approach, it offers the possibility of suitably modeling the general system behavior, such as by analyzing the impacts of alternative policies. In the SNPBZ case study presented below, in which it was possible to apply the proposed framework in its completeness, we based our modeling approach on SD, considering on the one hand that we worked in a context where adequate knowledge of the target SES existed, and on the other that we did this within a project offering the possibility of filling existing knowledge gaps.

Soft System Methodology

Lane (2000) points out the necessity of integrating SD in a methodology that takes into account local community perspectives, such as the Soft System Methodology (SSM). Checkland's (2000) SSM is one of the most-developed systems methodologies available today. SSM is deeply rooted in the evidence that the application of hard-systems thinking to real-world situations is inadequate. Thus SSM started to test a new methodology that shifted the systemicity from the real world to the process of enquiry itself. SSM articulates a learning process that takes the form of an enquiry process in a situation where people are concerned. This process leads to action in a never-ending learning cycle: once the action is taken, a new situation with new characteristics arises, and the learning process starts again.

SSM is not a "problem-solving methodology"; this can cause concern and unease among practitioners. SSM according to Lane and Oliva (1998) is a methodology to explore the real world; because its models are not descriptions of the real world, they are not normative but "ideals," faithful only to one particular worldview. Methodological practices that combine the hard–soft systems methods spectrum have been widely reported in many studies and well synthesized in Rodríguez-Ulloa and Paucar-Caceres (2005), among others. Over the last few years there has also been some debate about how SD links with other systems methodologies and about its role and position within wider social theories (Lane 2000). Essentially, a methodology has developed from the combination of 2 widely used systems-based methodologies, coming from 2 different systems thinking paradigms: SSM and SD (Rodríguez-Ulloa and Paucar-Caceres 2005).

The 5-module framework developed for the HKKH Project

The framework we adopted is based on the contributions illustrated on the left-hand side of Figure 2. We chose these studies because they employ approaches that combine soft and hard methodologies, and because they suggest a framework supporting Participatory Modeling applied in different contexts, as briefly summarized here.

To support decisions on environmental investments and problems, Costanza and Ruth (1998) propose a 3-step process for developing computer models for problem scoping and consensus building. Fall et al (2001) propose a collaborative model framework to support landscape analysis in forest modeling projects. Modeling in this case is also centered more on people and issues than on outputs. Walker et al (2002) present a 4-step framework for managing resilience in SESs, with resilience defined as the ability of the system to maintain its functionality when it is disturbed. The aim is to identify possible driving variables, as well as processes in the system that govern the dynamics of the variables considered important by stakeholders and decision-makers. Integrating these contributions, we developed and adopted the 5-module framework for collaborative modeling described below. By increasing the number of modules compared with past proposals (see Figure 2), a framework emerged that advantages the process one step further: being more detailed, our proposal allows increasing the value and

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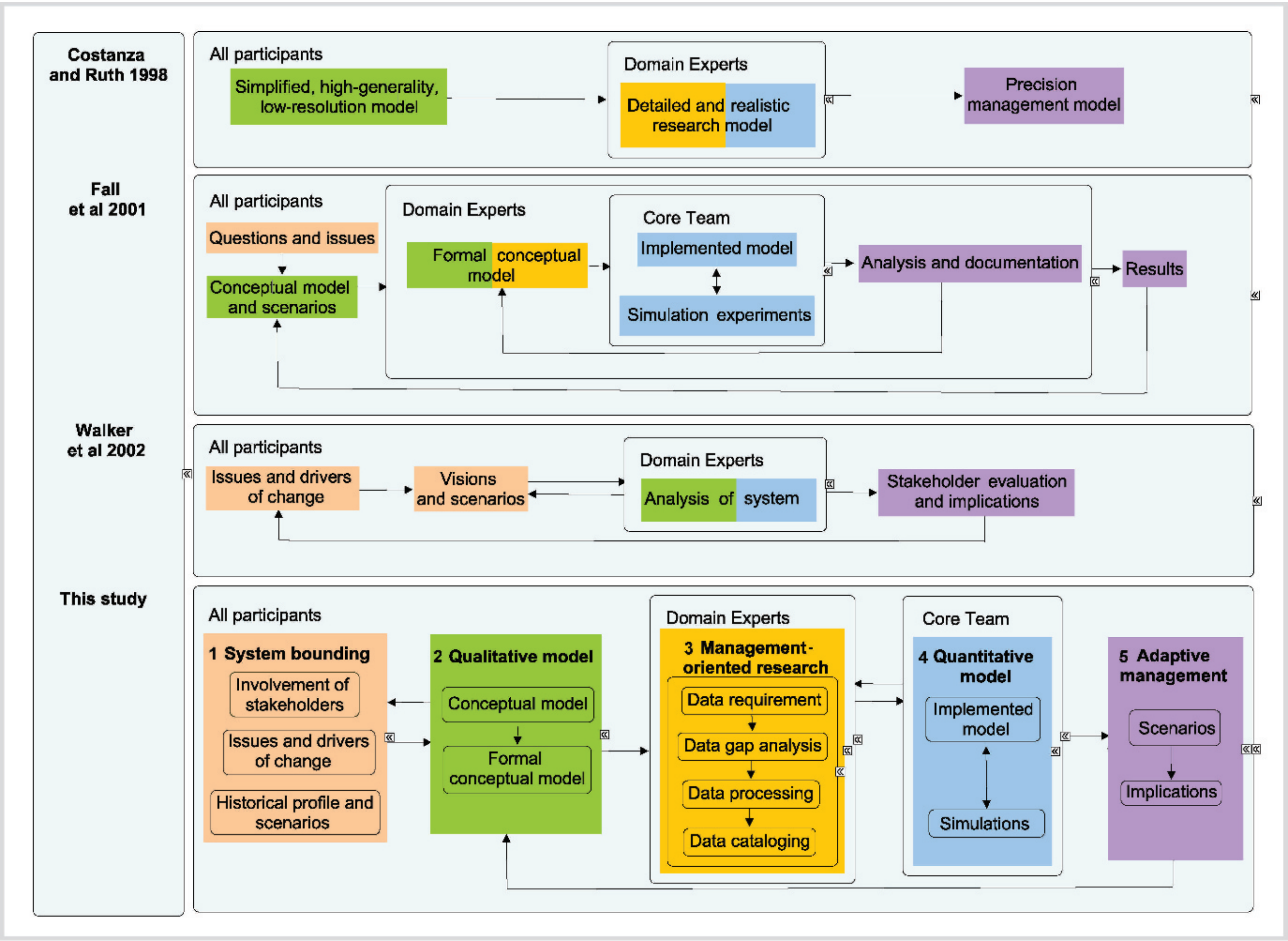
FIGURE 2 The 5-module framework for participatory modeling (bottom) in comparison with other frameworks. The colors used correspond to the 5 modules in our proposed framework. These have also been assigned to the corresponding structures of other authors. For example, in the "formal conceptual models" module proposed by Fall et al (2001), we use a double color to indicate that these authors provide recommendations for research required at this stage, a concept that we developed one step further in the management-oriented research module.



meaning of modeling results for those involved, with a number of goals:

1. As in the proposal of Costanza and Ruth (1998), the aim of overall participatory modeling is to build consensus and scope problems; this occurs particularly in the first 2 modules of our proposed framework, where participation of stakeholders and decision-makers is most significant.
2. As in Walker et al (2002), our Module 1 permits the creation of models that address the major issues of concern to stakeholders and decision-makers (bounding the problem) and explore how the system will respond to drivers of change.
3. As discussed in Fall et al (2001), the formalization of conceptual models in Module 2 fosters communication among participants and helps to define research requirements. Fall et al point out that this step may elicit recommendations for required research, data collection, or technological advances.
4. Introducing a new module based on 2 former modules (Module 3) devoted entirely to research makes it possible to design research in a truly management oriented manner.
5. After the quantitative analysis (Module 4), a module using scenario planning should make it possible to provide suggestions to tackle the identified problems at the level of policy and management. The iterative and cyclic nature of the process (see Figure 2) enables adaptive management of the SES.

The boxes in Figure 2 illustrate what groups participated in the different stages of the process in the

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SNPBZ, where all modules were implemented. In Modules 1, 2, and 5, all participants (stakeholders and decision-makers, domain experts [domain researchers], and a core team including modelers and project representatives) were involved in identifying major issues and drivers of change of the SES through explorative scenarios (Module 1), developing conceptual models for bounding the system (Module 2), and discussing the results of quantitative models along with simulation of management scenarios in Module 5. In Module 3 domain experts contributed their topic-specific expertise to performing management-oriented research in the field, while the core team took part in implementing quantitative models (Module 4), ensuring consistency with the conceptual models, running simulations, analyzing outputs, and coordinating the overall process.

Module 1: system bounding

The modeling process starts by involving the different actors from the very beginning. Lynam et al (2007) make a comprehensive description of different participatory approaches that can be adopted for adequately involving local views and perspectives. These can be understood as a continuum that ranges from simple extractive methods to collect knowledge, values, or preferences from a target group, to *co-learning* methods in which the perspectives of all groups change as a result of the process, and *co-management* methods in which all the actors involved are learning and are included in the decision-making process. The project design and the research questions and objectives should dictate the degree of participation necessary. By contrast, Wollenberg et al (2000) describe specific tools that are used for imagining possible future outcomes, but with different purposes: vision scenarios serve to elicit people's hopes and aspirations, projection scenarios identify the consequences of the current situation projected into the future, pathway scenarios illustrate routes of evolving scenarios and designs for strategies for change, and alternative scenarios show a range of possible alternatives of the future and help to deal with uncertainty. In agreement with Walker et al (2002), who like us sought to analyze the system starting from a local perception, from which the real issues and drivers of change could emerge, we adopt the Scenario Planning method, which makes it possible to develop alternative scenarios.

Explorative scenarios: Scenario Planning (Schwartz 1998; Burt and van der Heijden 2003; Peterson et al 2003; Bradfield et al 2005) offers a possibility of engaging stakeholders and decision-makers in developing a common understanding of the future. It is based on formulating narrative descriptions of hypothetical alternative futures based on the real experiences that stakeholders and decision-makers have had with the system in which they live. The narratives contribute to bounding the system, that is, to determining what aspects of the system need to be analyzed (subject of analysis). These *explorative scenarios* should not be confused with those presented in Module 5, which allow the results obtained by the modeling process to be projected into the future (see also Daconto and Sherpa 2010, in this issue).

Explorative Scenario Planning makes it possible to obtain information about the important issues that are of concern to stakeholders and decision-makers and the major drivers that govern the system's dynamics. This activity allows the system to be bounded by restricting the ensuing qualitative analysis solely to specific aspects of the SES. The process of discovery is necessarily iterative and begins with discussions among stakeholders, decision-makers, other local experts, and scientists aiming at examining how the system will respond and change under the various scenarios. In fact, these discussions in themselves will go a long way toward building a common understanding (Walker et al 2002). This phase focuses on investigating and/or modeling a specific problem rather than investigating the whole system; the exercise helps participants to identify and agree on the goal of the whole process by answering the questions: *What problematic behavior are we trying to change*? and *What are the major drivers that govern the system's dynamics*?

Module 2: qualitative modeling

Mendoza and Prabhu (2006) present 3 general types of soft system dynamics models that can be used under a participatory modeling framework: cognitive mapping, qualitative system dynamics, and fuzzy cognitive mapping. Their presentation of cognitive maps underlines features that led us to use such maps in our case studies, based on their potential as a learning and communication tool (Neudoerffer et al 2005). The process of defining and describing the system helps organize information and highlight connections. It helps explain the question: *How does the problematic behavior develop in the social-ecological system*?

All actors concerned participate in the process, starting by generating ideas concerning issues and factors affecting the management of their natural resources. The focus of this qualitative phase is on understanding the meaning embedded in participants' experiences through an open-ended, unstructured, and subjective approach.

Cognitive maps: A cognitive map (Novak 1998) can be used to frame a research project, summarize qualitative data, analyze themes and interconnections in a study, and present findings. Neudoerffer et al (2005) offer a good example of how cognitive maps have been used in development cooperation, in particular to understand the complex SES in Kathmandu, Nepal. The maps allow researchers to visualize participants' meanings as well as the connections made by participants between concepts or bodies of knowledge. No specific rules are needed for stakeholders and decision-makers to build cognitive maps. In this way the maps can trigger lateral thinking and help elucidate management problems.

After this creative process the maps—from being a useful tool for fostering the birth of ideas—can become useful for communicating concepts and their relationships. But this requires establishing rules for facilitating mutual understanding. In our framework, Module 2 foresees the formalization of the cognitive maps (Figure 2).

An important element that needs to be developed with the stakeholders during this conceptual phase is the definition of intervention points or policy levers in the analyzed system, to help focus on appropriate levels of decisions. This step guides participants in answering the question: *Where can we intervene in the system*?

We chose CmapTools as supporting software to facilitate the construction and sharing of cognitive maps (Salerno et al 2008). Along with a collection of Public Places (CmapServers) where Internet users can create folders and construct, copy, or publish their cognitive maps, the client–server architecture enables sharing of cognitive maps and collaboration during cognitive map construction.

Module 3: management-oriented research

Module 1 makes it possible to define what aspects of the system need to be analyzed, that is, what are the "issues of concern for stakeholders and decision-makers." This activity enables participants to limit the qualitative analysis to specific aspects of the SES in Module 2. In this framework, Module 3 is added to Modules 1 and 2 because it is only after having analyzed the selected dynamics of the system, and after having made the effort of formalizing this analysis (an action that brings the qualitative analysis very close to quantitative analysis; see Supplemental material, Table S1; http://dx.doi.org/10.1659/MRD-JOURNAL-D-10-00014.S1), that the research requirements for supplying data for the quantitative models can be identified. In a similar manner, Costanza and Ruth (1998) place the research step after the conceptual analysis of the system, while Fall et al (2001) consider that this should be preceded by a phase of better structuring the conceptual work. Walker et al (2000) do not address the problem of implementing new research and in their framework consider only very simple models (art, writing, music, or mathematics, for example).

In a project such as ours, where modeling is a crucial part of both the participatory and scientific processes, particular attention needs to be paid to correct research planning in order to both increase participants' understanding of the selected management issues (Modules 1 and 2) and satisfy quantitative modeling requirements (Module 4). Module 3 is conceived as the hinge between these 2 processes.

An added value at this stage is the emerging knowledge about what key data need to be collected in the long term through sites for permanent monitoring of the SES's dynamics. This monitoring concept is typical of natural science research (eg in fields such as meteorology and hydrology), but it can also be used in management-oriented research. In this way, data of relevance to management aims can be monitored over the long term, and the environmental effects of management interventions can be assessed.

Module 3 also foresees dissemination of existing knowledge and data in order to link research with management priorities; indeed, mechanisms need to be established to make findings available to both researchers and decision-makers (Feek and Morry 2003; Cokerill et al 2006). In order to achieve more robust knowledge for sustainable development, some phases of the research process should actually consist of co-producing knowledge between academic and nonacademic actors as a valuable tool to both decision-makers and local communities. If this co-production encourages social learning processes involving scientists, experts, politicians, and local actors, and their corresponding scientific and nonscientific knowledge, those involved will be able to move from a rather top-down understanding of sustainable *management* to a more participatory practice of sustainable *governance* of natural resources (Rist et al 2007).

Data requirement, gap analysis, monitoring, and dissemination: The data requirement list for implementing the quantitative model is reached through converting the formalized cognitive map into a primitive empty model designed to be run with invented data. This very iterative process involves both the core team with modeling capabilities as well as domain experts for the research component. At this point, the domain researcher must identify which data can be extracted from the literature and which must be gathered in the field (data gap analysis).

Once the research work plan is drafted and the monitoring campaign effected, some data must be processed before being inserted in the model. As a tool for supporting this process, which involves several researchers in field campaigns and modelers who make sure that all the necessary data are gathered for model implementation, we use Google Groups (http://groups.google.com/) and Google Docs (http://docs.google.com/); both services are free of charge and support discussion groups and sharing data. In the HKKH Project, while the data were being produced and processed, we took measures to create specific metadata and publish them online. As specified in Bajracharya et al (2010, in this issue) we created an Integrated Web Portal (IWP) (www.hkkhpartnership.org) as the main tool for hosting and disseminating the information on and research data collected in the target areas, as well as for promoting interdisciplinary collaboration and communication among concerned stakeholders and decision-makers, researchers, and users from the general public.

Module 4: quantitative modeling

In building mental models, humans typically simplify systems by founding their analysis mainly on qualitative rather than quantitative relationships and linearizing the relationships among components, treating systems as isolated from their surroundings (Mendoza and Prabhu 2006). When problems become more complex, we encounter limits to our ability to properly anticipate system change (Costanza and Ruth 1998). In such cases, our mental models need to be supplemented with quantitative research, with a view to developing and employing mathematical models, theories, and/or hypotheses pertaining to natural phenomena.

Quantitative simulation using System Dynamics: As specified above, we adopted SD to study the system's behavior and the impact of alternative policies. We used Simile, an SD modeling software designed by Simulistics Ltd. (UK) (http//www.simulistics.com). It uses a declarative modeling approach to represent interactions in complex systems in a clearly structured, visually intuitive way. Simile is billed as a "visual modeling environment," meaning that models are developed diagrammatically (as opposed to writing lines of text, as in a programming language or a simulation language). The first advantage of this approach is that there is no risk of the description of the model failing to match the implementation of the model: the description is the implementation. Second, once a model is represented declaratively, one can do many things with it apart from simulating the system's behavior: for example, generate descriptions in a variety of formats, interrogate its structure, compare its structure with that of another model, or transform it into a simpler or more complex model (Muetzelfeldt 2004).

Module 5: adaptive management

The design and concepts of this final module refer to the ideas developed and revised by Wollenberg et al (2000; see above). The aim is to simulate model *management scenarios* developed with the participation of all the modeling actors. The objective of this phase, as well as of the entire modeling process, is to build consensus on the understanding of the system, as well as to improve the decision-makers' adaptability not only in responding to changes, but also in anticipating them. These management scenarios have a different function to those presented in Module 1, which as described above precede the analysis of the system and can be defined as exploratory (for an illustration of the differences in implementation, see Daconto and Sherpa 2010, in this issue). The main question addressed at this stage of the process is: *What are the effects of possible policies aiming to mitigate problematic behavior?*

Management scenarios: Management scenarios are stories or "snapshots" of what might be. Decision-makers can use them to evaluate what to do now, based on different possible futures. Hence, the costs and benefits of policy options are analyzed through management scenarios, decision-makers are guided toward the desired system goals, and a new participatory process can start.

Our case studies in the HKKH

In this section we briefly describe the 2 case studies that embody characteristics of the 5-stage modeling process outlined above. We applied this framework in a sequential manner; however, in the case of the Central Karakoram National Park (CKNP) in Pakistan, we proceeded only as far as the end of the Qualitative Modeling (Modules 1 and 2), while in Sagarmatha National Park and Buffer Zone (SNPBZ) in Nepal it was possible to complete the whole process, for reasons given below.

The Central Karakoram National Park (CKNP), Pakistan

In Pakistan, the Central Karakoram National Park (CKNP) was officially established as a national park in 1993. The CKNP is Pakistan's largest Protected Area, covering over 10,000 km^2 and encompassing some of the world's highest mountains and largest glaciers outside the Polar Regions (eg the second highest peak in the world, K2). There are no settlements within the current boundaries of CKNP, but people living in the buffer zones surrounding the core park area rely heavily on natural resources and ecosystem services provided by the CKNP for their livelihoods (Salerno et al 2009a). Intense human pressure on natural resources in parts of the buffer zones make it necessary to develop a sustainable park management plan (Hagler Bailly Pakistan 2005).

Currently the Northern Areas Administration (NAA, Pakistan) is implementing a planning process to produce a Management Plan for CKNP through its Forestry, Wildlife and Parks Department (NAAFWPD). Although the NAAFWPD is responsible for this planning process and future CKNP management, they experience the constraints of inadequate manpower and insufficient resources for park operations. Many organizations working in the area share a concern for the protection and sound management of CKNP's resources and are working with the NAA government toward conserving natural resources and meeting the social needs of communities residing in the area.

The HKKH Project supported this process by organizing a series of events designed to develop a shared vision among the project, key national stakeholders, resource organizations and other resource persons. The workshops were attended by a diverse group of

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stakeholders, including senior government officials, researchers, academia, nongovernmental organizations (NGOs), and technical experts from international organizations, including project partners and others such as the WWF (World Wildlife Fund for Nature). This local exploration concluded with the agreement that the Project's role would be to introduce a range of planning and decision support tools. Participants noted that the management planning process would be successful only if the government and the communities really owned the process. A participatory approach was considered the best option to meet this requirement. Furthermore, the workshop highlighted the need for identifying key management issues and implementing baseline studies (IUCN 2008). The following is a brief summary of the results of the application of the first and second modules of the abovementioned participatory structure; these steps will lead to the drafting of the CKNP management plan in the next few years.

Explorative Scenario Planning (Gilgit, 10–13 June 2007) and *Qualitative Modeling* of the CKNP (Gilgit, 7–8 November 2007) were organized in 2 workshops with the aim of bounding and conceptualizing the SES. We observed that national and international political instability, and the subsequent local lack of confidence among stakeholders, played a major role in the scenarios, thus greatly restricting the capacity for exploration that could have been the contribution of a policy in the management of the SES. Therefore, we tried to bypass this restriction by exploring in detail the plausible implications of 2 possible extreme governance systems (strong centralization versus strong devolution). We attempted to stimulate a more articulate way of thinking about the consequences of these governance systems on natural resources. A wide variety of ideas and factors emerged, and the assessment of implications of governance systems started taking shape. The lack of laws and regulations for effective management of the CKNP to protect natural resources and the local economy was identified as the main local need.

During the same meeting on Scenario Planning, participants were asked to identify drivers that were likely to cause change in the CKNP over the next 30 years. The most important drivers identified were population growth, change in forest coverage, climate change, and agro-pastoral subsistence practices. Accordingly, within the second meeting on Qualitative Modeling, the conceptual exploration started by favoring the creation of cognitive maps linked to the identified system drivers. Moreover, the stakeholders pointed out the need to analyze the following aspects connected with livelihoods: mining activities, fuelwood and timber extraction, the increasing need for agricultural and pasture land, and, in relation to climate change, water availability for the future and possible occurrence of natural disasters (eg glacial lake outburst floods [GLOFs]) (IUCN 2008, 2009).

Participants' assessment of both workshops was generally positive. They found the participatory approach useful because it allowed them to stimulate reasoning about current problems afflicting the park and how these problems could be faced. In general participants advocated giving more power to local communities and developing local rules to preserve the communities' integrity and their natural resources. Stakeholders asked whether this type of initiative could be increased, underlining that although the government declares it is interested in this kind of bottom-up approach, such local initiatives have never occurred to date. A few participants emphasized that some important stakeholders were missing, such as miners.

One of the final requirements was that sound management data be collected at local level for the realization of a management plan capable of taking into account each individual valley's specificity. Moreover, the participants also explicitly required that the workshop techniques be used again in future and that the process be conducted with a full involvement of the local community. In the coming years the management plan process will be concluded by the Karakoram Trust Project and SEED Project (Social, Economic and Environmental Development in the CKNP and Buffer Zone; see www.evk2cnr.org).

The Sagarmatha National Park and Buffer Zone (SNPBZ), Nepal

The Sagarmatha National Park and Buffer Zone (SNPBZ) is situated in the northeastern part of Nepal, amid the world's highest peaks. Almost one third of the territory is characterized by snow and glaciers, and less than 10% of the park area is forested. In 2008, the park included about 100 villages. Although in many of these villages traditional agriculture and animal husbandry are still of the main source of livelihoods, more recently the local economy has become dependent upon tourism and tourism-related activities (climbing, portering, guiding, lodge management). As underlined by numerous authors (eg Byers 2005; Nepal 2008), the growth of mountaineering and trekking tourism since the 1970s has had a major influence on the social-ecological system, often with a positive economic impact, providing tourism-related employment opportunities, but also causing problematic environmental and cultural changes.

Embedded within the HKKH Project, our experience with the 5-module framework began with *Scenario Planning*, reported in detail in Daconto and Sherpa (2010, in this issue). Here we underline how this Scenario Planning became part of the general context of the overall participatory modeling process. It was introduced through 2 explorative scenario workshops involving different key local stakeholders such as representatives of the tourism industry, NGOs and trade associations, religious institutions, park managers, decision-makers,

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development and research organizations, and park communities. Participants were asked to identify the key events and changes in SNPBZ over the last 100 years and to imagine and write credible descriptions of the status of the park 25 years into the future (what each hoped to see, and their main fears about what they might see). They were also asked to identify major questions, challenges, and concerns about the future in SNPBZ in general and the tourism industry in particular. A high level of consensus emerged regarding the main challenge, *"How to develop quality and sustainable ecotourism in SNPBZ?"* and the main drivers of change affecting tourism. As the main output, a *text-based representation* of the identified past and alternative future systems was produced, linking the past and present state and events with hypothetical future states and events.

Stakeholders and decision-makers identified increase in tourism, immigration, and temperature as the main issues causing impacts on environmental quality and on the quality of life. The workshop approach also focused participants' attention on the uncertainty surrounding future changes and the ability of stakeholders and decision-makers to control these. We therefore decided to concentrate modeling efforts only on tourism and immigration flows as main drivers in SNPBZ's SES (Figure 1). Based on the identified impacts of environmental management, we extended the analysis to issues concerning energy, forests, air and water pollution, and solid and human waste.

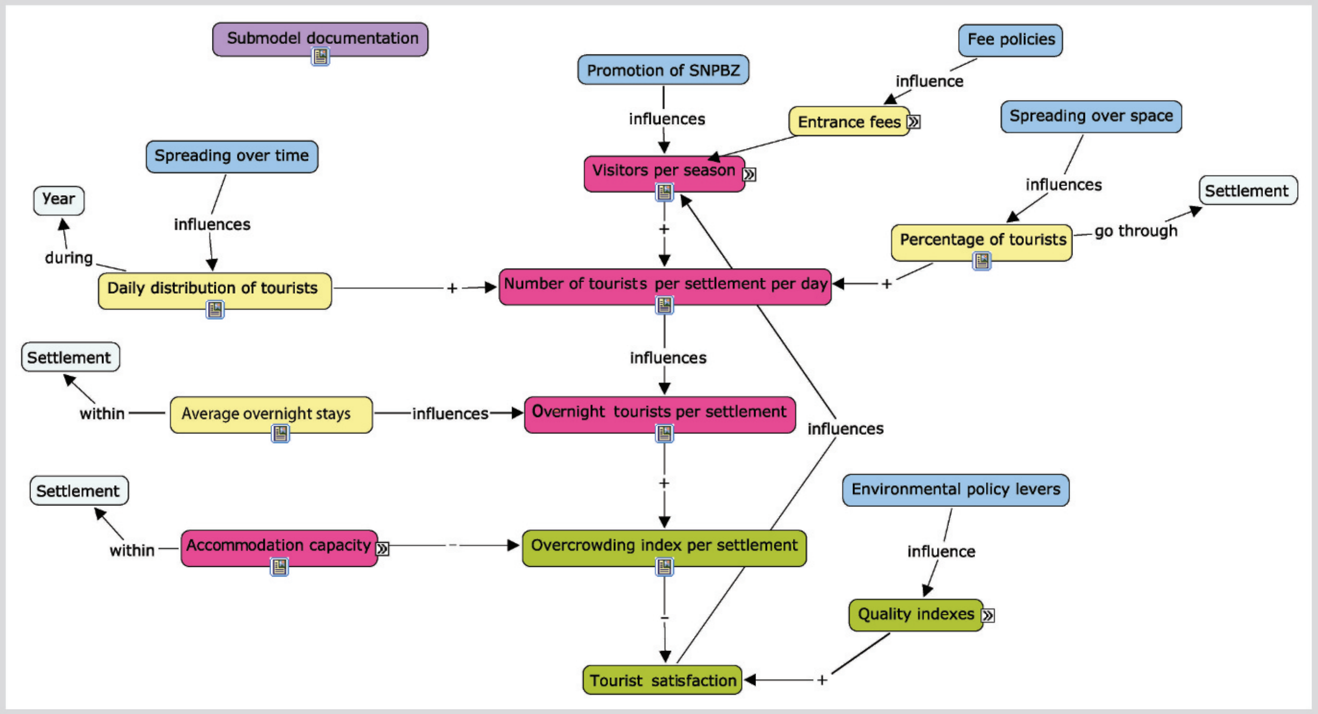
The conceptualization phase of the SNBZ's SESs (Module 2) consisted of a prolonged series of meetings in which a wide variety of stakeholders participated. Considering the number of themes that emerged during these meetings, this phase of analysis was extended for several months, carried out as face-to-face meetings between the core team, domain experts, and stakeholders, as well as more confined sessions and theme-oriented or individual analysis of the concept maps produced during the most-attended meetings. During the standardization phase of *Qualitative Modeling* in particular, the stakeholders and decision-makers were strictly supported by domain experts from each specific research field. In turn, domain experts were supported by the modeling experts (core team), who prepared a protocol for the formalization of qualitative diagrams. Moreover specific training activities on using cognitive maps and the software were organized.

This protocol included guidance on diagramming notations, such as the color to be used to express a kind of concept or the label to be used on the connectors (ie the arrows/arcs) to link concepts together. The protocol also supports preparation of the documentation annexed to the cognitive map. Table S1 (Supplemental material, http://dx.doi.org/10.1659/MRD-JOURNAL-D-10-00014.S1) summarizes the main guidelines inserted in the protocol for the standardization of cognitive maps. These cognitive maps reached a maturity level that allowed us to use them as a stand-alone management resource and communication tool, as well as for creating an adaptable picture of the selected SES's dynamics. More importantly, within the context of the 5-module framework, this activity invited domain experts, stakeholders, and decision-makers to think hard about which elements of knowledge (see Supplemental material, Table S1; http://dx.doi.org/10.1659/MRD-JOURNAL-D-10-00014.S1) are really required for passing from a conceptualization of the system to a quantification of its dynamics. It was thus the basis for the following module, ensuring adherence to real management needs of the system. Figure 3 shows an example of a cognitive map developed following these guidelines.

The process in the SNPBZ went beyond the qualitative phase, as knowledge of the social-ecological dynamics of the park and its management is already well developed. To establish the final list of required *management-oriented research* data needed to implement the quantitative models, as described below we went through an iterative process with inputs from both the qualitative and quantitative phases. We first created a quantitative model structure in order to consider quantitative requirements as well. After having completed the data gap analysis we defined what data were available in the literature and what data had to be acquired in the field. This eventually led to a management-oriented environmental monitoring plan. Field activities were then carried out in the SNPBZ, covering the areas of forestry, energy, air pollution (Salerno et al 2010, in this issue), waste, water quality (Manfredi et al 2010, in this issue), and tourism management (Caroli 2008). Suitable environmental monitoring schemes were initiated, and *permanent environmental monitoring sites* focusing on key management data were developed in SNPBZ (eg water quality, reduction of solid waste generation, forest condition and impacts of climate change, fuelwood consumption).

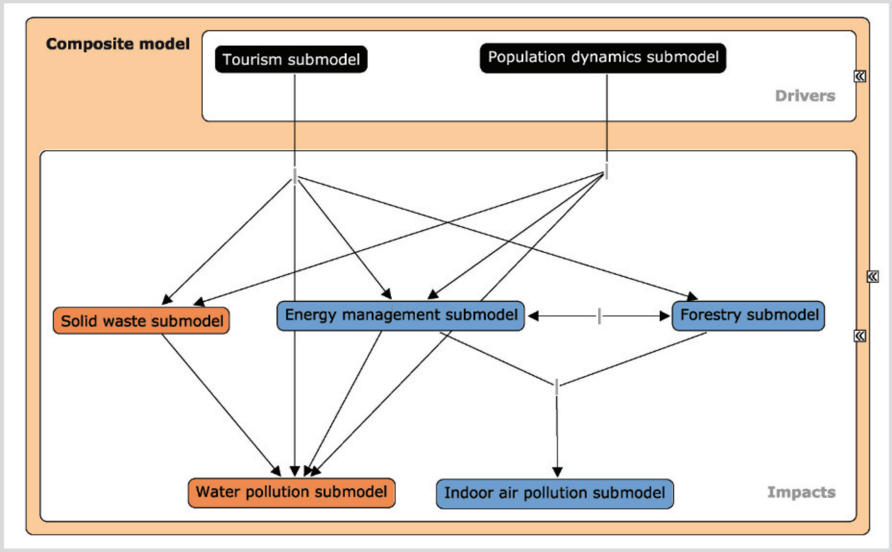
Figure 4 shows the overall structure of the *quantitative composite model* for social-ecological system management of the SNPBZ. Increasing tourist flow and changes in population dynamics were identified as drivers in the SNPBZ. The same diagram illustrates the influences among the submodels developed during the qualitative modeling phase (Salerno et al 2009b). The energy management model describes the demand and supply components for each selected settlement, with a view to assessing the energy balance and related costs. The indoor air pollution model was developed with the aim of evaluating the CO concentration in houses as an index for indoor air quality, and estimating the state of the local population's health in the study area. The development of the forestry model was conceived to address the problem of forest thinning, which represents a key management issue in the SNPBZ. The solid waste management model describes the process of waste production, collection, and

FIGURE 3 Cognitive map of the qualitative model for tourism management in SNPBZ.



treatment, providing the amount of solid waste produced, treated, and disposed on the soil. The water pollution model was developed with the aim of evaluating nutrient concentration in streams and assigning an index (Excellent, Good, Sufficient, Poor, Very bad) representing water quality. In-depth descriptions of the above submodels, including their design, objectives, and main outcomes (ie simulation scenarios) are provided by Salerno et al (2010) and Manfredi et al (2010) in this issue.

FIGURE 4 Overall structure of the composite model for the social-ecological system management of SNPBZ.



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For each submodel, researchers, stakeholders, and decision-makers identified specific management levers in Module 2. This was a crucial point within the whole modeling process because both research activities and the development of quantitative models were greatly influenced by the variables available to managers for modifying the system toward desired outcomes. Therefore, in Module 2 management scenarios were identified through definition of possible policy options that could be adopted to reduce or avoid specific critical states. By contrast, in Module 5, *management scenarios* were developed to evaluate how the model performance indicators answered according to different levels of implementation of individual management policies. Scenarios were more or less complex, depending on the level of knowledge acquired regarding the feasibility of policies in phase 3 of the modeling process. Caroli (2008), Manfredi et al (2010), and Salerno et al (2010) provide details regarding how scenarios were developed. In general the "business as usual" scenarios for the selected issues show that SES management is very far from preserving a suitable human and environmental health status.

In the workshop evaluations (eg see Daconto and Sherpa 2010, in this issue), participants remarked that scenario thinking is a powerful tool to support future analysis, grasp multiple perspectives, and even avoid future conflicts; some found the methodology conceptually demanding and oriented toward participants with a high literacy level. For the qualitative modeling phase, a thorough evaluation process was not organized, considering that the working sections extended over several months; but the level of participation in, and quality of, elaboration, discussion, and standardization of cognitive maps was so proactive that we can safely state that they are a well-accepted local-level exercise for involving people in conceptualizing an SES, learning about management issues, and suggesting feasible policy options.

The overall modeling process was presented and discussed during a final Regional Workshop attended by Nepali governmental decision-makers and representatives of NGOs from all HKKH countries except Afghanistan, as well as local and international researchers. The common perception was that this modeling framework was very close to real local needs. Participants emphasized a general need in mountain areas for "bottom-up management-oriented research" conducted through a process that considers issues of concern to stakeholders and decision-makers and analyzes system dynamics. Our case studies demonstrated the potential of the approach for decision-makers aiming to solve problems in complex SESs. The representatives of the HKKH countries expressed a clear desire to apply the framework in their mountain protected areas, but we had to underline that it is a costly process, and probably a previous stage is necessary in which the international community revives its interest in remote mountain contexts, now often out of funding.

Lessons learned and conclusions

Our implementation of the participatory modeling framework to structure issues, build consensus, and solve problems in complex social-ecological systems in the CKNP and SNPBZ led to the following conclusions and lessons learned.

We applied the modules in 2 very different contexts. In Pakistan, political instability made it difficult to reach the stage of system bounding through Scenario Planning, as the issues of concern at local level were felt to be very hard to address because of the absence of parkland regulations. On the other hand, Nepali stakeholders had far more experience with participatory processes, and the conceptualization phase (Module 2) was made much easier because systems knowledge of the area was already available for the Sagarmatha region. We therefore realized how important it is to have *flexibility* in the framework: as each module can be used a stand-alone management resource, it is possible to interrupt the process at any time, without losing the value of the participatory and explorative work achieved, as we experienced in Pakistan. The different degrees of application of the proposed 5-module framework under different conditions (local constraints, specific project aims, availability of funds, participants' attitudes and backgrounds) allow the participative modeling to be used either as a problem-structuring, consensus building tool or as a problem-solving method, or both.

Concerning the importance of *communication* in participatory modeling, we experienced that cognitive maps enable sharing of different kinds of information among diverse interlocutors and at different stages of communication processes, as they allow for a variety of forms of conceptualization in common. Indeed, working on maps within the participative framework may lead to over 20 versions of the original map before it is completely formalized. The maps become more congruent step by step, until they are a refined version including the knowledge of the domain experts. In this regard, we suggest that all versions should be properly kept and cataloged (eg on CmapsServer) as indicated in the protocol, as they document the process and can be used with different interlocutors depending on the latter's background and the aim of consultation. Such a conceptualization phase is iterative: often it happens that concepts ruled out during the process are suddenly reintegrated or re-evaluated in the course of time.

The overall participatory modeling process is a fundamentally *iterative process*. As is shown in Figure 2, Module 3 leading to management-oriented research is the phase that requires the greatest degree of iterativeness.

Research activities require time, even more so when carried out in a remote SES as in the HKKH (difficulties in logistics, data acquisition, and elaboration); they require accurate planning as well as focusing on management issues. This is well supported by formalized cognitive maps and a continued focus toward the quantitative modeling requirements. In our case, once the data gap analysis phase was performed and the research workplans had been elaborated, field research campaigns started at the same time as the creation of quantitative models. In this last phase the need to change the data acquisition plan often emerged, causing consequent practical difficulties regarding field activities. In addition, it was also sometimes impossible to obtain information requested for the model (for instance, because of the unsuitability of the season or high costs of acquiring the relevant data). In such cases, we were forced to modify the model design itself. Whenever such a modification produced a new modeling assumption, it was appropriately explained in the technical documentation for the model, in order to ensure consistency of results (NIST/SEMATECH 2002).

We would also like to underline that the focus on *management-oriented research* requires that those who manage and coordinate the modeling process (ie the core team) must take care to verify that natural researchers' tendency to focus on scientific discovery is mediated by the project's management needs. As pointed out by Amatya et al (2010, in this issue), there is a strong need for steering research projects more persuasively toward management priorities, as researchers are not often inclined to give this priority in their work, given the rules of the academic world within which they usually work. It is often difficult for researchers to distinguish between basic and applied scientific research, and to give the latter a management orientation. Such an orientation should not be perceived as a mere adjective of research projects: it must become their objective. In our experience, this can be achieved when participatory modeling is conceived of not only as a problem structuring and consensus building tool, but also as a problem-solving method.

The *involvement of local stakeholders* was very strong during the first 2 modules for both case studies here presented, in terms of both participation and constructive attitudes. The workshop evaluation forms showed that most stakeholders and decision-makers involved were very satisfied both with the process and with the results obtained in terms of increased awareness and knowledge about SES issues and dynamics. In the SNPBZ, the management-oriented research carried out in Module 3 actively involved key stakeholders in field surveys, thus increasing their capability to monitor key management-oriented data to be collected over the long term. However, during the quantitative phase (Module 4), as observed by Costanza and Ruth (1998), it is usually critical at this stage to maintain stakeholders' involvement with regular workshops and meetings to discuss modeling progress and results. In our experience as well, exchange of information among stakeholders and decision-makers as well as their interests definitely decreased at this stage. According to Costanza and Ruth (1998) and Fall et al (2001), stakeholders' involvement is more important in the early phases because the objective of problem structuring and consensus building can be reached; but in our experience, their participation during the elaboration of results is just as important, as it tends to ensure a far better adherence of the model management scenarios to reality, accomplishing the problem-solving purpose of the participatory process.

A reason for the declining interest in participation over time may be that most stakeholders are volunteers, and it is difficult to force them to come repeatedly to meetings. Moreover group composition keeps changing, with evident limitations for the process. Voluntary participants often have less time available for participation than people who participate as part of their job. In closing, we suggest that care be taken to find levers that may stir interest and the will of stakeholders to continue coming until the end of such a long and complex process. One idea could be to give the established Stakeholder Working Group more decision-making power in the planning of the project's activities (eg in the approval of project working plans and the allocation of some funds for management tasks). Another solution could be the institutionalization of the participatory process: this would guarantee a natural inclusion of the process findings in the correct decisional channels, in addition to increased involvement.

We have tried to review and integrate main conceptual frameworks developed in the recent past for assisting participatory modeling processes, and we presented experience with our own 5-module framework using 2 case studies conducted in high mountain SESs. Hopefully our rationale for the framework and the lessons learned will be of use to and comprehensible for both practitioners and scientists. We believe that the 5-module framework could be of greatest use to those projects and interventions that include a substantial research and modeling component aimed at investigating the dynamics of selected SESs, with an emphasis on considering the needs of decision-makers and stakeholders. The emphasis on management-oriented research, with an entire module devoted to this step in the process, allowed us to more efficiently shift activities from a consensus-building to a problem-solving objective, thus making research far more relevant to development.

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Supplemental material

TABLE S1 Main guidelines adopted for the formalization of cognitive maps.
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