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CONCEPT MAPS FOR COMBINING HARD AND SOFT SYSTEM THINKING IN THE MANAGEMENT OF SOCIO-ECOSYSTEMS

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Abstract. Despite the huge increase in the number of quantitative modeller studies undertaken, little attention in the literature has been given to the communication process among modellers, the researchers and local stakeholders. However, such communication is necessary to ensure that this research effort becomes a useful tool in the decision-making process. The work described here is based on the systems paradigm, and combines scientific environmental analysis and ecosystem modeller (the *hard-system* approach*)* with *soft-system* participatory processes. The development of concept maps is the main tool of the methodology proposed here: combining soft and hard approaches, concept maps are first developed with the involvement of local people and local experts and then used to guide the design of quantitative models. This paper discusses how concept maps and quantitative models were developed to capture the complexity of social and ecological systems in a declarative, systems-oriented and user-friendly manner, assisting stakeholders to increase the knowledge of problems and make decisions. Finally, advantages and disadvantages of the proposed methodology are discussed.

1 Introduction

What is the best way of producing good decision support tools for the management of mountain areas in developing countries, that take full account of local people's needs, aspirations and knowledge?

Currently major gaps exist in the knowledge of crucial socio-ecosystem dynamics of the mountain complexes, and no clear mechanism is established linking research with management priorities. Typically, resource management projects employ methodologies based on environmental analysis and ecosystem modeller *(hard-system)*, or on participatory processes *(soft-system)*. Each approach has its own strengths in dealing with the complexity of systems from a variety of perspectives. However, a major existing gap is the lack of a clear methodology for integrating these two approaches.

We start by introducing the soft and hard tools that can be used for the management of socio-ecosystems in mountain areas. We then show how they can be linked together in order to ensure a smooth flow of information between the conceptualisation phase of the system and its quantitative analysis, and between the people's needs and the development of solutions.

1.1 Soft Systems Methodology

The participatory process and qualitative research were chosen here as suitable Soft Systems Methodologies for working in socio-ecosystem (SES) management.

1.1.1 The participatory process

Key stakeholders are involved in the iterative process of system conceptualisation, development and implementation to assure that real user needs are answered and a sustainable process of improved natural resource management is established. We suggest the use of three kinds of tools:

a) *Workshops* to develop a common management process for researchers, stakeholders and modellers.
b) *Scenario planning* exercises to explore possible long-term scenarios for these ecosystems. Scenario planning is a technique means to identify and stimulate analysis around alternative futures as a way of short-circuiting biased and entrenched views of the world and prepare for developments which could not be anticipated by simply extrapolating past trends.
c) C*apacity building* of resource people involved in the management and study of SES is here considered an essential element in a participatory process that uses scientific and technological resources and tools. In fact Soft Systems Methodology requires that participants adapt to the overall approach. Through formal

and informal training a higher awareness of the aims and the proposed methodologies is required for all actors involved in the process.

1.1.2 Qualitative research

The focus of qualitative research tends to be on understanding the meaning imbedded in participant experiences through an open-ended, unstructured and subjective approach (Lincoln and Guba, 1985). The researcher builds a complex, holistic picture, analyses words, reports detailed views of informants and conducts the study in a natural setting. Concept maps can provide one strategy to deal with the methodological challenges of qualitative research. A concept map (Novak, 1998) can be used to frame a research project, summarise qualitative data, analyse themes and interconnections in a study, and present findings. The maps allow the researcher to see participants' meaning as well as, the connections that participants discuss across concepts or bodies of knowledge (Daley B. J., 2004).

Sophisticated computerised software programs have been developed to assist with the data analysis process in qualitative research. In our project we decided to use CmapTools®, mainly because it is a client-server software environment that greatly facilitates the construction and sharing of concept maps. CmapTools® has been designed with the objective of supporting collaboration and sharing. The client-server architecture, together with a collection of Public Places (CmapServers) where any Internet user can create a folder and construct, copy or publish their concept maps, facilitates the sharing of concept maps and the collaboration during concept map construction (Cañas, Hill, Granados, Pérez, and Pérez, 2003). CmapTools® supports the construction of "knowledge models": sets of concept maps and associated resources about a particular topic (Cañas, Hill, and Lott, 2003) (Novak and Cañas, 2004).

1.2 Hard Systems Methodology

1.2.1 Quantitative research

The objective of quantitative research is to develop and employ mathematical models, theories and/or hypotheses pertaining to natural phenomena. The process of measurement is central to quantitative research because it provides the fundamental connection between empirical observation and mathematical expression of quantitative relationships. We use System Dynamics (SD) because it is the modeller approach that most closely matches the requirements of the Systems Paradigm. It uses computer simulations to study systems behavior and impact of alternative policies. The SD modeller software we decided to use is called Simile, and has been designed by Simulistics Ltd. (UK) (http://www.simulistics.com) for creating quantitative computer models.

Simile uses a declarative modeller approach to represent the interactions in complex systems in a clearly structured, visually intuitive way. Simile is billed as a "visual modeller environment", meaning that models are developed diagrammatically (as opposed to writing lines of text, as in a programming language or a simulation language). There are significant advantages in adopting a declarative modelling approach (Muetzelfeldt, 2004).

First, 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 as well as just simulating its 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. Finally, the adoption of a declarative modelling approach encourages the development of common standards for representing models, the distributed development of modelling tools, and the sustainability of the effort put into developing models.

As mentioned above, this paper is concerned with the need to integrate soft and hard systems approaches. Therefore, the key innovation proposed here is the development of a methodology to support socio-ecosystem decision-makers focused on reducing the gap between research and management priorities. The use of concept maps is a key element of this strategy. On the one hand, it helps in managing the information flow in the participatory process, while on the other hand it helps to create a link between qualitative and quantitative modelling.

2 The case-study

The HKKH Partnership Project aims to improve ecosystem management in the Hindu Kush-Karakoram-Himalaya region (www.hkkhpartnership.org). It was developed in the framework of the priorities defined in the World Summit on Sustainable Development (WSSD) 2002 draft plan of implementation and considering the recommendations made for achieving successful implementation of the priorities identified in the Agenda 21. It is funded by the Government of Italy (DGCS). It is a partnership initiative and the executing agencies (partners) are:

- the International Centre for Integrated Mountain Development (ICIMOD) (www.icimod.org);
- Ev-K2-CNR (www.evk2cnr.org);
- CESVI-Cooperazione e Sviluppo (www.cesvi.org);
- IUCN Country Offices in China, Nepal and Pakistan (www.iucn.org).

The activities are focused in three national parks: Sagarmatha National Park (SNP) in Nepal, Central Karakoram National Park (CKNP) in Pakistan and Quomolongma Nature Preserve (QNP) in Tibet Autonomous Region of PR China. The implementation of the project recognises the specific characteristics of each site, and allows for political and knowledge constraints. This paper focuses on the SNP site in Nepal, because there is more knowledge about the socio-ecological dynamics of this site, and the park management is well developed.

3 Methods

The methodological approach described in this paper is inspired by the approach to the management of SESs proposed by Walker et al.(2002), and summarised below. The authors argue for an approach which recognises that uncertainty is an inherent characteristic of many systems: we need to live within the system, rather than setting goals based on unattainable assumptions. In this perspective, ecosystem management hinges on strengthening the resilience of the system in case we wish to maintain it in its present configuration; or to undermine the system resilience if we wish to move the system configuration to a different state.

Walker's framework is based on four steps:

1. System description through stakeholder participation;
2. Identification of possible future trajectories of the system;
3. Quantitative analysis of system;
4. Participatory and integrated assessment of policy and management implications.

3.1 System description through stakeholder participation

In this step, we create qualitative models of the system based on the identification or definition of spatial boundaries ecosystem services, processes and change - the institutional and legal factors and power relations which influence patterns of decisions by stakeholders. The key tool for this qualitative process is the concept map. This allows us on the one hand to manage the information flow in the participatory process, while on the other hand to create a link between qualitative and quantitative modelling.

To begin with, no specific rules were laid down for stakeholders to build concept maps. In this way the concept maps were able to to trigger lateral thinking and elucidate the real management problems. However, we found that this approach made subsequent use of the concept maps more difficult, since the qualitative analysis had to be translated first into a qualitative model and then used by modellers for quantitative translation.

Therefore, we decided to restrict the notation to be used in the concept maps, in order to ensure that they would be of greater use for the subsequent qualitative and quantitative modelling. The main actors involved in the standardisation and in the construction of qualitative models were the domain researchers in relation to their relevant expertise and project experts in the modelling exercise. Specific training activities on using concept maps and CmapTools® were organised and a Protocol for the preparation of the qualitative diagrams in CmapTools® was prepared.

3.1.1 The Protocol for the qualitative modelling

This Protocol provides guidance on the diagrammatic notation to be used in the Cmaps, and the section headings and content to be used in the associated documentation. The aim of the Protocol is to introduce some degree of formality into the qualitative modelling process.

The Protocol includes general rules such as:

- The concept maps should show the flow of information from the inputs to the management outcomes. However, it is essential that feedback interactions are also captured and highlighted.
- This phase does not imply the identification of data required by the model. However, the domain researchers should be starting to consider the quantitative variables which could correspond to the concepts expressed in the concept map.
- The files are ordered alpha-numerically on the CmapServers. In order to have the files ordered by version/date, it is useful to have a versioning or dating system which gets successive versions of the model listed sequentially. The proposed system is:
  [model name] [yy] [mm] [dd] [version] [author initials]
- Every concept map project is composed of:
  - the concept map itself, realised in the CmapTools ® with relevant annotations;
  - a folder in CmapServers with descriptions defining key concepts;
  - a document describing the concept map;

The Protocol includes guidance on the Cmap diagramming, including a table specifying the colour to be used for the nodes, according to the concept they represent.

Colour of the concept	**Meaning**
Blue	Policy levers
Green	Indicators of performance
Pink	Intermediate variables
Yellow	Input data
Orange	Connection to other sub-models
Red	Economical aspects regarding the policy
Purple	Connection with the sub-model documentation

In addition, the protocol includes guidance on the labels to be used on the connectors (i.e. the arrows/arcs) used to link nodes together.

Relationship type	**Linking phrases**	**Comments**
Causal	+, -, +/-	Used to describe positive, negative relationships or when they can be either positive and negative depending on specific conditions.
Spatial	through, near, within, is-next-to, from, to	Used to describe spatial relationships. Example: tourists *go though* valleys. The linking phrases can be associated with the appropriate verb.
Time	before, after, during, delays	Used to describe temporal relationships. Example: snow leopard *migrates during* winter. The linking phrases can be associated with the appropriate verb.
Action	creates, destroys	Used to describe relationships of population dynamics. Example: snow leopard *predates* musk deer. In this case *predates* is used as a synonym of *destroys.* Synonyms of cretes and destroys can be used as appropriate.
Undefined	influence	Used to describe relationships that are known but cannot be described according to the linking phrases available. This is a generic type of relationship and should be used only when all the other options available have been checked and discarded.
Unknown	?	Used to describe relationship of unknown nature. The narrative description must be provided in a file attached to the connector. The use “unknown” relationship should be as limited as possible.

The Protocol also includes guidelines on the preparation of associated documentation, as a Word document. The aim of this is to ensure a uniform approach across the various models, and to ensure that important information is included. It specifies that the documentation should have the following sections:

- Aims: the aim of the submodel
- Narrative description: Description in words of the Cmap diagram
- Time step: the time step over which the system changes
- Spatial disaggregation: how space should be represented
- Management levers: the variables available for a manager to change, to influence the system towards desired outcomes.
- Assumptions
- Links to other submodels: information coming from or going to other submodels
- Variable requirements: expressing a (mathematical) variable that can be used for a particular concept
- Open problems about the research activity

In Figure 1 an example of a concept map developing following the guidelines is shown.

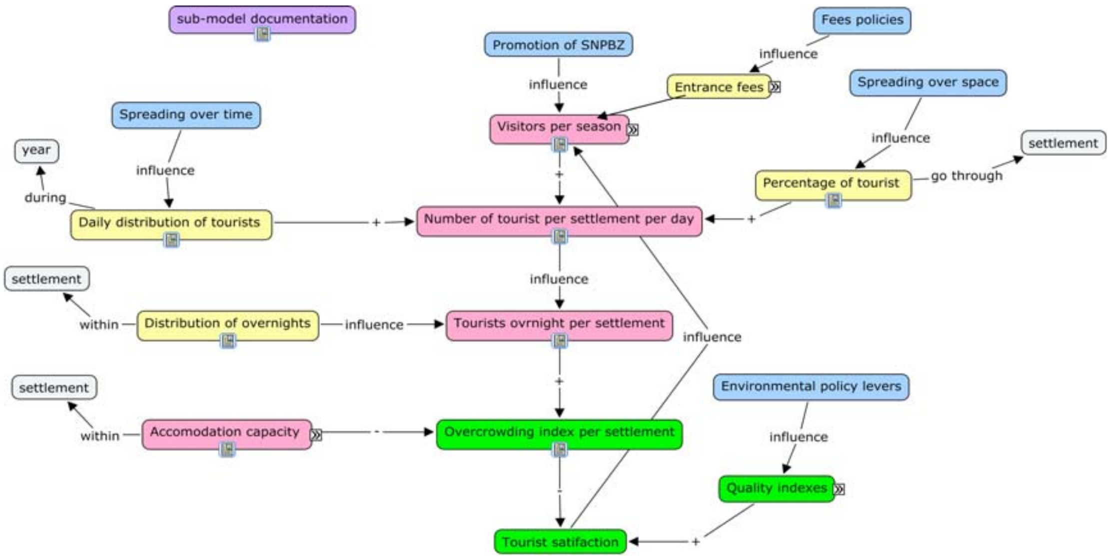

Figure 1. Concept map of the qualitative model for the analysis of solid waste management in SNP

3.2 Identification of past and possible future trajectories of the system

A scenario planning exercise was organised, at the same time as the creation of the qualitative models presented above, with the participation of 15 people from the SNP site, along with staff and experts of each partner (Daconto, 2007; Daconto and Lhakpa Sherpa, 2007). Participants were asked to identify through cards the key events and changes in SNP over the last 100 years and to land in the park in 25 years. The outcomes of this experimental exercise was the formulation of a *text-based representation* for past and alternative future system configurations, linking the past and present state and events with future hypothetical states and events. The facilitators assisted the groups and, after the meeting, reviewed the initial storylines to achieve a minimum of uniformity in style, eliminate gross inconsistencies and strengthen coherence.

Subsequently project resources translated the storylines in the concept maps to bring out the main changes (impacts) that have occurred in the SNP, the key elements (drivers) that drove and will drive the change, and the future expectations (scenarios). Figure 2 shows a concise representation of a concept map translated from narrative outputs of the scenario planning. On the left it is possible to observe that stakeholders identified the increase in tourism, the increase in immigration, and the increase in temperature as the main drivers that have caused impacts on environmental quality and on the quality of life. On the right it is possible to observe four alternative future scenarios based on the assumption of a further increase in tourism and on the new possible trajectories due to the recent Nepali revolution. The four scenarios are based on the four possible combinations of two alternative levels of centralisation of SNP governance and on two alternative roles of outside investors that could play a part in the management of new local infrastructure needs due to the assumed increase in the number of tourists.

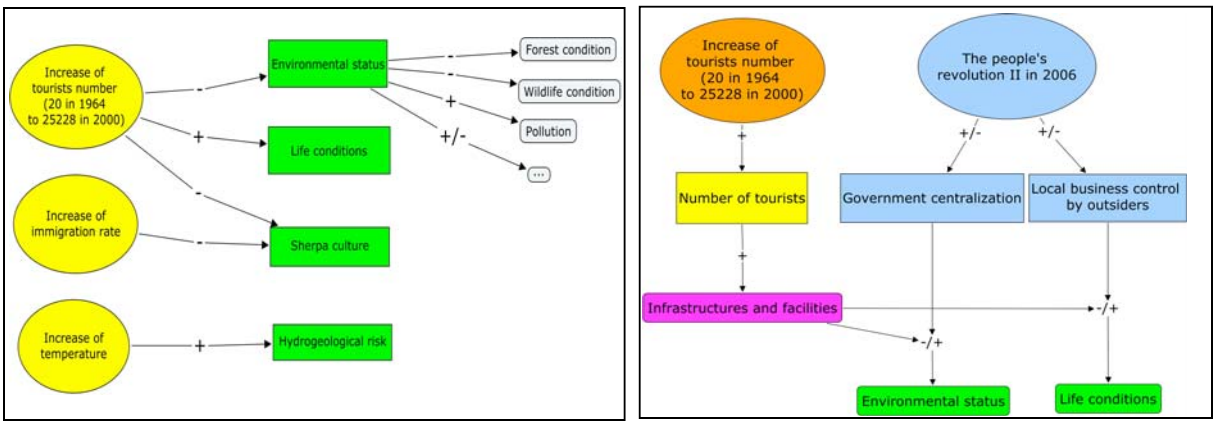

Figure 2. Left: Key events and changes in SNP over the last 100 years; Right: Alternative future scenarios in 25 years in SNP

This translation of the narrative output of the scenario planning into concept maps is necessary to ensure that the qualitative and quantitative modelling is focussed on a long term (strategic) timeframe, as a first priority. How to proceed for the full integration of these concepts into the modelling process will be considered in the discussion section.

3.3 *Quantitative analysis of the system*

In this step the *System description* performed through concept maps (step 1) is analysed to identify controlling variables at different scales, their rates, the non-linear behaviour of variables, and threshold effects. As described above, Systems Dynamics, based on the methodology of Sterman (2001), Binder et. al. (2005), was used as a hard system method to define the functioning of key process in socio-ecosystem function.The Simile modelling environment (Muetzelfeldt and Massheder, 2003) was used to implement the resulting models.

For the quantitative modelling process we use the following steps. It should be noted that the process includes iterative testing and refinement to ensure the validity, accuracy and operation of the models.

1. Quantitative red models: qualitative diagrams are translated in Simile model structure. Only the model structure is developed (the models in this phase are developed without data). These empty models are called here red models. In this phase stocks and flows, the main feedback loops, in the system are identified.
2. Model data requirement: the analysis of the structure will identify the knowledge and data required to define relationships (equations) and baseline values of model variables.
3. Data gap analysis: data gaps are identified by screening existing sources with reference to the model structure data requirements and if necessary research is conducted to complement data.
4. Metadata for data: available data are retrieved, classified and stored according to the model requirements;
5. Quantitative black models: production of models based on guessed data and relationship.
6. Simulations: the results are analysed.
7. The models and results are sent to stakeholders for review and feedbacks.

In Figure 3 the main quantitative modelling steps are described, while Figure 4 shows an an example of the quantitative model developed in Simile. The example is the same used for the qualitative modeller (Fig. 1).

Work to date has concentrated on producing the 'red' System Dynamics models in Simile - i.e. the models without numeric values and equations (step 1 in the above list). Work is underway to obtain the necessary data and to establish the appropriate equations to use in the model (step 2-5). Once this has been achieved, the simulations will be run and the results analysed (steps 6,7).

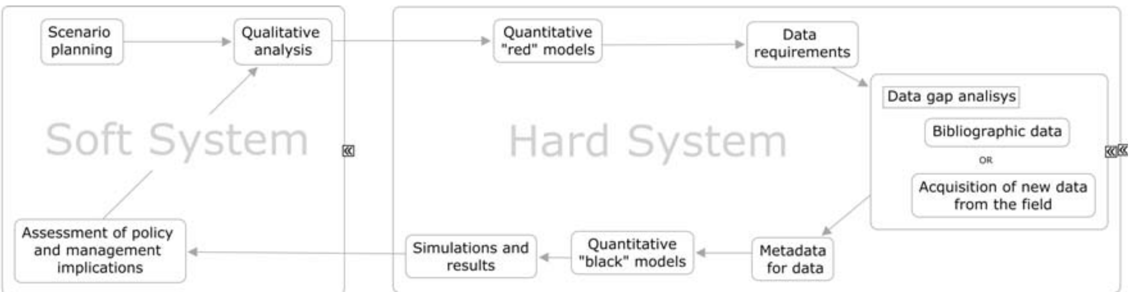

Figure 3. Steps proposed in the HKKH Partnership Project for the overall socio-ecosystem analysis and modelling

3.4 *Assessment of policy and management implications*

This is the final stage of the process, and is essential for a successful participatory and integrated approach. The stakeholders will evaluate the implications of a different set of policies on the resilience mechanisms identified in step 3. Hence policy options are identified, which can guide management towards the desired system goals.

4 Discussion

In this section we need discuss the lesson learn in the application of concept maps for combining hard and soft system thinking in the management of socio-ecosystems. For each of the four steps of the Walker’s framework for the management of SESs applied in this work, we asked relevant project experts to point out advantages and disadvantages in the use of concept maps and CmapTools® in this context.

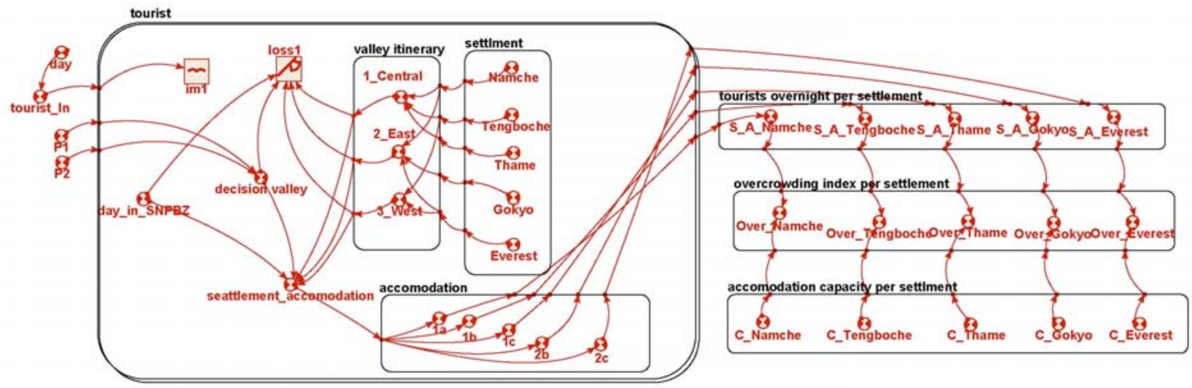

Figure 4. Example of declarative quantitative model developed in Simile: the tourism sub-model.

4.1 System description through stakeholder participation

The key drivers (pressures) identified by the groups, as well as the impacts on SESs, were used to develop the topics and themes (sub-models) for the decision-making modelling.

a) Because CmapTools has no mechanism for specifying that nodes or arcs can be assigned to a particular category, we developed a protocol to specify an indirect mechanism for classifying concepts through encouraging the use of colours for nodes, and labels for arcs. The proposed guidance seems to have an appropriate level of abstraction. It certainly helps in the later stages of the modelling process to have qualitative diagrams which have been constructed according to these guidelines, since these terms correspond in part to those used in the actual mathematical models. On the other hand, the conventions proposed here are not as technical as those used in formal mathematical modelling, so will be easier for the local experts to work with.
b) The protocol recognises that in some cases the people preparing the qualitative diagram may have information on the mathematical form of the relationship used to compute a particular variable. However, in practice the use of formal mathematical expressions seem inappropriate at this stage of the modelling process.
c) With CmapServers it is possible create a folder on the internet facilitating the sharing of concept maps. However, we note that CmapServers should improve their capability to create discussion space during the concept map construction process. Annotations facilities provided by CmapTools are not enough to support and encourage such interaction. An alternative solution is to use a *WIKI* in which one can add conceptual maps and relevant documentation, user-editable pages, and discussion forums, as well as well as customisable index pages for accessing the concept maps and related content.

4.2 Identification of possible future trajectories of the system

a) The methodology should be further adapted and simplified when stakeholders are not fluent in English. One idea is to use participatory drama to engage participants through an effective role-playing exercise.
b) Storylines developed during scenario planning required elaboration by technical people to enrich the analysis and translate the narrative into concept maps. This is one way of making a link between the soft system approach and the modelling process. The main drivers and impacts to develop modelling scenarios have been identified and already considered in the modelling process. The future scenarios suggest that in general local park management is sufficient for ensuring a reduced impact on the environment. This helps in reducing the amount of work, since we need consider only local policy levers rather than those associated with central government.

4.3 Quantitative analysis of system

As discussed above, our concept maps may be either unstructured or structured. The first has the advantage of identifying ideas, of investigating unstructured problems, looking at the problem situation from different perspectives without restrictions. This approach is suitable for the start of the process, working with a large number of participants who do not have a strong background in analytical research. However, if the final aim of the analysis is to develop quantitative models, a system of rules for constructing the concept maps is needed. In this case, the concept maps can be considered to be real qualitative models. The guidelines are more likely to be followed if training is provided for the concept map-makers. The degree of standardisation of a map can be considered adequate when possible misunderstandings in map interpretation are avoided, and for this reason the Cmaps must be properly documented. We conclude this section by pointing out the dynamic nature of concept maps. To speak about the "final version" of a concept map, developed by a large number of map-makers and users in an iterative process, is meaningless. Several versions of the same concept map can live together to reflect different conceptualisations by the map developers, and different uses for the map. The first versions of Cmaps should be developed directly by local people and they will show the interactions in the systems they are familiar with; while the latter ones will have a major orientation towards quantitative modelling, and their development should be supported by experienced modellers. The main thing is to maintain a close logical connection between each stage of the concept map process, and to document any non-obvious deviations from a straightforward conversion between one diagram and the next.

4.4 Assessment of policy and management implications

Once the quantitative modelling has been finished, a new participatory process should start. A strong effort must be made to ensure effective communication between modellers, researchers and local stakeholders. This is necessary to ensure that these research results become a useful tool in the decision-making process. It also helps if concept maps are used to show alternative management scenarios.

5 Summary

Concept maps offer a powerful way for integrating hard and soft system methodologies, and make it possible to create innovative models for socio-ecosystem management. Furthermore, concept maps afford opportunities to integrate the concept of management-oriented research into the methodology, bridging between researchers and decision-makers. From the identification of problems and ideas, passing through a structured qualitative analysis, to the sharing of alternative management modelling scenarios, all actors involved in socio-ecosystem management using concept maps can play an active role in the process. Short and long term manager perspective can be brought into the modelling process, making it more likely that the results will be incorporated into management decisions. This paper points out that different levels of concept map structure are required, depending on the intended use and the ability of the concept map makers and the users.. Training courses to increase the capacity to build concept maps and to use the relevant software are strongly recommended in order to improve the map quality. We conclude by underlining the value of CmapTools® in following the concept maps developing and suggesting and improving of tools to facilitate the communication among map makers and users.

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