The Implications of Complexity for Integrated Resources Management

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Abstract: Integrated environmental resources management is a purposeful activity with the goal to maintain and improve the state of an environmental resource affected by human activities. In many cases different goals are in conflict and the notion "Integrated" indicates clearly that resources management should be approached from a broad perspective taking all potential trade-offs and different scales in space and time into account. However, we are yet far from putting into practice integrated resources management taking fully into account the complexity of human-technology-environment systems. The tradition of resources management and of dealing with environmental problems is characterized by a command and control approach. The increasing awareness for the complexity of environmental problems and of human-technology-environment systems has triggered the development of new management approaches. The paper discusses the importance to focus on the transition to new management paradigms based on the insight that the systems to be managed are complex adaptive systems. It provides arguments for the role of social learning processes and the need to develop methods combining approaches from hard and soft systems analysis. Soft systems analysis focuses on the importance of subjective perceptions and socially constructed reality. Soft systems methods and group model building techniques are quite common in management science where the prime target of management has always been the social system. Resources management is still quite slow to take up such innovations that should follow as a logical consequence of adopting an integrated management approach. Integrated water resources management is used as example to provide evidence for the need to implement participatory and adaptive management approaches that are able to cope with increasing uncertainties arising from fast changing socio-economic conditions and global and climate change. Promising developments and future research directions are discussed. The paper concludes with pointing out the need for changes in the scientific community to improve the conditions for interdisciplinary, system-oriented and trans-disciplinary research.

Keywords: Complexity, Mental models, Group model building; Adaptive Management, Soft systems analysis, Complex Adaptive Systems, Social Learning

1. INTRODUCTION

Integrated environmental resources management is a purposeful activity with the goal to maintain and improve the state of an environmental resource affected by human activities. Management should guarantee services provided by the resource (e.g. water for irrigation, fisheries), prevent damages (e.g. flooding) and maintain the state of the resource for the use of future generations (e.g. preserve groundwater resources) but respect also the maintenance of the integrity of ecosystems as a goal in itself (e.g. maintenance of a good ecological state of rivers). In many cases these different goals are in conflict and the notion "Integrated" indicates clearly that resources management should be approached from a broad perspective taking all potential trade-offs and different scales in space and time into account. However, we are yet far from putting into practice integrated resources management taking fully into account the complexity of human-technology-environment systems. Experiences in managing environmental problems and resources provide partly success stories but when judged from a long-term perspective many policies showed unexpected side-effects. To name just a few:

- Flood control efforts such as levee and dam construction have led to more severe floods by preventing the natural dissipation of excess water in flood plains. The cost of flood damage has increased as the flood plains were developed by people who believed they are safe.
- Pesticides and herbicides have stimulated the evolution of resistant pests and weeds, killed of natural predators, and accumulated up the food chain to poison fish, birds and possibly humans.
- Programs to increase the capacity of roads designed to reduce congestion have increased traffic, delays, and pollution by attracting more people to drive with the

car and by providing incentives for a spatial segregation of workplace, residential and shopping areas.

- Policies of fire suppression have increased the size and severity of forest fires. Rather than frequent, small fires, fire suppression leads to the accumulation of dead wood and other fuels leading to larger, hotter, and more dangerous fires, often consuming the oldest and largest tress that previously survived fires unharmed.
- High security standards for heavily subsidized water supply systems designed to meet maximum daily demand have lead to quite expensive and inflexible systems and to exaggerated expectations of the public regarding the provision of services at no cost.

In all these cases policy makers, resource managers and engineers underestimated the importance of feedback effects, non-linearities, time delays and changes in human behaviour as a consequence of policy interventions. Human actors typically tend to reduce the complexity and dimensions if they are confronted with a problem to be tackled (Sterman, 2000; Vennix, 1996). What may be more appropriately described as a messy problem situation is often compressed into a description of a well defined problem with simple cause-effect relationships. Open loop structures that behave quite “benign” are assumed instead of feedback cycles. The problem of traffic congestion and the corresponding dissatisfaction of car drivers for example have been attributed to a lack of road capacity. However, such a simplifying approach is misleading. It helps to handle the problem, may be successful in the short-term but the negative effects of long-term consequences may often outweigh short-term benefits. What has been neglected in the traffic example was the fact that more and better roads provide an incentive for people to use the car more often and abandon public transport, to move to a place where they depend on the car etc. Hence it is crucial to develop methods that allow exploring all possible scenarios of the co-evolutionary development of human-technology-environment systems that may result from policy interventions, methods that allow to categorize different policy problems and that allow to develop and apply appropriate management strategies.

The insight emerging from these examples that environmental problems should be addressed from a wider perspective taking into account complexities, non-linearities and the limits of control is not really new. As already Ludwig et al. (1993) pointed out in the case of fisheries management, it seems to be more appropriate to think of resource managing of humans than the converse. They make a strong argument against the illusion of control of environmental problems. The idea of adaptive management has been introduced in resources management for quite some time (Holling, 1978; Walters, 1986; Pahl-Wostl, 1995; Lee, 1999). It is based on the insight that the ability to predict future key drivers as well as system behaviour and responses are inherently limited. But the implementation of consequences for policies is quite slow. It is argued here that the major reason for the slow pace in change is not the absence of alternative management strategies but rather the obstacles encountered in the transition process towards new management paradigms. To better understand the nature of the transition process it is useful to contrast current management paradigms with alternative approaches and to investigate the importance of learning processes at different scales both for new management styles and for the transition towards them.

The operations research and engineering approach to management has been mainly characterized by a control paradigm. Some assumptions that are important to implement management as control in a system are:

- A system can exist in a finite set of states and each state can be uniquely characterized by observation.
- Based on this characterization one can devise a unique set of control measures to move the system from one state to another state.
- Uncertainties in the state transition functions can be quantified by probabilities.
- Risks are quantified by multiplying the probability of an event with the magnitude of the expected damage.

Technical systems are constructed such that they can be controlled. However, human-technology-environment systems are more appropriately described as complex adaptive systems where different paradigms have to be used. What are the consequences if one takes into account that one deals with complex adaptive systems both regarding the systems to be managed and the learning and decision making processes that are the essence of the management process? Complex adaptive systems are characterized by self-organization, adaptation, heterogeneity across scales and distributed control. The state space is not closed and predictable but open and evolving. Development may be path and context dependence, the system attempts to escape external pressures by adaptation in changing its internal structure. The system itself is in constant change. Regarding the assumptions of a control paradigm one can note the following deviations:

- *A system can exist in a finite set of states and each state can be uniquely characterized by observation* – the state of a system depends on history and context, systems are hierarchical.
- *Based on this characterization one can devise a unique set of control measures to move the system from one state to another state* – systems may escape attempts of external control by adaptation and human beings may behave differently than anticipated.
- *Uncertainties in the state transition functions can be quantified by probabilities* – for some extreme states it may be impossible to quantify transition probabilities, non-linear developments may render probabilistic judgements exceedingly difficult.
- *Risks are quantified by multiplying the probability of an event with the magnitude of the expected damage* – some risks are related to ethical issues and require risk dialogues and people judge risks differently based on their perception of being able to influence the risk (e.g. dying in a car accident versus dying in an airplane crash).

Remaining within the concepts of dynamic systems and optimization one can illustrate the difference between the paradigms using the metaphor of a fitness landscape where hills refer to desirable states and valleys to states to be avoided. The control paradigm is based on finding optimal solutions in a constrained and rigid state space. The learning and evolutionary paradigm is based on finding methods to support navigation in a fitness landscape that is in continuous change. Rather than sticking to one paradigm it is important to develop and apply methods to choose the appropriate approach for the management problem to be tackled.

2. COMPLEXITY AND THE IMPORTANCE OF LEARNING PROCESSES

The increased awareness for the complexity of systems and for management as learning rather than control seems to be an overall trend in different fields (Senge, 1990; Pahl-Wostl, 1995, 2004; Levin, 1998; Hartvigsen at al, 1998; Berkes et al, 2002). On one hand the systems to be managed and the problems to be tackled have become indeed more complex. The pace of change in socio-economic conditions and technologies is tremendous. Uncertainties arising from global change in general and climate change in particular pose major challenges for the management of environmental resources. On the other hand the awareness for the need to take the complexity of problems fully into account has increased and the frame of analysis has partly changed. One may talk of socially constructed problem domains. The frame of reference determines how a problem is conceptualized (Shakley at al, 1996). Such a socially constructed problem domain stabilizes itself. Institutions are developed, technologies are implemented based on a shared paradigm. Hence, any transition to a new management regime requires collective learning processes and new methods are required that allow to analyse the origins and importance of socially constructed reality and the impediments for a change.

Regarding the social construction of reality and the origin of subjective perceptions, it is useful to introduce here two concepts – frames and mental models. More than one definition exists for frames and mental models and sometimes the distinction is blurred (Doyle and Ford, 1998; Sterman, 2000; Craps et al, in review). In the current paper the following distinction is made: A mental model refers to a specific mental representation of information about reality. A frame refers to the context into which such a mental model is embedded and which gives sense and meaning to it. Differences in framing are one of the key reasons for problems in communication among actors. Two people may engage in a conversation – one acts in a power frame (goal to dominate the conversation) the other in a cooperation frame (goal to engage in a collaborative relationship). They will interpret each others arguments very differently and hold contradicting expectations about each others behaviour. People make judgements about motives other actors hold. Hence the framing of the goal of a negotiation process – the role of different actors, their position, their views on what is at stake are key factors and determine entirely the outcome of a process.

Figure 1 represents the role of mental models and frames in the processing of information. People hold internal representations, mental models of reality. Mental models are assumed to be quite enduring structures of the internal representation of a real system (Doyle and Ford, 1998, 1999; Sterman, 2000). Such mental models may be shaped by the role of actors in a social system, their previous experience and cognitive biases that result from heuristics that allow human beings to survive and act in a very complex and partly unpredictable world. Mental models determine the processing of information which is selective. Experience may help to construct a context from few pieces of information, to draw analogies to previous situations and select a type of response and behaviour that is deemed to be appropriate based on previous experience. Sometimes selective information processing may prevent learning and the adaptation to a changing environment – this applies for individuals, for enterprises or for scientific organizations.

Human beings have a confirmation bias – they search for and process selectively information confirming their beliefs (Evans, 1990). Sometimes beliefs may be proved to be wrong by factual knowledge. Sometimes beliefs about the social environment may support the construction of social reality and influence it (e.g. expectations about the behaviour of others). If one believes for example that other actors in a negotiation process are not willing to cooperate one is full of distrust which may trigger a corresponding behaviour from the other side.

Mental models should be corrected if they are factually wrong – this requires first an agreement among actors on the soundness of the factual knowledge that is provided by empirical analyses or modelling exercises. Mental models may be linked to normative assumptions, values and preferences which determine the interpretation of knowledge. In this case a change of mental models requires processes of reflection and negotiation. Hence we need to combine hard and soft systems approaches and put strong emphasis on the role of different types of learning in management processes.

Table 1 illustrates the differences between hard and soft system approaches in systems science.

	Hard	**Soft**
objective	given	problematic
focus	reality how to do it	perceptions what and how
models	of X relevant to Y	of pure purpose to structure a debate
paradigm	optimising goal seeking	learning
expert	external expert	participative (facilitator)
system	exist in the world	in the process of inquiry

Table 1 Comparison between Hard and Soft systems approaches (after Checkland, 1989)

Whereas hard systems approaches emphasize factual knowledge and the role of the analyst as external observer, soft system approaches emphasize subjective perceptions and the role of the analyst as participant in a process of social learning. Similarly the role of models is different in the two approaches. Whereas in the hard systems approach models serve to represent the relationships of variables in the real world, in the soft systems approach models serve to structure the debate.

Figure 2 represents schematically a combination of hard and soft systems approaches in model and scenario development. Pioneers in this field of participatory model and scenario development come mainly from management science (de Geus, 1992; Lane, 1992; Vennix, 1995; Van der Heijden, 1996). The parentheses indicate that the distinction between facts and subjective perceptions is a gradual transition rather than a distinction between two polar and well defined categories.

In such a process, mental models that are factually wrong, should be corrected. Actors may hold erroneous and divergent views on the magnitudes of effects, causal relationships and conclusions drawn from statistical inference. The requirement for learning is the acceptance of factual knowledge. A group of actors has to agree on the soundness of facts provided by the analyst. The soundness of the scientific method used for deriving the data should be the prime criterion – this may not always be guaranteed. Finding agreement is easier for empirical data than finding agreement for results derived from simulation models. The latter contain already embedded assumptions that may be questioned. Methods to improve the sound use of factual knowledge in a stakeholder group are for example the elicitation of mental models by different techniques (e.g. mental mapping, system dynamics approaches) and the subsequent comparison of such models with results derived from factual analyses. Such an elicitation process can be the first step of a group model building processes (Vennix, 1996; Sterman, 2000; Pahl-Wostl, 2002b). Developing models in a group model building process is of particular importance if uncertainties and decision stakes are high and more than one interpretation can be derived from model results.

More demanding than correcting mental models that are factually wrong are those situations when mental models determine and stabilize a socially constructed reality in a group. Examples may be the perception of a messy problem situation or norms and rules of good practice shared in a group of practitioners (e.g. water managers). People may hold for example a mental model of the role of a scientist or engineer. Such mental representations shape the social exchange in a group, determine expectations and behaviour.

Methods to facilitate learning in such situations include behavioural simulations or group model building exercises combined with role playing games (e.g. Barreteau et al, 2001;

Den Exter, 2003; Duijn et al 2003; Pahl-Wostl, 2002b). In such gaming approaches the social interactions between the participants are the driving force for the simulations. By adopting another role than in real life, actors may start to improve their understanding for perspectives of other actors. The games enable the participants to reflect on the way in which the decisions are taken and identify needs for change.

The methods outlined above are quite common in management science where the prime target of management was always the social system. Resources management is still quite slow to take up such innovations that should follow as a logical consequence of adopting an integrated management approach. But developments are promising as illustrated for the example of integrated water resources management.

3. THE EXAMPLE OF INTEGRATED WATER MANAGEMENT

3.1 The role of participation in integrated water management

Water management has traditionally been characterized by a control paradigm that is now slowly changing. Such change is partly attributable to the need to implement IWRM and to the insights that water management faces increasing uncertainties from climate change and fast changing socio-economic boundary conditions. Integrated water management should provide a framework for integrated decision-making, where we strive to: (1) assess the nature and status of the water resource; (2) define short-term and long-term goals for the system; (3) determine objectives and actions needed to achieve selected goals; (4) assess both benefits and costs of each action; (5) implement desired actions; (6) evaluate the effects actions and progress toward goals; and (7) re-evaluate goals and objectives as part of an iterative process. This sequence sounds quite logic and straightforward to being implemented. However, integration and new approaches to manage risks in the light of increasing uncertainties require transformation processes in institutional resource regimes and management style. Technical solutions are not anymore sufficient to tackle the intricate problems we face today. Equally important are issues of good governance, with the human dimension in a prominent place. Scaling issues need to be explored to understand the complex dynamics of institutional resource regimes and to improve the match between biophysical and actor based scales. The strong tradition of local and regional water resources management has to be combined with integrative river basin approaches and an embedding of them into a perspective of global change. This necessitates linking research areas that have up to now developed rather independently with little exchange among them and social learning of different stakeholder groups.

Currently the concept of social learning is under investigation in a number of European FP5 projects. The SLIM (Social Learning for the Integrated Management and sustainable use of water at catchment scale) project explored the importance of social learning in a couple of case studies in water management. Their approach is explorative by extracting more general insights from the different cases (www.slim.open.ac.uk). The HarmoniCOP (Harmonizing Collaborative Planning) project follows a different approach by developing testable hypotheses on social learning that are investigated in a number of case studies (www.harmonicop.info). The major objective of the HarmoniCOP project is to increase the understanding of participatory river basin management in Europe. It aims to generate practically useful information about and improve the scientific base of social learning and the role of ICT tools in river basin management and support the implementation of the European Water Framework Directive.

Elements of Social Learning for river basin management can be summarized as

- Build up shared problem perception in a group of actors and the ability to communicate about different point of view.
- Build trust for self-reflection - recognition of individual mental frames and images and how they pertain to decision making.
- Recognize mutual dependencies and interactions.
- Reflect on assumptions about the dynamics and cause-effect relationships in the basin.
- Reflect on subjective valuation schemes.
- Engage in collective learning- and decision processes.

The notion of social learning has been used in quite different meanings to refer to processes of learning and change of individuals and social systems. In the influential work of Bandura (1977) social learning refers to individual learning based on observation of others and their social interactions within a group e.g. through imitation of role models. It assumes an iterative feedback between the learner and their environment, the learner changing the environment, and these changes affecting the learner.

This approach is too narrow to embrace all the learning processes of relevance in resources management. Of major interest in this respect is the concept of “communities of practice” developed by Wenger (1998) emphasizing learning as participation. Individuals engage in actions and interactions that have to be embedded in culture and history. Such interactions are influenced by and may change social structure and, at the same time, the individual gains experience situated in a context. Such learning processes confirm and shape the identity of the individual in its social surroundings. They confirm and change social practice and the associated interpretation of the environment.

Such a broad understanding of social learning that is rooted in the more interpretative strands of the social sciences characterizes also the approach adopted by the HarmoniCOP project. Figure 3 represents the framework for social learning developed in the HarmoniCOP project to account for learning processes in water resources management. The concept of social learning was developed in HarmoniCOP that has two pillars. They relate to the processing of factual information (content management) and engaging in processes of social exchange (social involvement). Social involvement refers to essential elements of social processes such as the framing of the problem, the management of the boundaries between different stakeholder groups or the type of negotiation strategies chosen.

ICT tools play a key role (Maurel et al, 2005) in promoting relational practices. They may elaborate and provide well balanced information for the debate in ways that are relevant for the stakeholders and that allows collective learning, helps to elicit perspectives and behaviours of stakeholders, to make them explicit to the others and facilitate relational practices – e.g. participative mapping, role playing games, behavioural simulations

Currently the importance of social learning and the role of ICT tools are investigated in nine case studies on participatory water management related to the implementation of the European Water Framework Directive in nine European countries. The goal is to investigate if social learning takes place, how it is promoted and what its implications are on the goal of developing river basin management plans and of managing the river basin in a more sustainable way. Case studies focus on different scales (local to trans-boundary) and in particular on the interaction between scales. Social learning includes processes at the level of local committees up to negotiation processes in trans-boundary basins and their mutual influence. The knowledge about the interactions between scales and the type of institutional settings that are required to promote them is still quite limited. First results indicate clearly the importance of culture, regional context and the reigning management paradigm on social learning processes. Preliminary results support findings from the MANTRA East project (Timmerman and Langaas, 2003) providing strong evidence that water management in most European countries is not yet based on a participatory approach but on expert knowledge guiding management decisions. Stakeholders are mainly informed or engaged in consultation processes. Involvement and co-decision-making is far from being realized in practice which is a certain impediment to implementing new water policies.

The European Union is particularly active in the area of Integrated Water Resources Management regarding the implementation of innovative water policies (European Water Framework Directive and the European Water Initiative). During the 5th Framework Programme more than 30 Millions of Euro have been spend to fund projects related to IWRM and the development of integrated catchment models. However, most of the projects have little interaction with stakeholders during model development and include decision makers and water management authorities as potential "endusers" at the end of the process of tool development. This corresponds to the "hard system approach" and the corresponding perception on the role of models in the whole process of river basin management. The HarmoniCOP projects starts from the perspective of social learning and the role of stakeholder perspectives in river basin management and by investigating how ICT tools and models can be used to support learning processes. This corresponds to the soft systems approach. Currently the two approaches coexist without much interaction. This situation should be changed in order to increase the use of models in river basin management and to move towards more participatory management approaches as required by innovative water policies.

The HarmoniCA concerted action tries to bridge the gap between science and policy with specific emphasis on the implementation of the European Water Framework Directive. A number of interactive workshops provided evidence that the perception of model developers on the importance of models and the perception of policy makers on the current role of models in water management diverge considerably (Hare, 2004). Whereas model developers consider the management of complex river basins to be impossible without model support, policy makers are quite suspicious towards complex models they do not understand. In particular the high degree of uncertainty in model predictions and the possibility to have more than one valid model structure describing the same complex environmental problem were perceived by policy makers as issues of major concern. The participants of the workshops identified as one possibility to improve the role of models in IWRM to establish in general a closer link between stakeholder participatory processes and model development. These results indicate that a paradigm shift in understanding the nature of water management and using the role of models is really on its way.

3.2 The transition to adaptive water management

Another development pointing in a similar direction of a paradigm shift is the increasing popularity of adaptive water management. The idea of adaptive management has been introduced in resources management for quite some time already but has only more recently become of major interest in water management (Holling, 1978; Walters, 1986; Pahl-Wostl, 1995; Lee, 1999; Walker et al, 2002; Richter, 2003). It is based on the insight that in the management of natural resources the ability to predict future key drivers, as well as system behaviour and responses, is inherently limited. As a consequence, in particular authors working in the area of ecosystem management suggested that resources management should be based on experiment that test well-defined hypotheses about system behaviour and the consequences of management interventions. The outcomes of such experiments should then feed into a learning cycle that allows changing and improving management strategies when new scientific knowledge and insights become available.

Adaptive management can more generally be defined as a systematic process for continually improving management policies and practices by learning from the outcomes of implemented management strategies. The most effective form of adaptive management employs management programs that are designed to experimentally compare selected policies or practices, by evaluating alternative hypotheses about the system being managed. As it is defined in the approach promoted here adaptive management has as another target - its goal is to *increase the adaptive capacity of the (water) system*. It is aimed at integrated system design. The problem to be tackled is to increase the ability of the whole human-technology-environment system to respond to change rather than reacting to undesirable impacts of change. Hence it is a pro-active management style. Increasing the ability for change includes for example increasing the use of small-scale technology or combing formal regulations with informal institutional settings (Pahl-Wostl et al, in review).

Two new EU projects (AquaStress and NeWater) currently in the phase of implementation under the umbrella of the 6th framework programme of the European Union are based on such a new water management paradigm. NeWater – New approaches to adaptive water management under uncertainty – focuses on the transition to adaptive water management building on the concept that management is a learning process in complex adaptive systems.

The focus on the transition to adaptive water management reflects the insight that understanding the transition is the most crucial point for adaptive water management. The adaptive water management regime to be achieved will depend on the path chosen. Given the interdependent nature of social, technical and environmental processes change must be based on a collective learning process. The approach for social learning introduced in the previous section strongly suggests that the social capital and governance structure generated depends on the quality of the learning process implemented in the transition phase.

The NeWater project has a strong methodological component. New methods will be tested in a number of case studies in Europe, Africa and Central Asia. Much emphasis will be given to assess key drivers of global change and the vulnerability of river basins. The practitioners in a basin will play a crucial role in guaranteeing that the methods developed meet the demands from the practitioners and take into account concerns and expertise in a basin. They will benefit from being able to direct research efforts to the issues of most relevance to them. Based on a joint assessment, suitable methods and tools for improved basin management will be developed and tested.

The 6th framework programme of the European Union offers major advantages important to pursue the type of research described in the previous sections that can be summarized as:

- Possibilities for interdisciplinary projects where disciplines can be chosen to meet the demands of the complex problems under investigation instead of being constrained by the disciplinary structure characterizing many funding agencies.
- Strong stakeholder participation and participatory action research.
- Direct combination between basic and applied research and tool development for practitioners
- New opportunities for public-private partnerships.

- Possibility to include case studies from Europe, Africa, and Central Asia.

4. CONCLUSIONS AND OVERALL DEVELOPMENTS

The paper emphasized the need to take complexity into account in resources management and to develop appropriate methods for different situations. We need approaches that allow characterizing messy problems and finding solutions to deal with them in an adequate manner. These are situations in which there are large differences regarding the perceptions of the nature of the problem, the need for action and what type of action should be done. Such differences arise on one hand from uncertainties in the factual knowledge base and on the other hand from ambiguities in problem framing and diversities in the perception of the nature of the problem. It is important to have a sound base for using the appropriate methods since participatory processes are resource intensive. Duijn et al (2003) suggested a categorization of different problem situations along two dimensions. If there is little consensus about knowledge and the values and aims involved, policy making as interactive learning process is of particular importance. In the case of a high degree of consensus about knowledge and the values and aims involved, policy making can proceed as management in the classical sense. However, as pointed out before the framing of the problem in a stakeholder group may not correspond to the real nature of the problem situation. Hence, a sound analysis for categorizing a problem situation and the stakeholders involved, their interests is highly recommended for any environmental management problem.

The research questions to be tackled in understanding the complex dynamics and the management of human-technology-environment systems are highly intellectually challenging and new insights are in major demand from the policy side. Hence, we need the best and highly skilled people to address these burning questions. At the same time the incentives in the scientific community to go in this direction are quite small. The opportunities for doing basic research tackling interdisciplinary questions are very slim. Hence we need a transition in science as well!

The research agenda outlined in the previous sections is based on new partnerships between science and society. We need more emphasis to promote interdisciplinary research. The prevailing structure of the disciplinary scientific community is an impediment to the development of cutting-edge pioneering research in this field. Most faculties at universities are still organized in disciplinary structures. Funding agencies are not well prepared to handle proposals crossing disciplinary boundaries. However, scientific breakthroughs and the development of new fields occur when different disciplines meet. A certain progress has been made (e.g. the life-sciences) - the deep divide between the social and the natural sciences has yet to be overcome. However, new innovative approaches are urgently needed to support sustainable strategies for dealing with complex socio-environmental problems.

A number of promising developments can be noted. New societies start to emerge and prosper. TIAS, The Integrated Assessment Society, was founded recently (www.tias-web.info). Its aim is to promote research on methods for the integration of knowledge on a problem domain from different sources and for understanding complex societal learning and decision making processes required to deal with the problem. Ecological Economics has established itself with much success as a society at the interface between natural and social systems (www.ecologicaleconomics.org). The resilience alliance has renamed its highly cited journal from “Ecological Conservation” to “Ecology and Society”.

All these promising developments are clear indications for the fast emerging field of studying the complexity of coupled socio-ecological systems. We can expect to witness major progress in the years to come.

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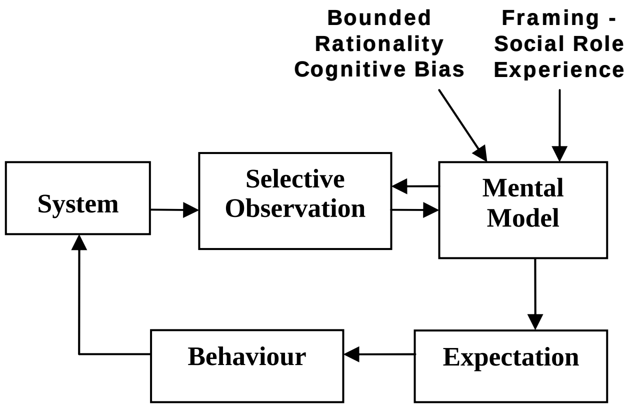

Figure 1 The role of mental models in processing information

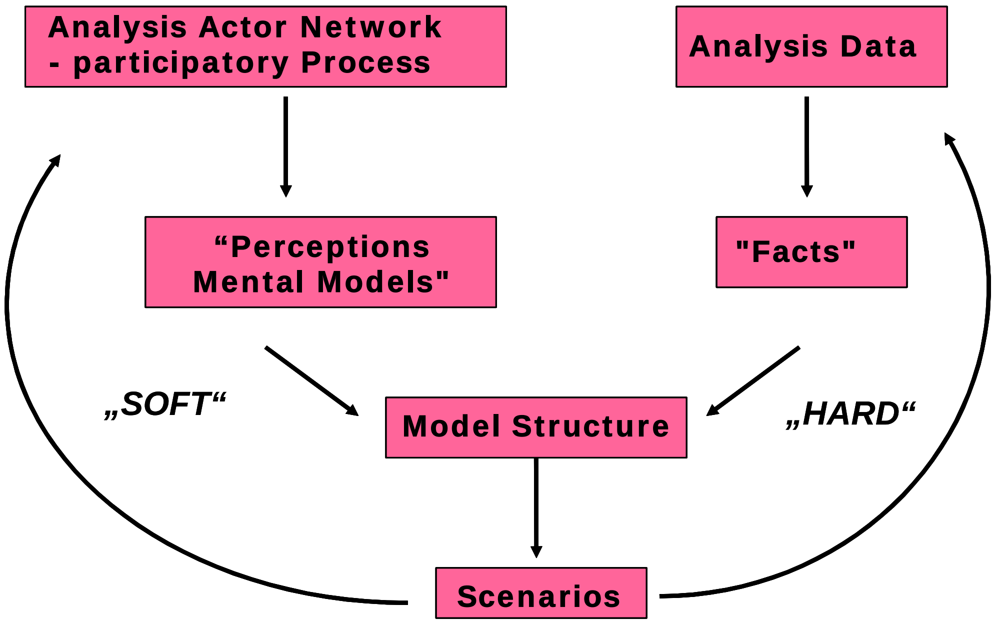

Figure 2 shows the overall approach of combining subjective perceptions and factual knowledge in a participatory group model building process

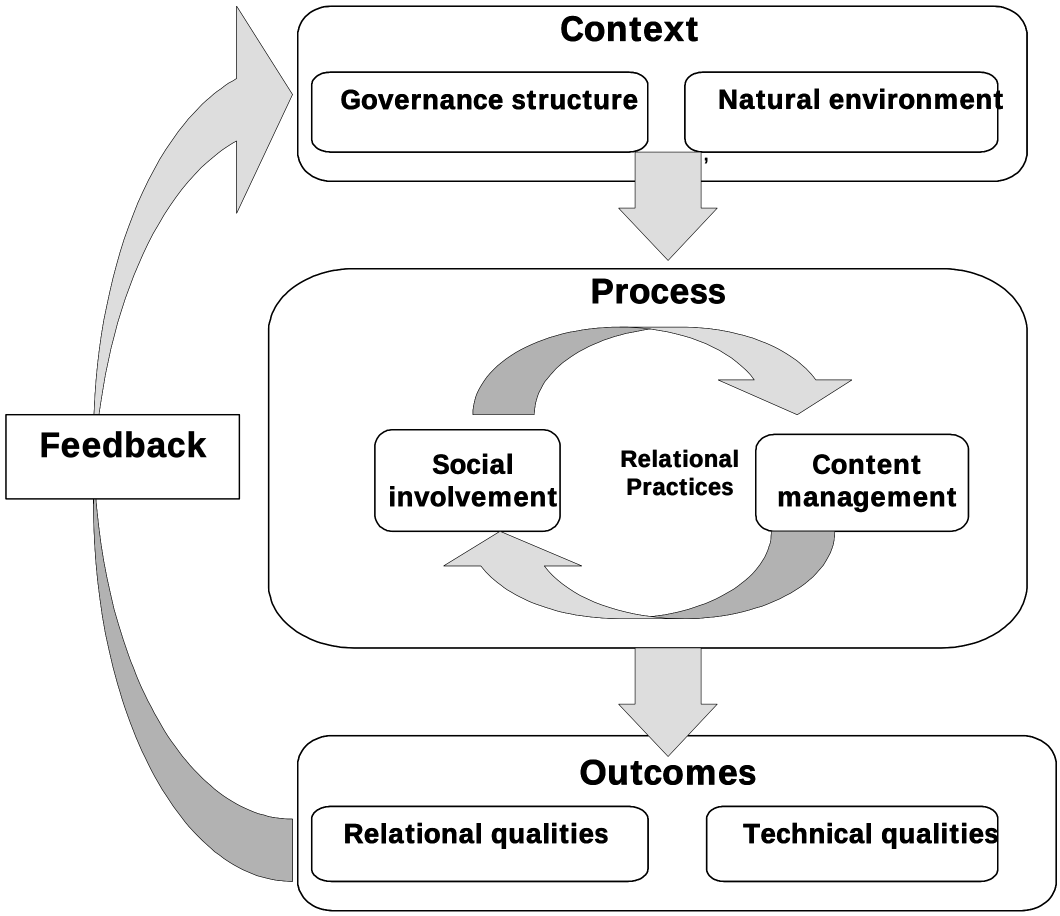

Figure 3 Conceptual framework for social learning in resources management (Craps et al, 2003