"A Weaker Partner: Why the knowledge from soft sciences loses out in interdisciplinary research for Natural Resource Management"

Analysis and Ways Forward

Thorsten Arnold and Caleb Wall

ZEF Interdisciplinary Course

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Introduction

This paper seeks to explore how and why the 'soft' sciences have often been marginalised by the 'hard' sciences in conducting interdisciplinary research, and outline ongoing trends to overcome that in order to address more complex problems. In order to confront this broad topic this paper confines itself to a discussion of how natural resource management projects can marginalise the soft sciences. Having established how this occurs, the focus shifts towards finding a set of solutions to deal with the complexity inherent in natural resource management.

The analysis begins with a discussion of why the soft sciences have traditionally been neglected in natural resource management. This begins by defining what the soft sciences are and what distinguishes them from the hard sciences. This is followed by an explanation of why it is important that the soft sciences work together with the hard sciences, and why this is vital for both sciences as well as for natural resource management projects. In light of the rationale for integration, a set of barriers to integration are presented.

This problem statement is then followed by a section on developments to integrate the soft and hard sciences. This is done by looking at basic cause and effect systems. In these systems the types of inter-disciplinary (ID) research required is very different from complex systems. In the field of natural resource management (NRM) we deal with complex systems that include physical as well as social aspects. It is the complexity of these systems that necessitates an ID approach to NRM. Thus a discussion of the characteristics of complex systems is entered into in terms of how NRM projects are characterised by uncertainty and necessarily include manifold parameters . Having established what complex systems are, we then deal with some different methods of dealing with complexity. These three approaches can be broadly grouped as; adaptivity, management and co-management.

From this analysis we find that one promising way forward is adaptive co-management (ACM). There are particular knowledge needs for this approach – which include a requirement to move towards transdisciplinary research and ways of knowing. It is equally vital that we include participation from various stakeholders, user communities and that the scientific community integrates these concerns and interests into their research. From this analysis it is then possible to construct various options for the management of natural resources.

Finally we discuss the various approaches that can be used in integrating mathematical modelling with soft forms of knowledge. Three pillars are provided to include the soft sciences into mathematical computer models: conceptual, natural resource and human behaviour; models. These pillars may be combined in different ways to tailored scientific modelling for specific policy problems. Three examples are presented which are aimed at different types of stakeholder interaction.

Why ‘soft’ knowledge from social science is often neglected in natural resources management

Natural resources are real, tangible objects – they are quite literally ‘hard’. It is possible to measure, examine, describe and quantify natural resources. Yet there is a social aspect in the management of all these resources, indeed judgements about what constitutes a ‘resource’ are essentially human activities, ‘soft’ activities. Water has no resource value, a priori, yet it is essential for human existence and thus assumes a social value. Likewise gold is considered a precious metal because it occupies this place in the mentality of humans (as well as having several properties useful for industrial processes).

Despite the importance of human decisions and social dynamics in the management of natural resources, the field of natural resource management (NRM) has traditionally been dominated by ‘hard’ disciplines (Miller et.al, 2004). Many (hard)-scientists are sceptical of involving softer decision making models for natural resources and common-pool resources (Bryan, 2004). Likewise the real world management of natural resources tends to dominated by those people who have been trained in the hard sciences. Working from this premise, this paper seeks to explore if and why this is problematic. This is followed by an in depth analysis of ways in which we can deal with complexity – confronting the challenges to integrating the ‘soft’ sciences into the study and practice of natural resource management. Firstly however we need to examine the mechanisms through which the soft sciences are marginalised and neglected.

What are the Soft Sciences?
When we refer to the ‘soft’ sciences we are adopting a, partially pejorative, tradition of distinguishing between the ‘hard’ sciences and the ‘soft’ sciences. This dichotomy exists within Universities through the segregation of students and staff into disciplinary departments. However a similar, if less explicit, segregation also occurs in the practical management of natural resources. The implication of this dichotomy is that there are forms of science that deal with specifically measurable and conceivable facts and materials – that these quantifiable objects are hard and can be compared (Lancet, 2004: 1247). Whereas the soft social sciences deal with the qualitative, that which is not easily measured (ibid). It is interesting to note the pervasiveness of this dichotomy, no where else is this more evident then in the emergence of post-WWII economics. This also serves as an interesting study in the marginalisation of the soft sciences.

The academic discipline of economics is a rather new academic discipline, which only gained currency with paradigm creating works such as ‘The Wealth of Nations’ (Smith, 1776), drawing upon political treatises by the likes of Locke (1924). Initially economic theory was highly qualitative, establishing very broad normative frameworks for how economic systems should be managed. This was particularly evident in Ricardo’s (1971) analysis of comparative advantage. This concept, very much current in the contemporary free trade debate, was introduced by Ricardo using only the simplest of allegorical and anecdotal evidence. In short there was little in the way of quantitative, hard, science used in introducing this theory.

Compare this qualitative tradition to the very hard quantitative tradition established pursuant to the 1930s depression. Here the perceived failures of the discipline were met by a move towards quantification of data. This move was provided a real stimulus with the outbreak of war in 1939, which enabled leading researchers, pre-eminent among them being Keynes, to devise a system of monitoring a war time economy. This saw a huge rise in the quantification of inputs and outputs – a move towards the hard sciences. This development occurred concomitant with the rise in processor power, especially in the post-war period where there was a real public demand for better economic management. What is worthwhile noting from the case of economics is the growth in the discipline that was experienced after the move was made from soft to hard science. Indeed, many economists (including some within ZEF) see economics as separate from the social sciences. We also see in post-WWII social science a move towards greater quantification. Seminal works such as Moore's 'The Social origins of Dictatorship and Democracy' (1966) provide large amounts of quantitative data in an attempt to legitimise their findings to the policy, political as well as academic realms. Similar comparisons can be found with early Marxist theory, for instance Maley (2004) provides a fascinating account of how interpretations of Max Weber's work have changed over time.

Why it is important that the soft sciences work with the hard sciences

In terms of NRM the soft sciences are the traditional social sciences, dealing with human and social dynamics. Anthropology, sociology, history, political science, (at least some efforts of) economics as well as many of the newer disciplines such as gender/feminist studies, contribute to the soft science analysis of NRM. It is argued here that integration of the hard and soft sciences is essential to ensuring effective management of natural resources. This is discussed in terms of; efficiency, efficacy and equity.

In seeking to optimise the management of natural resources, we will always encounter difficulties. Some of these difficulties will be technical and to solve such problems we require the expertise of hard scientists. However many of the challenges will involve social dynamics of some form or another (Adeola, 2004). Should we attempt to solve these problems as they arise by treating them as new and unique challenges, there will be a lot of research duplication. It is not necessary to 'reinvent the wheel' every time a social dynamic makes NRM difficult. Rather, the social sciences have a broad corpus of research and theory on all manner of social dynamics. Naturally, these cannot be simply copied across to the NRM problem at hand. Instead soft sciences will seek to explore commonalities and differences between the present problem and past theory/solutions. By accessing the corpus of already existing knowledge it is no longer necessary to constantly 'reinvent the wheel'. This improves the efficiency of NRM research and interventions by reducing duplication of research and by learning from previous experiences in the soft sciences (Miller, 2004).

The second issue is that of efficacy. Many NRM research projects arrive at a sound understanding of the technical problems, however many of these projects flounder because of an incognisance of the social dynamics (Lubell, 2004). Simply put, NRM projects that understand the technical aspects of a system yet fail to situate it in terms of the social realities tend to be less effective. Thus by integrating an understanding of social dynamics, it is possible to improve the effectiveness of research and development interventions. The challenge here is to create an inter or cross-disciplinary team of researchers who can combine their knowledge. ZEF is making efforts in this regard, with the creation of the research group – Natural Resources and Social Dynamics. This research group, whilst still in its infancy, seeks to improve the effectiveness of ZEF research into NRM.

The third issue is that of equity. Whilst the hard sciences may well be capable of designing a system of resource management that meets all the technical criteria – such as system may well result in considerable inequalities amongst the local population, especially gender inequalities (Gupte, 2004). This approach is one of ignoring complexity, rather than accepting the imperfection of systems and seeking to better understand these complex systems (Bryan, 2004). Certainly such an allegation is often levelled against projects designed with a strong economic/technical focus, especially when applied to the developing world. Including the social sciences, whilst no panacea, may well enable interventions to be designed with a much better understanding of the likely social outcomes of the research or development intervention. Whilst equity may not be an issue that concerns those seeking technical solutions, it is certainly an issue for those in the policy arena and should definitely be included in the international development sphere. It is also important to note that long term sustainability can be argued to rely upon affecting equitable outcomes – there is a limited but growing literature on the importance that equity plays in guaranteeing the long term sustainability of NRM projects (see for example Johnson et.al., 2004; Kellert etl.al, 2000; Milich, et.al., 1999).

Barriers to Integration

Despite the potential gains to be made from interdisciplinary (ID) research there are some very real barriers to integration. These constraints constitute an entire literature on interdisciplinarity, so the brief précis given below only gives a representative introduction to the subject. The first issue is that of bureaucratic control, which is followed by a discussion of how a lack of understanding constrains ID research. Thirdly disciplinary entrenchment is analysed as a key constraint.

Universities and research institutions are typically designed in a hierarchical, bureaucratic way. By dividing the disciplines into separate departments, each seeking to protect their own budgetary and organisational position, we create barriers to ID research (Gershon, 2000). Campus based universities are typically geographically divided along disciplinary lines, further reducing the likelihood of serendipitous ID interaction. This departmentalisation of knowledge and research poses a key constraint to an 'open marketplace of ideas' model which may serve the interests of ID research (Gershon, 2000). In terms of NRM research there is little opportunity within a traditional university structure for real ID research. What usually occurs is that a new department or research group is formed, which integrates several different approaches into one 'new' approach. This new department remains part of the bureaucratic structure, subservient to the same problems of jealously guarding its budget and organisational position.

A mutual lack of understanding can be a real problem in integrating the hard and soft sciences. To adopt a metaphor, different disciplines speak a different language, which makes them mutually unintelligible. In the midst of this lack of understanding it is very possible that each discipline simply disregards the other discipline's work as nonsense. Be this through the social sciences rejecting purely quantitative data as 'irrelevant' or by the physical sciences deeming qualitative data as 'useless' or 'inapplicable' (Kelleher, 1998, provides an illuminating discussion of how different teaching styles and approaches to different disciplines can increase or reduce levels of understanding between disciplines). In the post-Renaissance world of immense information it is no longer possible for any one individual to understand all disciplines – so, how do we step down from this disciplinary tower of Babel?
There is no simple answer, and the option of all researchers learning each discipline is impractical. Thus there may be a need, as we use in the real world, for interpreters. To act as conduits between the disciplines, facilitating ID research yet conducting little by them. However, operationalising this may be difficult.

Disciplinary entrenchment is perhaps the biggest challenge to ID research in the field of NRM (Gershon, 2000). Whilst some of this can be understood through the prism of a mutual lack of intelligibility, almost all disciplines are structured to reject external views. The mechanisms of academic advancement; conferences, publications, research collaboration; all militate against ID research. There are very few genuinely ID journals, instead most journals and conferences focus on one discipline. This enables research to build upon a set of "shared rules and systems of understanding" within a given paradigm (Kuhn, 1972). When adherents of a particular discipline become accustomed to this discipline, they tend to conceive of problems within a certain mindset and set of methodological approaches. Such as mindset tends to see other 'competing' disciplines as somehow 'having it wrong' or of not understanding. Whilst few researchers will openly admit to such a perspective, it sometimes becomes very apparent in the design and management of research.

Levels of Collaboration

It is also important that we measure in some way the levels of collaboration between the disciplines. Provided below is a simplified matrix (adapted from Wall, 2004, unpublished) that sets out the different levels of collaboration between disciplines on NRM projects. We see here that the two variables are intensity and scope. Intensity can vary widely; from a basic level of information exchange (which is complicated by the 'mutually unintelligibility' barrier discussed earlier). This can progress through to co-ordination, collaboration and then finally towards collaboration. Likewise this collaboration can be measured in terms of scope. Provided below is a simplified scheme of single or multiple foci – this of course can be expanded. We could look at single focus research as project determined research, on a particular and well defined problem or system. Whereas multiple focus research concerns research programmes confronting several problems, most likely a complex system as discussed in the following section.

		INTENSITY			
SCOPE		**Information Exchange**	**Co-ordination**	**Collaboration**	**Integration**
	Single Focus	Scientists communicate via a newsletter or e-mail conference on a single subject	Institutes co-ordinate field testing of a product or development using both soft and hard tools of analysis	Collaborating disciplines allocate research tasks among the disciplines, focusing on who is best to solve a set problem	Disciplines merge into a project based initiative in order to confront a specific problem
	Multiple Focus	Hard and Soft scientists exchange information relevant to a wide range of issues	Institutes work together on mutually agreed problems, each taking their own approach but consulting	Collaborating disciplines assign lead disciplines for several problems and allocate resources accordingly	A number of multi-problem projects emerge into a interdisciplinary research centre

The Way Forward

Given that there are some real barriers to conducting ID research, it is useful to note that there is a large amount of interdisciplinary research that is conducted. Likewise much of the research that is conducted does indeed produce some positive results.

The following section sets about describing how the hard and soft sciences have grown together in some instances. Essential in understanding how this has occurred is by examining the types of natural systems and the diversity of (often conflicting) uses and user groups that we are attempting to understand and to model. A distinct aspect of natural systems, i.e., those which we attempt to understand in natural resource management, is their complexity and the levels of uncertainty inherent in these systems.

Because of these unique characteristics, it is necessary that both the hard and soft sciences work collaboratively to overcome both complexity and uncertainty. Provided below is a discussion of recent developments in inter-disciplinary research. The first section deals with specific developments that have occurred, integrating the soft sciences into NRM as a way of dealing with uncertainty. This is followed by an analysis of complex systems and an explanation of why the soft sciences need to be involved in the research process of NRM. Finally, a model of adaptive co-management is proposed as a mechanism for dealing with the three main barriers to integration; bureaucratic control, disciplinary entrenchment and a mutual lack of understanding.

In conclusion, the need to develop new methods and procedures that address the quality of complex problems can be observed in many disciplines and over a wide range of applications. Since system knowledge remains constrained and our ability to predict is – by definition – very limited, authors call for softer and more flexible management strategies, which science can support then. Such strategies could address adaptation to change (towards a new equilibrium), but the existence of innovation and emergent institutions are centrally important non-equilibrium behaviour. The role of a designer or planner is disputed, and might render obsolete if ACM is indeed the result of self-organisation.

Developments to integrate soft sciences under irreducible uncertainty

*I often say that when you can measure what you are speaking about,
and express it in numbers, you know something about it;
but when you cannot measure it, when you cannot express it in numbers,
your knowledge is of a meagre and unsatisfactory kind.*
(Lord Kelvin)

*I confess that I prefer true but imperfect knowledge, even if it leaves much undetermined
and unpredictable, to a pretence of exact knowledge that is likely to be false.*
(Friedrich A. von Hayek, Nobel price lecture, in criticism against dogmatic
and over-simplistic contemporaneous economic mainstream beliefs)

First, this chapter suggests differentiating three forms of systems, their inherent problems and subsequent strategies to address them. Second, some characteristics of complexity are summarised. Then methodological approaches to integrate existing knowledge are discussed followed by a summary of concepts for problem solving, management and decision making in complex systems .

Systems and cause-effect relationships

For didactical purposes, Ruithenbeek (2001) distinguishes simple, complicated and complex systems. ***Simple systems*** have clear cause-effect relations and behave in a predictable manner (e.g. Newton's mechanics). Having understood them fully, managers may fully control their future development.
Complicated systems result from coupled systems with feedback mechanisms, some of which are unknown and may be difficult to assess. After thorough investigation, these systems may be divided into simple subsystems that are then accessible to our understanding. Such system may include chaotic attractors. A stability analysis for parameters may yield fractal parameter spaces. Since the systems are predictable at least for some time (e.g. until chaotic behaviour occurs), managers may still impose complete control, even though some monitoring mechanism is advisable. ***Complex systems*** have unknown internal feedback loops which are not detectable. Gaps between micro-level actions and macro-behaviour occur due to linkages over scales. Unreliable human choices are important, and effects from different time scales overlap. Surprises are the norm rather than the exception.

The challenges mankind faces have ***evolved*** from simple systems (threatening animals, need for mechanical tools or new forms of transportation, new machinery) towards more complicated systems, where new levels of abstraction and other methodological approaches were needed.

While in early times scientific discoveries were undertaken by all-round talents like Leibnitz, Alexander v. Humbold or Goethe, the developments of recent years required high levels of specialisation and highly differentiated scientific disciplines. Such differentiating approach of engineering science has shown remarkable successes, e.g. in developing of computers, machinery, genetic engineering and biotechnology, but also in many other fields of "multi-disciplinary" science.

Today, some people are becoming aware of a new structure of modern problems. These seem unanswerable with conventional differentiating approach, because they are driven by the dynamic interconnection of formally "unrelated" scientific areas. An example gives the ***Syndrome approach to describe global change*** (WBGU 1994, Schellnhuber 1997), which describes self-enforcing, vicious circles of non-sustainable development for *both* man and nature. These syndromes are driven by the *interaction of social and natural systems*, and therefor escape the description by disciplinary scientists.

The human capacity to solve simple problems and to tackle even complicated ones leaves us with two types of unresolved complex issues: First, for lack of methodologies, complex problems that always existed simply remain unsolved. Second, the people which tried to solve problems in complicated systems might have overlooked some feedback loops. The attempts to cure symptoms rather than causes triggered further problems on a higher & more complex scale.
The evolution from simple to complex problems requires new and less rigid methods of problem solving. Next, we take a closer look at the problem of complexity.

Complexity – Some Characteristics

Complex systems are strongly ***interconnected***, and many processes influence others in one or the other way. A short calculation shows how difficult it is to measure those effects on a *ceteris paribus* assumption: If six variables $x_1 - x_6$ all influence one another, the number of functions is 6+5+4+3+2+1=21. The number of potential feedback loops is approx. 6! = 720.

If 14 variables are interconnected, 105 functions need to be tested – and about 14! ≈ 87 billion (potential) feedback loops.

Examples: Interdependency
One example is the demise of the *International Coffee Agreement* in 1989 which regulated the volume of coffee exports. In effect, producer countries increased production and engaged in a 'race-to-bottom' as prices declined (http://www.fas.usda.gov/htp2/tropical/1997/97-12/chart03.gif).
It coincided with the end of the cold war and the fall of the iron curtain, which brought new countries into the market, and also with the fusion of companies and their more aggressive transnational strategies. Indirect effects were falling incomes of African smallholder farmers, but also the extension of large-scale coffee plantations with deforestation and adverse effects on Biodiversity in Brazil or Vietnam. Some years later, in 1995-6, the wheat prices rose due to dry conditions in the Western USA. African farmers who relied on their coffee income to supplement their diet were suddenly faced with famine, and their children now receive less education (Charveriat 2001).
The decision of few policy makers had effects on prices, trade flows, Natural Resource use, incomes, education and poverty. Effects were aggravated by non-related events (collapse of Soviet Union, drought in Western US)

The term "emergent" refers to a system having qualities that are not analytically tractable from the attributes of internal components. Different spatial or hierarchical scales permit the occurrence of ***emergent phenomena,*** which exhibit structures that are not explained by lower-level dynamics and typically persist beyond the average lifetimes of entities upon which they are build (LUCC 2002:10). Multiagent systems might show structures on a macro scale due to the interactions between micro-level agents, who recognise their direct environment and constantly adopt to it's changes (Janssen 2001, S. 1).

Examples: Emergent properties
What humans recognise as *temperature* or pressure are simple examples taken from thermodynamics: molecules move with a certain speed and energy in arbitrary directions. The force they pose on their surrounding we call pressure, the energy they transmit we feel as heat. More complex examples include *prices*, which are determined by aggregate supply & demand as well as interventions by institutions and market failure. *Revolution* against nepotic governments and the emergence of *co-operation* to govern common resources can also be regarded as emergent structures I n social systems. In a larger sense, *evolution* might be an emergent property in its effect of on biogeochemical cycling, just as *development* of a country.

In the analysis of bio-economic systems, a ***multiplicity*** of legitimate perspectives needs to be accepted (Funtowicz 2000). Since knowledge is incomplete, different opinions might not be contradictory, but actually reveal different dimensions of the system that we are not yet fully aware of. Especially for management problems, different humans and groups have own objectives and goals which are neither wrong nor right.

Even with sophisticated research efforts on complex systems, a significant and irreducible ***uncertainty*** remains (Funtowicz 2000). Such uncertainty forbids the prediction of future development. Subsequently, the effectiveness of rigid management tools remains dubious. Often enough, even the management objectives and goals remain disputed. Many types of uncertainty exist: Deep uncertainty arises when the parties to a decision do not know or cannot agree on one or more of the key components of a Bayesian decision analysis: the system model, the parameters describing the system model, and/or the value function used to rank model outcomes (ibid.). With reference to mathematical models, uncertainty includes (1) limitations imposed by data availability and accuracy, (2) questions about the "mechanistic" relations and formulas used in the model, including human decision/choice (3) uncertainty about which *further* processes that are not represented in the model might become important under future conditions.

If systems incorporate a form of ***memory*** which allows ***learning*** – either by conscious choice or silently encoded in the gene pool, a system looses its MARKOW property[1] and becomes non-deterministic: Even under exactly the same environmental conditions, the system might behave different not because of chance, but because of memory and learning. For human development and common property management, the possibility of individual and group learning is a basis for success.

Dealing with Complexity – Adaptativity, Management and Co-Management

Thought likes solutions,
wisdom abhors them.
C. West Churchman

Accepting complexity

As first and most important precondition for successful management of complexity, researches from many fields (e.g. the ecologist and cyberneticist Frederic Vester 2002, the GTZ development workers Burger & Mayer 2001, Pahl-Wostl 2004b) stress the need that system managers ***accept system complexity as a new quality that demands new approaches***. Positivist and stiff attempts of top-down control will cause surprises, so softer – and more flexible and recursive – approaches are needed. In response to failures of 'conventional' NRM, scientists from the field of complexity call for a ***paradigm shift that enables us to deal with complex systems*** (Janssen 2002).

If systems are accepted to be complex, that they are of interdependent nature, that our knowledge restrained by irreducible uncertainty partly because combined (observable) micro-effects emerge into macro-phenomena, and that our opinions and views are multiple, then demands for ***new management strategies and tools*** arise. These should make fullest use of "soft" skills and knowledge, draw on the diversity of our opinions and objectives. Current trends towards a more participatory NRM, the involvement of stakeholder in research, outsourcing in companies, the devolution of political responsibilities and decentralisation could merely be regarded as withdrawal of state influence in an era dominated by neoliberal ideology. On the other hand, it also reflects first adaptation of societies to tackle problems of a new structure that become obvious today.

Self-organisation and its discovery for science

Self-organisation (Probst 1987) became a topic of interdisciplinary research. Three phases can be distinguished around the phenomena that work was focus at (ibid., pp. 16ff):

a) Adam Smith (1796) introduced the "***Invisible Hand***" (17th – mid 20th century). In his time, prices emerged – not as the result of central planning or the directive of aristocrat rulers, but "spontaneously", "dialectical" or from the "invisible hands" of a higher being.

[1] Since a vast corpus of statistical tools and methods implicitly assumes such MARKOW property, their application would disregard the possibility of learning. This has important implications e.g. for the viability economitric analysis.

Meanwhile, biologists and sociologists developed along the concept "fitness" as a property of species or individuals in a larger, "evolving" system. Merging system thinking, social, biological and economic theories, Carl Menger referred to economic institutions as "evolving social organisms". F. von Hayek stated *"order can emerge, neither independent from human action, nor as the intended outcome of such action, but as an unpredicted result of combined behaviour*" (in Probst 1987, translation T. Arnold).

b) The phase of "***conservative self-organisation***" (1920 – 1960) started with the emergence of system theory, e.g. by biologists like Paul Weiss, Ludwig von Bartalanffy and Jan Smuts, by physicists like Norbert Wiener and Walter Cannon who worked on coupled systems, feedback loops and control. The notion of control gave way to the idea of homeostasis, the management imperative to hold key system variables in a certain range – of systems deviating from equilibrium and appropriate counteractions in order to stabilise it. Ecology supposed the evolutionary "climax".

c) The phase of "***innovative self-organisation***" (1960 – 1985) or, as labelled by Maruyama (1963), of "cybernetics II", was initiated with the description of self-enforcing feedback mechanisms that amplify little deviations from an equilibrium – inspired also by Lorenz's discovery of deterministic chaos and chaotic attractors. The need was seen to balance stability and flexibility, conservation and renewal, conservative forces and forces of change, of development. Maturana & Varela formulated the idea of autopoiesis of biological systems: Systems were no longer seen as independent from their framework, but it was understood that ecosystems form a self-referential unity with their context. The paradigm of "climax ecology" was challenged by the existence of chaotic attractors. These allow continuous amplification of deviations from equilibrium while trajectories are convoluted back. ***Internal interconnectedness and redundancy was discovered as safeguard for stability and resilience***.

   F. von Hayek criticises the prevailing believes in "exact" scientific statements and warns that "*what looks superficially like the most scientific procedure is often the most unscientific, and that in* [the field of complex phenomena] *there are definite limits to what we can expect science to achieve*" (Nobel price presentation Hayek 1975, insertion by author). He argues that the sudden leaps in physics have spread the belief that we could mould societal development towards our liking. Instead of trying to predict the future, he opts to focus on the monitoring and predicition of "*emerging patterns*" as a second best, but truly scientific option.

It is important to distinguish between "***conservative, adaptive***" and "***evolutionary, creative***" self-organisation. The first assumes that a changing contexts triggers a system to adapt towards a new equilibrium, while the latter describes innovative processes in a system in imbalance and disequilibrium (Probst 1987. p. 18).

Hayek's arguments focused mainly on mechanisms of the "free market" and on prices as effective emergent property. Recently, this view was considerably widened by new evidence. In many cases, rationality to optimise individual utility explains our actions, but often social norms and/or altruistic incentives seem to control our choice.

While some of the observed common-property management can be explained by self-interest of the individuals, to understand other cases the existence of ***altruism*** needs to be accepted. Ruitenbeek (2001) elaborated Adam Smith's "theory of moral sentiments" and its underlying ethics. He concludes that one should regard co-operation as ***further emergent properties*** (e.g institutional arrangements for the management of common goods, see also Ostrom 1990, 1994). His argument is in line with Gintis (2001), who observed "*strong reciprocity*": In experimental economics players could punish others who defect rules commonly agreed on. A tendency was observed that punishment exceeds by far the expected direct rewards, a behaviour that cannot be explained with rational actor-theorems alone. Frey (2001) stresses other psychological factors such as social preferences, intrinsic motivation and identity.

Ruitenbeek warns that the current fixation on prices as *only* market mechanism is far too simplistic. To describe altruistic behaviour as emergent property, he uses the image of an "***invisible wand***" in analogy to Adam Smith. The role of governance then is restricted to "*removing barriers to the full emergence of common good": prices AND social cooperation*. Such includes the prevention of monopolistic behaviour, uncompensated environmental damage, unfair labour practices etc. How this shall be achieved remains unclear – either through top-down control, or by giving bottom-up initiatives space to organise themselves.

As self-organisation is a process without external planners, Ruitenbeek and even von Hayek see the need for a central power like the state. It should restrain from seeking control but should restrict itself to ensure an enabling framework, by building and protecting beneficial conditions for both markets and social cooperation.

Adaptive Co-Management as emergent property

Adaptive Co-Management (ACM) was described by Ruitenbeek (2001) as containing two pillars: (1) the rights and responsibilities of stakeholders are *shared*, and (2) stakeholders need to *learn* through actions in one period so that they may modify actions in the future. The time horizon at which ACM operates adequately must cover long timeframes, reflecting the long time-scale of cycles in bio-economic systems. *Conscious* participation should then lead to *conscious adaptation* to long- and short-term change (p.7f).

An enabling framework includes agreement on the measure of success and the will to develop a common vision as basis for co-operation. A balance between the exploitation of existing ideas and strategies and exploration of new ideas avoids (homeostatic) stagnation of system development and lock-in behaviour. Networks of reciprocal interaction should foster trust and co-operation. The role of scientists is to explore strategies to enlight and discuss how consequences of potential actions might spread. Valued criteria in addition to prices need to be developed, to assess the progress towards short-term as well as long-term goals. The final point made is that, in reaction to reap small efficiencies, more failures are commonly sowed – especially if system redundancy is removed which makes it less resilient towards stress (Ruitenbeek 2001).

In disagreement to other authors, Ruitenbeek et al. elaborates that ACM has proved most successful if they emerged naturally. Attempts to centrally impose ACM have generally failed or even caused resource capture and other adverse and unexpected outcomes, while sustainable co-management regimes generally evolved naturally. Ruitenbeek warns that "*premature introduction of ACM as a policy intervention could lead to system failure. This may occur because the introduction of such process disrupts existing evolutionary processes within the system*" (p. 17).

The ACM approach seems compatible with the view of other authors on sustainable development in agriculture. The *German Commission for Sustainable Development* (Deutscher Bundestag 1998) recommends an "open process of search for operational goals and objectives, based on a common "leitbild". IUCN states that "*Sustainable Development is a journey, not a harbour*" (IUCN/IIED 1994). Haufler (2003) distinguishes industry self-regulation from co-regulation and multi-stakeholder regulation. Burger (2001) recommends to GTZ that such co-governance is a venture that starts in our minds, one that requires courage for transparency, for responsibility and for co-operation.

In order to avoid vertical incoherence between planning and implementing institutions, Burger suggests to examine the ***subsidiarity principle*** closely: decision-making shall be decentralised to the lowest effective level[2], while governance structures shall support the self-development of lower, decentralised

[2] Since some redundancy in decision structures is tolerated and even welcomed to foster resilience of the system, some tension was observed with the "efficient approach" of some economists who recommend the "optimal" level, often hierarchically *above* the subsidiarity level. Other economists claim that the valuation and realisation of „optimal" mainly depends on the value system applied, including the valutation of properties like "system resilience".

entities and foster an enabling environment. The subsidiary principle was also recommended by large German NGOs (BfdW, EED, MISEREOR, DWHH) and the *German Ministry of economic Co-operation* (BMZ).

In conclusion, the need to develop new methods and procedures that address the quality of complex problems can be observed in many disciplines and over a wide range of applications. Since system knowledge remains constrained and our ability to predict is – by definition – very limited, authors call for softer and more flexible management strategies, which science can support then. Such strategies could address adaptation to change (towards a new equilibrium), but the existence of innovation and emergent institutions are centrally important non-equilibrium behaviour. The role of a designer or planner is disputed, and might render obsolete if ACM is indeed the result of self-organisation.

Knowledge needs for ACM

Transdisciplinary knowledge & research

The differentiation of modern sciences into more and more disciplines, pronounced in "hard" engineering sciences, has led to considerable ***successes*** with solving "complicated problems" (see p. 7). Prominent examples are the production of computers and other microelectronic consumer goods, software development, biotechnology and military.

Challenges that were brought up by environmental and sustainability science, by the high societal expectations and by needs for scientifically robust and relevant recommendations evoked a shift to integration of disciplines and transdisciplinary research – in assessment, but also in decision-making.

Rotmans (1998) defines ***integrated assessment*** as "*a structured process of dealing with complex issues, using knowledge from various scientific disciplines and/or stakeholders, such that integrated insights are made available to decision makers*".

Marc Mogalle (2001) identifies four common issues of ***transdisciplinary research:*** it is (1) oriented towards problems in the real world; (2) research is expected to suggest practical solutions for that problem; (3) since problems are not structured according to the existing scientific disciplines, such research requires to draw on methods and theories from different disciplines; and (4) since research is conducted close to the actual application, stakeholder participation is common.

Examples of transdisciplinary research and integrated assessment include interdisciplinary case studies (Kasperson 1995) and concepts like the SYNDROM approach (Schellnhuber 1997).

The pooling of disciplinary knowledge into ***coupled models*** (e.g. Alcamo 1998) is a more formal approach to integration. While the coupling of physical, chemical and biological models may be feasible (climate models, meteorological models, hydrology, soil and natural land cover), it remains difficult to formalise human decisions and action in NRM. Attempts to formalise and integrate human decision-making are ongoing, but application remains on an experimental basis. Yet our knowledge about the locally relevant preferences and values is limited, which led to the emergence of participation and multi-stakeholder platforms.

Participation of stakeholders / user communities and integration of their views, concerns and interests

The need to integrate knowledge from diverse fields brings forth new challenges. Central planning of resource use often built on the positivist paradigm that reality can be described in accurate terms, a single management objective and goal can be defined and may be passed to "implementers" through top-down planning. The need to integrate perspectives of stakeholders/user communities is seen (Babin 1999), but remains a methodological challenge: different moral and value systems collide, diverse and sometimes conflicting management objectives become apparent. Power structures remain and interfere with stakeholder communication (Röling 1996). The need to integrate scientifically "hard" expert knowledge with "soft" human beliefs and processes arises.

The idea of ***stakeholder platforms***[3] for collective action in multiple-use common property resources is currently spreading considerably as the prevailing top-down '*transfer-of-technology*' approach used in agricultural extension had appeared to be a failure in many settings (Chambers 1997). Social learning aimed to achieve guidance for NRM has become a centre of scientific attention, as "*a process that can be encouraged by lifting barriers to communications and by encouraging interaction between the parties involved in policy issues. The core idea is that parties can learn from each other by more open and responsive communication*" (Steins 1998, citing Glasbergen 1996). ***Objectives*** of multi-stakeholder platforms include (den Hond 2003):

- sustainable use of resources
- to offer an holistic approach to NRM
- conflict resolution or prevention
- social justice and democratisation in NRM
- decentralisation.

Steins summarises ***central issues*** identified systematic evaluation from field ***experiences***:

- the relation of the platform to the existing institutional setting
- questions of scale, since the effects of actions might occur on other scales than conventional management and enforcement institutions
- the wide range of issues emerging in such a the platform often include social, economic and natural science disciplines
- the question of representation or: Who has legitimacy and sufficient capacity to represent a user group in the platform
- the heterogeneity in user groups as well as between user groups with their often colliding beliefs, morals and values.
- prevailing power structures
- influence on and of higher levels of decision-making

Participatory management is a vague and disputed term: some mean "participation to share costs", others merely consult stakeholders. The resource management platforms suggested here are effective only if their suggestions and *decisions are politically relevant and salient.*

Choosing our futures – from prognosis to the use of multiple scenarios

When the positivist paradigm still dominated scientific thinking, predictions were normally undertaken with reference to error bars and standard deviation. As soon as outcomes are influenced by human decisions, such approach has proved little reliable. The effect of our choices can be better represented by agreement of "*feasible & consistent*" future scenarios, which suggest paths for the system's evolution as consequences of our action. Such efforts may be model-based (IPCC 1995), or based on logic reasoning and discussion (e.g. Pimbert 2001).

The use of scenarios may have different purposes. IPCC uses scenarios to facilitate communication between scientists and policy makers, and to offer a common platform for data sharing. The scenarios developed for the citizen's jury in Andra Pradesh (Pimbert 2001) had a different purpose: Three consistent futures of the agricultural production and trade system were presented to an audience, based

[3] A platform can be defined as „*a negotiating body (voluntary or statutory), comprising different stakeholders who perceive the same resource management problem, realise their interdependence in solving it, and come togehter to agree on action strategies for solving the problem*" (in Steins 1998 , S. 4).

on three different development paradigms. The jury was then asked to judge, based on the impact that these scenarios might have on their families and friends.

Scenarios have proved to be very powerful tools to stimulate discussion, but also to reflect the uncertainties inherent to mathematical modelling.

Approaches from integrated mathematical modelling to include "soft" knowledge in NRM

Sustainable development (SD) is driven by multiple and conflicting goals and constraints, complex interdependencies among interest groups and considerable moral and ethical considerations. On the other hand, the diverse (and often poorly co-ordinated) scientific disciplines have developed a large body of knowledge, methodologies and tools as policy and decision support (Kersten et al, 1999). Kersten also recommends a Management Science / Operational Research view on SD, with guiding principles such as (a) mainstreaming SD in thinking and strategic policy, (b) establishment of "all-level leadership to champion SD", (c) making full use of business tools [4], (d) the leverage of decisions with information technology. The implementation of SD decisions also requires (e) careful project management.

This chapter explores the knowledge needs for adaptive and participatory management, outlines some approaches and elaborates the use of mathematical models to support participatory decision-making.

General consideration for the use of models and for the predictions of reality

Mathematical modelling has advanced in recent years, and is applied to inform policy makers on Land Use / land-Cover Change (LUCC). As knowledge is integrated from different disciplines, and of different depth and certainty, one should keep in mind the structure and design philosophy of models, in order to match the specific needs for NR governance with the potential of LUCC modelling.

In LUCC (2002), two types of models are distinguished: "explanatory" and "descriptive" models, referring to the purpose of the model[5].

Descriptive models, even if parameterised with real world data, might or might not capture the structural mechanisms of real world dynamics. They fit observations from the real world to model equations, which may always be achieved with a sufficiently high number of fit parameters[6]. For *predictive modelling*, models must correctly represent the mechanisms governing the observed system, which is not a requirement of descriptive models.

Explanatory models are often designed to analyse certain system behaviour (effects like hysteresis, bifurcation, stability). These models are often aimed to reproduce one aspect of the real world and enable analysis. For reasons of simplicity, other effects are normally disregarded. For predictive modelling, *all* relevant mechanisms must be internalised appropriately, especially if a *new* sort of system behaviour is expected.

The term ***mechanistic*** is used to describe "scientifically robust" system processes, which shall be valid without any exception. Physical laws, chemical balances, weathering or nutrient depletion can be

[4] Kersten calls to „*use sound economic principles to clearly define decision issues, capture all opportunities and constraints, search for team consensus and find optimal solutions*" (p. 2). Even though few people will criticise the use of "sound principles", authors like Burger or Ruitenbeek are cautious that current management practices disregard *redundancy* in their "optimal solutions", which leads to less resilient systems. Due to amplified vulnerability against change, external pressures might cause non-optimal outcomes in the long run. Again, such concerns stress the importance of time scales in decision-making.

[5] The distinction between „analysed" and „designed" components that was suggested was not adopted, since most integrated models combine some sort of parameterisation (e.g. of sub-grid-processes) that may be "designed" with analysed data. Also economic models use "designed" rational actors that are then parameterised with real-world data.

[6] An example is the use of least-square polynomial fits. Even though a higher order polynomial will have lesser fit errors, the actual representation of system dynamics may even decrease, so prediction remains impossible..

considered of that type. Mechanistic models are ***deterministic*** and may run backwards in time (e.g. for validation).

The term ***comprehensive*** is used to describe observations that *are true in the general sense,* especially on aggregated levels (macro-scale). Comprehensive models or statements have strong explanatory power (e.g. many economic observations and theories). Yet, if rules should be verified on the individual or micro-scale, deviations are frequent. If mechanistic and deterministic laws are not applicable, such comprehensive laws remain as second best option[7].

Agents are virtual software objects with three properties: (a) they *perceive* information about environment, (b) they *process that information* in order to make decisions about future actions, (c) they *take actions* that effect them & their environment. Agents might have a memory and certain "states of mind", own asset endowment and one or more rules to decide on their actions. Agents might interact with each other and form networks on higher scales.

Valid prediction requires the correct representation of *all relevant internal mechanisms* of reality in the model. From past data, models shall reproduce observations. Since reality is of irreducible complexity, new and surprising processes that have not yet been observed might always emerge, thus setting a limit even to the best model-based predictions.

Three pillars of mathematical computer modelling for NRM: Conceptual models, Natural resource models and Human behaviour models

The model types as suggested here are pedigree in the sense that, especially for LUCC, combinations of that prototypes are normal. These prototype 'pillars' are used in the next subchapter for further categorisation.

Pillar I: Conceptual models that explain certain behaviour of a system (explanatory)

An early "integrated" model[8] that had tremendous impact on the debate on resource management was suggested by Dennis Meadows (1972) By coupling variables that were previously considered as unrelated (land use, population growth, energy consumption and emission of pollutants), he triggered a heated global discussion on our common future[9]. Similarly simple models are worth re-visiting due to their direct explanatory power (e.g. Fife 1971, Clark 1973) or the famous "daisy world" (von Bloh 1997).

Rather than predicting the future, such models enhance our understanding of processes and stimulate thought. The modelling goal is learning about, understanding and demonstrating the behaviour of systems. Data requirements are minimal. Interconnectedness is represented, and even emergent structures may be captured if specially addressed. Due to their simplicity, neither multiple views nor system uncertainty can reduced within a single model.

Pillar II: Integrated Modelling of natural resources and their dynamics
(mechanistic, generally parameterised with real-world data, often aimed to be predictive)

In recent years, supported by ever more powerful and affordable computers, large-scale integrated models become widely spread. Highly sophisticated meteorological, oceanographic, hydrological and land cover models, each implemented with a (not necessarily complete) set of rigidly tested and verified laws, are coupled into a single model, e.g. global climate change, which are driven with (exogenously determined) emissions of green house gases.

Similarly, coupled models can show the effect of interventions into the coupled system – like deforestation in mountainous areas which reduces water retention time, thus causing rapid discharge

[7] In conceptual models located in an "artificial world", the distinction mechanistic /comprehensive is obsolete since all assumptions are mechanistic *inside* this world.
[8] The term integrated modelling is used if social, economic and natural processes are combined into one model.
[9] F. v. Hayek strongly criticised Meadows model as too simplistic and scientifically flawed.

and downstream flooding. They may be used to demonstrate the effect of a dam on downstream water availability in time, on soil moisture and reveals the potential of irrigation and agricultural production. After careful calibration by diverse scientists and under the *ceteris paribus* assumption, such models are intended to represent reality and were successfully used for predictive purposes. A danger remains that unexpected feedback mechanisms that are *not* represented in the model might have severe real-world consequences.

Human decision-making and action remains exogenous. The modelling goal is to predict the effect of certain incidents. Data requirements are very high. Interconnectedness is internalised. Structures that emerge from action of human individuals are disregarded, but accumulative effects of resource flows are captured. Only changing parameters or model equations can test the effects of multiple user views. With regards to the natural system, uncertainty may be reduced - but often uncertainty in assumptions are disregarded and not discussed properly, while uncertainty from parameter knowledge is normally analysed extensively.

Pillar III: Models of human behaviour
(comprehensive; descriptive & explanatory; may be parameterised with real-world data)

Simple multi-actor models are used in game theory to show the effectiveness of strategies and overall outcomes. The prominent choice model is that of *rational actors*, but other models use heuristic or experimental decision frameworks. Social scientist suggested rule-based decisions. Recently, comparative studies were made to analyse the effect of diverse choice models.

Examples include game theoretic models, many economic models, models of negotiation processes or the very simple models like the iterative prisoner dilemma from Axelrod (1997).

Computerised models to support the Governance of Natural Resources

The models types presented here are used to support or facilitate natural resource management, as combination of mechanistic knowledge, normative analysis and truly "soft" sciences. The focus is to show how the pillars I-III may be combined for a range of purposes.

a) *Modelling to facilitate decision platforms: VESTER'S SENSITIVITY MODEL*[10]
(Group learning. Model development based on the knowledge of stakeholders. [I])

A unique type of model was developed and widely applied by Frederic Vester. Instead of applying ready-made models, this method translates the views of diverse stakeholders into a simple and illustrative mathematical representation. It is based on ideas from Masao Maruyama, who distinguishes three ***modes of perception***:

- by *classification*, sub-classification and ordering (attributed to our western societies)
- by *relation* to other entities (attributed to many indigenous cultures and oriental philosophy)
- by *relevance* and importance to our life, our dreams and longings.

First, stakeholders are asked to identify all variables that they consider important for the system (***classification***).

Then, they are requested to describe the strength of interaction with values symbolising weak to strong [-2, -1, 0, 1, 2] into a matrix (***relation***). Such exercise might require discussions and already reveals how opinions converge. If no consensus can be reached, the process can continue with more than one model matrix. At this stage, variables are already classified as (a) critical: effected &

[10] A similar approach was developed by Lynam (1999, 2002). Stakeholders identified key variables and related them with weights. View possible states of each variable were identified and later translated into a Baesian network. Participants very much welcomed the method, but also stated that the value added during the „model building session" was much higher than the actual model use.

effecting, (b) active: only effecting, (c) passive: only effected and (d) buffering: neither effected nor effecting.

After reducing the model to critical variables, subsystems are specified in a similar manner and are then translated into a time-evolving dynamic system, using fuzzification and fuzzy differential equations to translate influences into numerical values. Active variables are used as external drivers, and passive variables are integrated as they are affected by the system. The participating stakeholders can then use the 'model' to test their own assumptions, to discuss unexpected results and to revise their own understanding (learning about ***relevance***).

The action of humans may be internalised into the model. The goal of modelling is to facilitate a decision process by (1) enhancing stakeholders' understanding of the complex system, (2) their understanding of each other, (3) support a process of social learning and finally (4) support convergence of views. Real "prediction" of reality is not feasible, but potential feedback effects can be demonstrated. Apart from stakeholder knowledge, no further data are required. Interconnections are internalised into the model. The multiple views of stakeholders are revealed during the process and can be discussed. Uncertainty remains, but the model can be used to create at least awareness.

b) "Experimental" participatory agent-based modelling: Co-development of model with stakeholders and modellers, based on the knowledge from experts as well as stakeholders. [I & III]

A very promising approach was developed with CIRAD around Patrick d'Aquino, Christophe Le Page and Olivier Barreteau. As a tool for adaptive and iterative decision-making under irreducible uncertainty, the participatory development of a model was realised and tested as a self-design by (even illiterate) stakeholders with minimal support.

The model is based on a basic and simplified GIS framework that lays out the natural setting and environment, coupled with a Multi-agent system of resource users or managers. Due to a good user interface and the strong simplifications, stakeholders can easily design and test agents. During workshops, the modelling exercise was combined with role-playing games where stakeholders were asked to switch roles.

The approach was adopted and tested for land use management in Senegal (SelfCormas, D'Aquino 2003), for sylvopastoral management planning in France (Etienne 2003), and for the design of a water Catchment institution of the Drome River Valley in France (Barreteau 2003).

Instead of predicting a future, the aim of the CIRAD modelling is to define and commonly agree on a desired future (the *patrimonial approach*, ibid., p. 444): a shared representation of the system, agreement on the stakes of negotiation as well as on the long-term objective, suggestions for future scenarios by the involved stakeholders, a discussion which scenario may bring about the desired objective and decisions. Finally, the process aims to ritualise and legitimise such co-operative decision routine for ACM.

While the environmental context is strongly simplified, the action of stakeholders is directly represented in heuristic models. Interactions are represented, but emergence of structures not. The focus lies on social learning of stakeholders, not of agents. Data requirements are low-medium, but a modeller needs to implement the (virtual) environment.

c) Combining multiple agents with sophisticated NR models [II & III]

This last category aims to couple integrated, predictive natural resource modelling with "realistic" agents. These may include farmers, water users, industrial users and institutions. These agents need to earn their living through production of agricultural or other products; they might trade their assets or change their technology. The model may internalise markets & prices of grain and water, land markets and rental markets, labour migration, innovation and social networks (Berger 2001, 2002). The policy framework may be altered, which has effects on actors' decisions and subsequently on resource use and sustainability. The AGRIPOLIS-model (Happe 2003) was developed to show and explain the effects of policy interventions on income and asset distribution and other micro-level effects that are lost in aggregated agro-economic models. Based on a farmers' choice model, the software agents may be calibrated with real-world data.

The FIRMA-project of the European Union applied this approach in four case studies (Zurich, Thames, Maaswerken and Orb). Around stakeholder workshops, coupled integrated and agent-based models were presented and / or co-develop. The aim was the development of scenarios in order to derive policy options for water management (and methodological questions). Preliminary results were presented in (Firma 200XXX_5):

The ***involvement of stakeholders*** in model co-development was a time- and resource-consuming effort which was only possible since the problems addressed were "not really urgent". It brought up some important changes to model assumptions and considerable enhancement of short-term predictions. The feasibility and degree of stakeholder involvement is discussed in (Firma 200X_4). Apart of the opportunity to develop along a methodology that combines mathematical models, role-playing games and internet-based forums, the ***advantages*** mentioned include continuous validation of model plausibility and the inclusion of new insights. For stakeholders, especially the combination of high-tech models with low-tech paper models and role-playing was appreciated since it allowed non-specialists to alter and manipulate the system and increase their understanding of complexity. ***Disadvantages*** of the stakeholder involvement include high costs (time, money and social interaction). The analysis of mental models as well as coupled agent-based models is still an art. Contradicting statements by stakeholders were not easy to resolve. It was pointed out that the key claims of participation were seldom reflected (local stakeholder knowledge is good, participation enables empowerment, participatory processes have results that reflect stakeholders' views). Areas of improvement were identified concerning the role of facilitation, the ability to deal with power structures and the question of political salience of recommendations.

Two goals were identified by scientists (LUCC 2002): the development of scenarios, and demonstrating and explaining how policies may effect the use and condition of natural resources.

Due to model complexity, this approach may be the one that was least tested and applied which requires the most expertise and time. Interconnectedness of the natural systems, its interactions with the socio-economic system, human decision-making and actions are internalised, so data requirements are very high. Emergent structures like prices, institutions and others may be explicitly modelled, which adds to the uncertainty of assumptions. Due to high expertise needed to adjust the model, it remains a challenge to internalise multiple views from stakeholders (even though the development of tool boxes are currently undertaken, see Pahl-Wostl & Ebenhöh 2004). While uncertainty of the integrated natural resource model can be quantified, the uncertainty due to assumptions about human choice, their networks and interactions as well as their responses to institutional change are large and hard to quantify (e.g. Reusser 2004).

In summary, three interactive approaches to integrate modelling into participatory policy processes were presented. One only relies on stakeholder knowledge, one uses a simple natural resource model and agents that are developed with participants, and the third combines sophisticated natural resource models with sophisticated model agents.

The VESTER-approach, (d), addresses the knowledge of stakeholders and is a method to translate "soft" knowledge into a more explicit "hard" form. Social learning and consensus are the key goals.

The agent-based approach from CIRAD, (e), gives large space to integrate stakeholder knowledge into the model since it relies on relatively simple math. It cannot be used to predict futures, but proved effective to facilitate stakeholder dialogues. Assumptions derived from "soft" knowledge (agent behaviour & relations) can easily be formalised, tested and communicated in "hard" models.

The last approach integrates sophisticated resource models with agents. Since it provides coherency between resources and human action, results are promising if the development of "real" scenarios is anticipated. It was used to demonstrate quantitative *and* qualitative effects of policies, but challenges regarding verification and uncertainty analysis remain. In comparison to (d) and (e), the integration of soft knowledge has proved most difficult, due to the high expertise needed to manipulate the model. To minimise the area of conflict between modelling experts and stakeholders, good facilitation is a pre-requisite to avoid top-down workshops and frustration with participatory approaches.

Conclusion

What this paper has established is that there has traditionally been a lack of cooperation between the hard and soft sciences. In the realm of natural resource management this disconnect can be particularly problematic. In the complex world of natural resource management this disconnect can be understood for several reasons. Firstly there are the traditional barriers to ID research, such as bureaucratisation, disciplinary entrenchment and a mutual lack of understanding. Secondly natural resource management is by its very nature complex. This leads researchers to seek to simplify the system under analysis as a means to cope with complexity. Such a move is understandable, especially in light of the afore mentioned challenges to conducting ID research. Last but not least, research and management has developed advanced methods to manage 'complicated' systems, but methodologies to face complexity are still in an initial stage and not yet mainstreamed in management- and research institutions. Despite these challenges there is real benefit in studying the complex system in its entirety – an approach which calls for ID or Transdisciplinary research.

As mentioned in in the paper, the potential benefits of interaction between the hard and soft sciences also has considerable potential benefits in the case of NRM. Because NRM entails both physical as well as social dynamics, a unified understanding relies upon integrating both the hard and soft sciences. The hard sciences bring an unrivalled ability to understand physical phenomena, whilst the soft sciences bring an understanding of human and social dynamics at play within the NRM system. In combining the expertise of the hard and soft sciences there are benefits to science in terms of equity, efficiency and equity. Moreover, each discipline can be argued to benefit by enabling it to specialise on what it does best, rather than by attempting to confront problems which the discipline is incapable of addressing without external assistance.

Having set out the potential benefits of collaborative research, this paper has then set out a number of tangible ways in which integration is possible. We began by analysing the ways in which the soft sciences are traditionally marginalised, both in natural resource management as well as in the illuminative case of economics as a discipline that transitioned internally from soft to hard science. There are a number of very real barriers to integration, not least amongst them being the bureaucratic nature of universities and research. This bureaucratic nature is combined with the tendency, at least traditionally, for disciplinary entrenchment. However in recent years, especially in the realm of NRM, there appear to have been moves towards disciplinary engagement. Finally there is also the problem of mutually unintelligibility. This links with the issue of complex systems – in a world of considerable complexity it is not longer feasible for a single scientist to master an entire system. Rather the complexity of natural resource systems makes it necessary for a degree of specialisation. As the disciplines become more specialised, so to does their own set of 'shared rules and scientific standards' develop. As these shared rules grow so to does the potential for mutual misunderstanding.

Having established that whilst barriers exist, that there is potential and previous experience of successful integration of the hard and soft sciences. This has become more necessary as problems and scientific enquiry have progressed from simple systems towards complex systems. Within the framework this paper set out why and how it is important that we integrate the soft and hard sciences. We found that doing so benefits both disciplines. In the case of complex systems such as natural resources it can be argued as essential in order to fully understand the processes at work. The simplification of a complex system into an understandable model is of course essential for academic study. However in doing this we need to avoid the temptation to disregard that which is too difficult. Instead a better solution, one championed here, is to seek to answer the research question by adopting the adaptive co-management approach to NRM research.

From a research perspective, the model of adaptive co-management is particularly useful. This approach to managing NRM projects calls for a flexible approach to research – one that is open to internal learning and to the modification of research design as the project progresses. In this regard ACM is an 'open' method of management – the approach to the research evolves as the understanding of the problem evolves. Equally important is the call for co-management. It is not feasible to have one discipline managing the entire project and bringing in other disciplines if and when the dominant discipline deems it necessary. Rather there must be a policy of co-operation and mutual respect from the inception of the project. In terms of the intensity and scope of research provided in the first section, this should be at least at the level of collaboration. Whilst integration may not be feasible, or indeed desirable, in many cases – it is still possible to adopt a co-management model.

Of course, the management of a project is not the only way to achieve an effective outcome. We must also have tangible ways in which the hard and soft sciences can be integrated. How this occurs will of course depend entirely on the nature of the research problem at hand. To provide some real world examples, this paper investigated computer modelling. In the case of modelling natural resource systems it was shown that by using conceptual, natural resource and human behaviour modelling systems it is possible to incorporate both the hard and soft sciences. The use of computer modelling provides a unique opportunity for high intensity collaboration between the disciplines, potentially on a research problem with multiple foci. It is through combined natural resource and human behaviour modelling that we can begin to understand complex natural resource systems. This also has the added benefit in terms of sustainability, because we can combine an in-depth understanding of the natural system with views of the stakeholder community.

To summarise, there are indeed some barriers to the integration of hard and soft sciences in the realm of natural resource management. However these barriers are more than matched by the potential benefits that can be reaped from a research project which uses adaptive co-management. Such a project can indeed improve the efficacy and efficiency of research, indeed we would argue that an interdisciplinary approach is the best way to deal with complex natural systems. Interdisciplinary research does not need to be a situation where the soft, or the hard, science "loses out". Rather, both disciplines can benefit from ID research. It is no longer necessary to have a weaker or stronger partner – instead this paper demonstrates that ID research in NRM is both desirable and possible.

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