Introduction

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In 1996, an interdisciplinary group of researchers working the field of renewable resources management set out the first components, of an approach named 'companion modelling' (Bousquet *et al*., 1996; Barreteau *et al*., 1997). For many years these researchers had been involved in environmental research, such as the environment programme of the National Centre for Scientific Research (CNRS) or the Institut de recherche pour le développement (IRD) research programme 'Dynamics and Use of Renewable Resources' (Gillon *et al*., 2000), which was based on research carried out in the 1980s, such as the CNRS action 'Ecosystems and Social Systems' (Jollivet, 1992). Among the numerous conclusions produced by this research, was the recommendation to go beyond the multi-disciplinary juxtaposition and to commit to a cross-disciplinary approach in addressing environmental issues, and the proposal to rely, whenever possible, on the modelling method as a catalyst for the interaction process between researchers from different disciplines. During the same period, groups of researchers made exploratory inroads into new modelling tools and their suitability for facilitating interdisciplinary dialogue by creating a common representation. Based on the theoretical foundations of the sciences of complexity, methods such as multi-agent systems (MAS) (Bousquet and Le Page, 2004), individual-based modelling (Grimm, 1999) and micro-simulation emerged within some disciplinary communities. The research presented here is based on these findings as well as on the sharing of a few premises[1].

– The socio-ecological systems that we study are complex objects and, therefore, supporting the decision-making process does not involve attempting to predict the future state of the system. It is more akin to understanding the organization in which it is found, to envision the organizations sought, to encourage the system of interactions that govern change, to monitor constantly and render explicit the changes in the system, to be able to suggest adaptations and to learn continuously by observing their effects.

[1] For fuller discussions on the theoretical foundations of companion modelling, please refer to Collectif ComMod (2009).

– Every stakeholder in a social system has his own view of the reality of the system, a point of view that he has built up on what he has experienced during his life trajectory in the physical and social space. These constructions come from, and constitute, the system of representations specific to the culture to which the stakeholder belongs (Friedberg, 1992). Where key issues and high uncertainties lead to constructions that are not just conditioned by scientific facts but also by the values of stakeholders, Funtowicz and Ravetz (1993) suggested using a post-normal approach. Then, decision quality relies on the quality of the decision-making process itself, among other things, the existence of prior dialogue between stakeholders, not just to check that these decisions are acceptable but also to construct them together.

The first experiments proposed models incorporating various types of disciplinary knowledge and were based on multi-agent modelling (Barreteau, 1998). From a basic principle, to recognize and formalize the diversity of viewpoints in a complex system, rose other experiments aiming at interaction between the various bearers of knowledge, be they researchers or local stakeholders, using different tools, such as role-playing games and simulation models. The approach set up, the subject of this book, is designed as an iterative and sustained interaction process between scientists and other stakeholders involved in renewable resource management. It aims at structuring, even integrating, this heterogeneous set of knowledge into a comprehensive synthesis that helps in settling a dispute. Let us emphasize that the creation of a common representation does not aim at substituting it for plural representations; it is more a question of developing an agreement whereby different viewpoints can be expressed. Knowledge can involve natural dynamics as well as social dynamics or their interactions. Highlighting the various representations produced forces the stakeholders into an awareness of the diversity of individual viewpoints, to share them, enrich them, raise doubts over them and discuss them during collaborative exchanges of views from which a shared representation can emerge. As the scientists in this perspective are considered stakeholders like anyone else, this type of approach implies that their initial analyses can also be questioned.

The research developed during the last decade was carried out in parallel with other developments in the field of participatory modelling. Although we do not consider participatory mapping here as it does not include the simulation of ecological and social processes, we retain from the conclusions of Fox (1998) that the formalization of space is not consistent with the flexible and fuzziness properties of boundaries. It also violates the right to keep the information confidential. We also question the influence of these activities on power relationships among stakeholders (Abbot *et al.*, 1998; Chambers, 2006). A tentative typology of participatory modelling experiences can be based on the seminal work of various initiators such as the group model Building (Vennix, 1996) and mediated modelling (van den Belt, 2004), or can be based on tools such as Bayesian networks, system dynamics or MAS. These typologies are not very useful because they hide similarities and differences among the approaches. We have selected here some relevant experiences. Costanza and Ruth (1998) proposed a three-steps approach (from an abstract model to a contextualized model), each step involving the stakeholders. Other scholars proposed the reverse approach starting from contextualized models. There are different categories of stakeholders (Hare and Pahl-Wostl, 2002) that are involved in different ways as noticed by Lynam *et al.* (2007) after Pretty (1995) and Arnstein (1969). Pahl-Wostl and Hare (2004) assessed the impact of participatory modelling through the concept of social learning, while other scholars focused on organizational or technical transformations. In 2001, Korfmacher (2001) proposed general rules for participatory modelling: a transparent process, continuous involvement, appropriately representative involvement, influence of stakeholders in modelling decisions, and assessment of the modelling role in management. These guidelines have been confirmed in recent publications (Reed, 2008; Voinov and Brown, 2008). These controversies and guidelines orientated our research and stimulated the comparisons and synthesis proposed in this book.

The beginnings

Two applications put these conceptual constructions to the test and, through their complementarity, laid the foundations for future experiments. In 1998, Barreteau and colleagues, who had recently developed a computer simulation model on the dynamics of irrigated perimeters in the Podor region of Senegal, used a role-playing game to present this model to the stakeholders with whom he had worked (Barreteau and Bousquet, 1999; Barreteau *et al.*, 2001). The task was to simplify the model to make it playable whilst maintaining the complexity of decisions and interactions, and allowing processes comparable to those actually observed to be revealed in the dynamics of the game. The stakeholders played, discussed the roles assigned to them, the system of interactions they could activate, the simplified representation of the biophysical model, and the global observations at the scale of the irrigated perimeter. This revealed characteristics of the system such as, among others, the crop success rate, the conflicts in accessing water and the problems of credit management. A role-play computer model was thus developed and used with local stakeholders to explore rapidly various scenarios. A few months later, d'Aquino and colleagues, who were working on land use and allocation plans in the Senegal river delta region as part of the decentralization of natural resource management to the rural councils, organized a companion modelling workshop with this fledgling organization (d'Aquino *et al.*, 2002c, 2003). This time the idea was to develop with different stakeholders (i.e. herdsmen, fishermen, farmers) a shared representation expressing their multiple viewpoints. A three-day workshop was organized. On the first day, the protagonists constructed a space-resource model, which they shared and used to create a list of rules specific to each user. On the second day, this knowledge was tested with a role-playing game mobilizing the stakeholders in a situated dynamic using the rules identified on the previous day. The actual problems encountered came to light and the discussion focused on the confrontations of rationalities and the scenarios that could potentially accommodate them. On the third day, a computer model, the numeric equivalent of the role-play, was used to initiate discussion on the consequences of these scenarios.

Identity of the ComMod network: the charter

Following these first attempts that served to test the application of the principles enacted, and which allowed the articulated organization of theoretical research phases, field experiments and the design of appropriate tools, it proved necessary early in the 2000s to formalize the method accurately in the first instance, and above all, to specify the particular stance of the researchers involved in this 'companion modelling'. The fundamental principles of this gradually co-constructed approach (i.e. formalization of a diversity of viewpoints, scientific knowledge considered as one point of view among others in the consultation, priority on the iterative consultation process rather than on its products) needed to be formalized clearly to justify better the group's methodological choices. Documents were produced on the participatory process (d'Aquino *et al*., 2002a) and its ethical rules with a charter produced and published in English (ComMod Group, 2003) and French (Collectif ComMod, 2005) in the journal *Natures Sciences Sociétés*, where it was commented on by reviewers from different disciplines.

The ComMod stance is based on a dynamic perception of the decision-making process, considered as 'the result of an interaction process between individuals and/or collective actors with different weights and representations in negotiation' (Weber, 1995b). The aim of the ComMod process is either to produce knowledge (intended for researchers and local stakeholders) under an improved understanding of a system of interactions, or to support negotiation under a process explicitly targeting a transformation of practices or forms of social and economic interactions. The approach uses modelling and simulation tools to construct a shared representation (which does not mean unifying) of the system studied, account for its dynamics and provide support for analysing scenarios. Lastly, the ComMod approach assumes a researcher stance, which we believe must be stated imperatively.

Producing knowledge about complex systems

Few collective decisions involving interactions between a social group and its environment are predictable in technical, economic or social terms. This unpredictability suggests a need for a different approach, one that accepts the incompleteness of analyses and the subjectivity of future choices, which justifies the existence of potentially contradictory viewpoints and allows them to be taken into account and re-assessed. The objective here is learning about the existence of these different viewpoints and the consequences of their diversity on the functioning of the system.

When one or more stakeholders in a resource management system expresses the wish to gain a better understanding of the functioning of the system, the ComMod approach is to construct a representation of this system in one or more diverse forms (e.g. diagrams, maps, simulation models, role-playing games, videos). This co-construction normally unites a certain number of stakeholders in constructing this representation before submitting it to other stakeholders for comments, challenges or modifications. The preliminary phases such as identifying the issue, wording the question and selecting the stakeholders concerned are integral parts of the ComMod approach.

Supporting the collective decision-making process

The objective can be to go beyond sharing viewpoints, to committing to a process with the explicit purpose of modifying the functioning of the system. This objective can be issued directly or after previous work on the sharing of knowledge by all stakeholders. The support is upstream of the technical decision, to boost the thinking of the various stakeholders involved to reach a shared representation and possible routes towards engaging in a social process of taking charge of identified problems. In this instance, this involves giving the community the means of taking over the uncertainties of the situation examined jointly in the best possible way. The ComMod approach thus aims at encouraging the quality of the process behind the decision and at establishing conditions for monitoring and possibly revising it.

Models as support tool

The researchers who develop and use this companion modelling approach propose various modelling tools, such as diagrams, maps, videos, etc. Note, however, that in practice most operations have used MAS models to conceptualize a representation, which has then been converted into real-life computer simulations and role-playing games. These two tools are frequently combined: role-playing games are a simulation where the stakeholders play a role whereas computer simulations use virtual agents. The aim is to clarify and share viewpoints on the situation studied. The use of models is reflexive: the stakeholders learn together by creating, modifying or observing the models. Stakeholders can use these tools to issue hypotheses, suggest scenarios and jointly observe the consequences. It is sometimes said that these models are ‘disposable’, representations shared between a group of stakeholders at a given moment. They are frequently an extremely simplified representation of the problem yet sufficient to reflect the complexity of the system by taking the main dynamics and interactions into account.

The position of the researcher

The researcher is found in several positions in the companion modelling process. He is firstly a researcher in the classical sense, inasmuch as he produces, with other stakeholders, knowledge on the management context and on the participatory process. His results lend themselves to rebuttal as he provides the elements which led to the conclusions issued. However, as already stated, he is also a stakeholder in the system and his role can be questioned. The ComMod Charter provides an ethical framework highlighting the following points:

– the transparency of hypotheses and underlying procedures; graphic and spatial modelling and role-playing games have been developed with this very much in mind

– the clear display of domains of use in the models developed

– the researcher’s involvement in the process; the researcher who adopts this approach is a bearer of knowledge like anyone else, although he frequently plays a singular role in initiating and facilitating the process

– the ongoing undermining of the proposed process, be it by local stakeholders or by scientists; this undermining takes concrete shape in many circumstances through failure to commit to a ComMod process as the analysis of the social context brought risks to light, or by halting an ongoing process due to the refusal by key stakeholders to take part in the process.

The publication of this charter in *Natures Sciences Sociétés* gave rise to miscellaneous comments, which are presented in Chapter 2, principally the status of the scientific knowledge in the dialogue engaged. Although debating this viewpoint is consistent with the foundations laid down, should this scientific knowledge be placed on the same level as the knowledge of other stakeholders or should it be debated differently?

Diversity

From the early 2000s, many new applications have been carried out in various countries worldwide concerning different resources and in various ecological and social contexts. New researchers joined the network, each of them performing their experiments using a method they considered suitable, by organizing *ad hoc* stages and mobilizing specific modelling tools.

Let us observe a significant trajectory to illustrate the diversity of companion modelling implementation. Based on over 20 years research into forestry-pasture development and forest-fire prevention, the regional grassland specialist departments in Provence and Languedoc have set up several operations combining livestock breeding and forest-fire prevention. Faced with the sheer size of the areas involved and the emerging potential conflict of usage between foresters, breeders, hunters and other users of the Mediterranean forests, the Ministry of Agriculture (via the Groupement d'intérêt scientifique Incendies de forêts) and the French Forestry Commission (Office national des forêts – ONF) (under the forestry-pasture programme of the Var Department), sought a tool to facilitate consultation between these various stakeholders. The Ecodevelopment Unit of the French National Institute for Agricultural Research (INRA) suggested, therefore, constructing a model for use didactically in the three main types of forest in the Var, that is, cork forest with maquis undergrowth, Pin d'Alep pine forest with Kermes oak undergrowth, and white oak forest with broom undergrowth. This experiment illustrated the first attempt at companion modelling applied to forest development (Étienne, 2003). The approach was divided into four phases:

– integration of available scientific knowledge on forest dynamics, sensitivity to fires, brush-clearing techniques and forestry and breeding practices most commonly used in this type of environment in the form of a multi-agent computer simulation model

– simplification of this model from simple management entities (i.e. forest plots, grazing units, fuel breaks) and three virtual territories, each representing major characteristics of the three types of forest

– situation simulation exercise for stakeholders taking part in most of the silvopastoral management plans, in the context of a role-playing game in a fictitious forest close to their real-life situation, to make them react to the forest dynamics and effects of grazing on these dynamics

– reconversion and adaptation of the role-playing game for use in teaching students in forestry, agronomic or veterinary colleges.

The feedback on this case study carried out in the 2000s led to several institutions requesting adaptations of this type of approach for similar issues. In December 2005, the Gard Departmental Agricultural and Forestry Service (Direction départementale de l'Agriculture et de la Forêt – DDAF) suggested tackling the forest-fire prevention problem at the peri-urban interface. The Environment Service of Nîmes-Métropole Urban Community, keen to raise the awareness of its elected representatives to this issue, offered its area as a test zone. The approach was divided into four phases:

– compilation of available mapping data on the forest, the dynamics of urbanization and practices of the main local stakeholders (i.e. farmers, urban developers and foresters)

– development of a virtual map representing three typical adjacent municipalities in the northern Nîmes area and validation of this map by a group of technicians covering the main activities of the area

– co-construction, with the same group, of a conceptual model representing the current functioning of this area and the likely dynamics over the next 15 years, then implementation of this model by INRA researchers as a multi-agent computer simulation model

– A situation simulation exercise for elected representatives from 14 municipalities involved in discussions on the issue of forest-fire prevention in conjunction with urbanization, in the context of five sessions of role-playing games involving an urban developer, three mayors, a DDAF technician and a representative of Nîmes-Métropole.

The initiative culminated in a collective awareness of the implications, in terms of fire, of expanding urbanization at the expense of agricultural wastelands and natural areas. The importance of reflecting collectively on setting up fire-prevention devices was identified clearly, but the elected representatives debated long and hard on the failure to integrate these systems within urban planning projects and the lack of financial resources to maintain them. The quality of the interactions and learning prompted the various stakeholders to agree to it being standardized at district scale and to provide financing for this purpose.

This account of two companion modelling operations raises the question of the essential facet of this approach. Here administrative bodies place an order with recognized research for its expertise on a specific theme, there other administrative bodies call on the researcher's methodological skills to lead a dialogue and raise awareness of certain stakeholders. In one case, the aim was to trigger dialogue between users of spaces and resources (i.e. foresters and breeders) with very different powers, in the other it was to raise the awareness of elected representatives, armed with their decision-making and management powers, with economic strategy stakeholders (urban developers). In the first operation, the researchers summarized the scientific knowledge, incorporated it into a computer model and used a simplified role-playing game to bring the stakeholders into confrontation. In the second operation, the various stakeholders collectively constructed a conceptual model, which highlighted the representation of their knowledge. The approach aimed at triggering dialogue between land users was then extended for educational purposes the one aimed at raising the awareness of elected representatives in an urban community generated a dialogue arena where it was decided to disseminate on a wider scale. What are the common points of these two operations so that the researcher, and also the partners who were inspired by the first to commence the second, thought them similar enough to talk about companion modelling in both cases?

Diversity giving way to invariants?

Although each member of the ComMod network thought they were conducting their experiments in the companion modelling approach, the group rapidly had to face two questions.

– What are the invariants when applying a ComMod approach? Given the diversity of operating procedures and the increasing demand for training and new applications, a reflexive analysis was clearly needed to better describe the ComMod approach.

– What are the effects of the method? The various experiments have shown the feasibility of companion modelling. Wherever models have been developed, so dialogue arenas have been created and interactions taken place. What have they produced? Is it possible to measure the resulting learning? Have there been actual changes through technological innovations, through concerted management planning or through organizational changes? If so, what influence has companion modelling had on these changes?

This tension between a homogeneous stance and sought-for diversity, pragmatism, adaptation to contexts, questions and issues arising from case studies, requires a period of reflection to understand the potential divergences and enrich the experience of the group.

The ComMod approach invariants and its assessment

To respond to these questions, the majority of the ComMod network members replied to a call from the National French Research Agency (Agence nationale de la recherche française – ANR) on the theme of agriculture and sustainable development. Four types of result were expected.

– Understanding and comparisons of the effects of the companion modelling approach when implemented in a variety of ecological, institutional and socio-political contexts. The context is taken to be the combination of a geographical situation, stakeholders concerned, resource or area in play, social context of the use of the resource (e.g. conflict, routine situation, existence or otherwise of formal or informal dialogue arenas), and questions asked. The effect of the context should be assessed by its consequences on the collective decisions made or the knowledge produced when implementing companion modelling.

– Understanding of the effect of context on the implementation of the approach itself and especially on the effectiveness of the link between research activities and the practical applications. As the practical implementation was open, the framework in which it was applied, and especially the questions asked, can result in steering its implementation in one direction or another whilst respecting the founding principles laid down in the charter.

– Production of a methodological guide proposing flexible 'know-how' to help implement the ComMod approach successfully and to disseminate it.

– Production of a methodology to assess the companion modelling approach, stating the indicators to be monitored and highlighting the points for later methodological development. Precise collective and individual social and economic indicators have to be identified given the difficulties in assessing the approach; these account for changes in the stakeholders involved in terms of networks, social representations and management practices.

Research during the project has produced several tools and results. The first task was to perfect a common canvas to describe a successful ComMod process. It was developed through tests on a sample of seven cases, to account for the diversity of case studies, then discussed and amended by all members of the group. This document known as the Montfavet canvas was completed by each team initiating and running a ComMod process. It describes the initial context, the origin of the request, the questions asked, and presents a time chart of the various activities undertaken and describes the operations achieved to develop the various models (as role-playing games or computer simulations).

Another document was produced to describe the operations in progress, a 'logbook', which was also filled in by the team running and initiating any new ComMod process. Just like a log, it reports chronologically on all the operations undertaken and especially on the sequence of meetings where stakeholders share ideas and representations. The second task was to perfect a protocol to assess the effects of such an operation. The resulting Canberra Protocol is divided into two parts. The first part covers the approach designer(s) who must indicate their objectives, the anticipated individual and collective learning, the modifications to interactions between the stakeholders and changes in their practices. The investigation also covers the various tools used. The second part of the protocol is intended for participants and aims to assess the same elements.

Once this descriptive and assessment material was finished, 27 case studies (a description sheet for each one is available in the Appendix) were described and some 18 were assessed. This material is now available and through comparison and synthesis provides elements of reply to questions raised in the ComMod approach. This work is based on the experience of the ComMod network. It reports on a collective reflexive approach to practices at the interface between renewable natural resource management, a stance of intervention in collective decision-making processes and sustainable development. It has the twofold intention of clarifying what companion modelling is exactly and to put these definitions to the test.

Organization of the work

Chapter 1 presents the elements for implementing a companion modelling approach, as it is and as it is applied in the case studies. It introduces the protagonists and the dynamic of interactions between them. It emphasizes in particular the notions of iteration, interaction between companion modellers and participants in a collaborative action dynamic, and the key points in exploring collectively a virtual world during what we called collective key moments. Based on the original gathering of these elements, this chapter shows the diversity of implementations, adaptation to the context and the skills used.

In Chapter 2 we stand aside from the principles founding the origins of the ComMod stance to show that adopting the stance comes from practices, methods and techniques mobilized and developed by the commodian to facilitate, in the sense of giving life and/or making live, the approach and associated partners.

Chapter 3 explains how models are developed with the objective of sharing representations of an actual system and how these models are used in workshops based on the exploratory simulation of scenarios where the results are interpreted with reference to the actual system. Special attention is paid to multi-agent simulation models, using human agents (role-playing game) or virtual agents (computer simulation model). The advantage of combining the two types of agent in a simulation tool and/or the two types of simulation tools when implementing the approach is analysed in particular.

Chapter 4 attempts to understand the effects of taking the context into account when implementing the approach and its results. Based on an analysis framework of the social and environmental context and the intervention context, this chapter discusses the consequences of considering the context, or not as the case may be, in the various ComMod case studies, defining objectives, choosing participants, the dynamics of the process and the decisions or actions resulting from it.

Faced with the need for the ComMod network to improve its formalization of the positions it assumes when taking the social and political context into account, particularly in terms of asymmetries of power, Chapter 5 suggests a way of explaining these positions. When applied to ComMod researchers, this method reveals the existence of contrasting profiles within the network, both dialogical and critical. However, beyond this variability, two major points of agreement stand out within the group: a changing, adapting positioning based on the intervention context and changes in the power issues during the process, as well as the desire to explain this positioning to ensure that it is legitimate. This second point forms the basis for discussing one of the founding principles of the ComMod approach: the systematic explanation of all the hypotheses behind the modelling approach.

Chapter 6 addresses the question of assessing the effects of the ComMod approach. Having justified the principle and bolstered the theoretical foundations of such a procedure, we present the assessment protocol. Before describing the results of the meta-analysis based on the 18 case studies assessed, we felt it important to illustrate the protocol appropriation process suggested by assessors with different profiles of contrasting contexts. Lastly, we suggest a series of worthwhile improvements to the current protocol.

Chapter 7 dissects the technologies used in our approaches, especially the simulation tools. The analysis covers compatibility with the cognitive framework of stakeholders, their ability to be manipulated directly by participants and their different effects. It also addresses participant perception of the validity of the tool and its link to reality, as well as the ability of the tool to explore possible evolution trajectories.

Chapter 8 shows how the ComMod approach is totally committed as a contribution of science to sustainable development. It addresses how the approach comprehends sustainable development as a process and commits to implementing the principle of participation. It then lays down the companion modelling boundaries faced with an obligation of means and results and finally, evokes the prospect of introducing a quality approach, based on a precise monitoring/assessment method.

In Chapter 9 the relevance of the hypothesis is discussed whereby the participation of stakeholders in a companion modelling process works, during developed interactions, towards modifying their viewpoints, opinions and representations, thus providing an insight into their interactions, relations with the environment and the dynamics of the socio-ecological system. This chapter demonstrates the importance of collective key moments in the individual and collaborative learning processes observed.

Chapter 10 presents the issues and questions raised for companion modelling by integrating multiple, frequently relative and changing scales and, therefore, the evolution of the approach with stakeholders' mobilizing scales other than those considered initially. Taking multiple organizational levels into account does in fact affect the tools to be mobilized as much as the stakeholder interactions in the discussion arenas. Having revisited a few definitions and issues specific to this problem, this chapter presents and discusses the formal and participative processes used to consider these multiple dimensions and levels and changes in the approach.

Chapter 11 discusses the teaching and training of the companion modelling approach. This knowledge transfer is examined under three contexts: academic teaching, training sessions or observation of an actual companion modelling process.