Adapting Science to Adaptive Managers: Spidergrams, Belief Models, and Multi-agent Systems Modeling

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ABSTRACT

Two case studies are presented in which models were used as focal tools in problems associated with common-pool resource management in developing countries. In the first case study, based in Zimbabwe, Bayesian or Belief Networks were used in a project designed to enhance the adaptive management capacity of a community in a semiarid rangeland system. In the second case study, based in Senegal, multi-agent systems models were used in the context of role plays to communicate research findings to a community, as well as to explore policies for improved management of rangelands and arable lands over which herders and farmers were in conflict.

The paper provides examples of the use of computer-based modeling with stakeholders who had limited experience with computer systems and numerical analyses. The paper closes with a brief discussion of the major lessons learned from the two independent case studies. Perhaps the most important lesson was the development of a common understanding of a problem through the development of the models with key stakeholders. A second key lesson was the need for research to be adaptive if it were to benefit adaptive managers. Both case study situations required significant changes in project orientation as stakeholder needs were defined. Both case studies recognized the key role that research, and particularly the development of models, played in bring different actors together to formulate improved management strategies or policies. Participatory engagement with stakeholders is a time-consuming and relatively costly process in which, in the case studies, most of the costs were born by the research projects themselves. We raise the concern that these activities may not be widely replicable if such costs are not reduced or born by the stakeholders themselves.

KEY WORDS: adaptive management, Bayesian belief networks, developing country, dynamic modeling, multi-agent systems, participatory modeling, semiarid rangeland, Senegal, spidergrams, Zimbabwe.

Published: January 2, 2002

INTRODUCTION

At the interface between natural and social dynamics, environmental research is tackling development problems by examining questions that relate to resources and externalities. These include the management of renewable resources, externalities of production (pollution, effluent, etc.) and areas with multiple uses. Natural dynamics are composed of numerous interwoven processes involving different resources at different spatial and temporal scales. Social processes involve different stakeholders at various levels of organization, ranging from individuals or communities that use resources and spaces to large development institutions. The issues focus on the regulation of resource use, which is adapted to natural dynamics, through the application of economic, legal, or institutional management tools. In each of the cases presented here, the issues were related to problems of collective management where ecological processes have to be reconciled with social processes for resource use.

Public administrators, NGOs, researchers, agriculturalists, and migrants have different representations of the system. The management of natural resources is a collective learning problem. Models may be used to focus discussions on cause-and-effect connections between behavioral and interaction rules and the resource dynamics. The question is how to use these models.

Recent research in the smallholder sector of Zimbabwe and elsewhere has demonstrated the great complexity of these production systems based on natural resources (Fresco 1986, Scoones 1996, Cumming and Lynam 1997). Multiple stakeholders seek to satisfy multiple and often competing objectives using resources that are both spatially and temporally variable. To further add to the complexity, the resource users in these systems often function within diverse institutional circumstances, mixtures of quasi-private through common-pool resource management regimes that are established and maintained by mixtures of traditional, locally elected, and central government authorities (Cumming and Lynam 1997). At the same time, it has become increasingly clear that for development-oriented initiatives to achieve their objectives, the key stakeholders in the system must be involved in all stages of the process, from problem identification through the implementation of solutions (Chambers 1983).

Faced with such daunting complexity, many have advocated an adaptive approach to managing ecological systems (Holling 1978, Walters 1986, Rogers and Bestbier 1997). Much of the stimulus for advocating an adaptive approach is the recognition that it may not be possible to collect and analyze sufficient data to adequately understand the system of interest (Walters 1986, Johannes 1998).

Dynamic modeling is a key component of the adaptive management process and serves three core functions, as identified by Walters (1997). First, it seeks to clarify problems and improve communication among stakeholders; second, it facilitates the screening of management or policy options to eliminate unworkable solutions; and third, it identifies critical knowledge gaps. However, in the context of smallholder managers in developing countries, where most managers have no history of interaction with computer systems and have limited or no mathematical abilities, modeling is a complex challenge on its own.

Two modeling approaches are presented:

1. *Bayesian or Belief Networks* (BNs; Jensen 1996) provide a probabilistic and relatively, although not entirely, static representation of the relationships between input variable states and the states of the variables of interest, and have proven useful in natural resource management situations (Varis 1997, Cain et al. 1999). This approach was used in the Zimbabwe case study.

2. *Multi-agent systems* (MAS, also called agent-based simulation) provide a useful modeling framework in systems consisting of a large number of agents who interact with each other in various ways (Holland 1995). In these models, the agents change their actions as a result of events in the process of interaction. The behavior of the whole system depends on these interactions between agents, which can be represented in a model. MAS are used to set up spatial models, which integrate social and ecological dimensions (Bousquet 1994, Barreteau and Bousquet 2000, Janssen et al. 2000, Kohler and Gumerman 2000). The aim of the modeling experiment was not to represent the whole system, but to build and test theories. Complex dynamics may emerge from simple rules.

In this paper, we present the results of independent case studies, carried out in Zimbabwe and Senegal, that have used different modeling activities to facilitate communication between scientists and participating communities, and also to explore options for improved resource use. It is important to emphasize that, in the contexts in which these case studies are presented, the models were used more as part of a process of developing and exploring a common understanding of problems and possible solutions. They were not designed to be highly validated, predictive models in the sense in which systems models are usually developed and used. We are not aware of other examples in which local people, who have no history of computer-based modeling, have been involved, not only in the use of computer models, but also in their development. The paper begins by presenting a simple conceptual model of the adaptive management process that will guide the later presentations. Thereafter, results of field experiences in Zimbabwe and Senegal are presented in relation to this model. In the final section of the paper, the lessons learned from these experiences are presented in relation to the opportunities and constraints that might hinder or improve the effectiveness of adaptive change agents in the future.

THE ADAPTIVE MANAGEMENT CONTEXT

In this section, we provide a brief outline of the process of adaptive management as a context for the modeling processes described in the case studies. Adaptive management is generally accepted as a continuously iterative, learn-by-doing process, in which objectives, activities, monitoring protocols, and evaluative procedures are established and then refined as new information is gleaned from the experimental manipulation of structures or processes. FIn order to simplify the discussion in this paper, we condense this set of processes into five sets of activities: *Problem formulation* (including needs analyses and setting system objectives); *System understanding*(including modeling the system to locate key leverage points or to identify optimal activities or designs as well as the selection of actions to be taken); *Action* (those activities undertaken to achieve the objectives); *Monitoring and evaluation* (including all observations and evaluation of system performance in achieving objectives); and *Updating.*The last set of activities explicitly recognizes that adaptive management calls for continuous and careful updating of each set of activities. In the context of the work presented here, the adaptive management process is seen as distinctly nonlinear; refinements and improvements in any of the stages can, and indeed should, happen at almost any stage of the process.

It is important to recognize that learning by doing is a long, time-consuming process. In some cases, it may have negative consequences, which implies a risk to the participating stakeholder. Often there is no possibility of repeating particular trials or experiments. Therefore, modeling and simulation can play important roles in each set of activities in the adaptive management process. Models provide an important tool when it comes to clarifying the nature of a particular problem. Both case studies in this paper reflect the use of models in this mode. Perhaps the more common view of models in systems activities and in formal system analysis is in their role of representing current understanding of the system, and thence being used in a predictive mode to identify key intervention points or activities as well as key gaps in understanding. Instead of prediction, models can also be used for communication and mediation in a collective decision-making process (Bousquet et al. 1999). Although models may not play a direct role in the actions themselves, they do form the stimulus–response framework, which guides the nature of the actions and their implementation. Models play an important role in devising monitoring protocols as well as in providing a useful set of evaluative tools to suggest when critical thresholds or conditions are likely to be reached or exceeded.

The more formal modeling tools presented in this paper are by no means the only useful representations. They represent a small sample of potential models and model applications. Perhaps their importance, however, lies in their use in a developing-country context and where they are having a significant impact on the direction taken in the described development projects.

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Zimbabwe: Participatory development of vegetation resource management strategies

In the Zimbabwe case study, a collaborative research project was initiated in early 2000 with the community of Mahuwe Ward, Guruve District, a semiarid area, of about 400 km^2, in the eastern Zambezi valley of Zimbabwe. The project's objectives were the design of management strategies for the common-pool vegetation resources that would improve productivity in terms of the supply of livestock feeds as well as other goods and services that households use (e.g., timber, wild fruits, thatching grass). A major objective of the donor funding the project was the development of a replicable approach to improving management of common-pool vegetation resources. Recognition of the failure of so many similar development initiatives prompted the Zimbabwean research team to ask themselves what would most meaningfully contribute to the sustainability and replicability of their initiatives. The answer was obvious: enhancement of the capacity of local managers to manage adaptively. As a consequence, the project shelved many of its pre-determined objective and activity sets, and focused instead on how to enhance local adaptive capacity.

A community-based coordination committee was formed, drawing on local leaders. Each village in the community was asked to select two local informants, called "Village Representatives," as well as a communications team member. Different experts were called in to assist with any one particular stage of the research process.

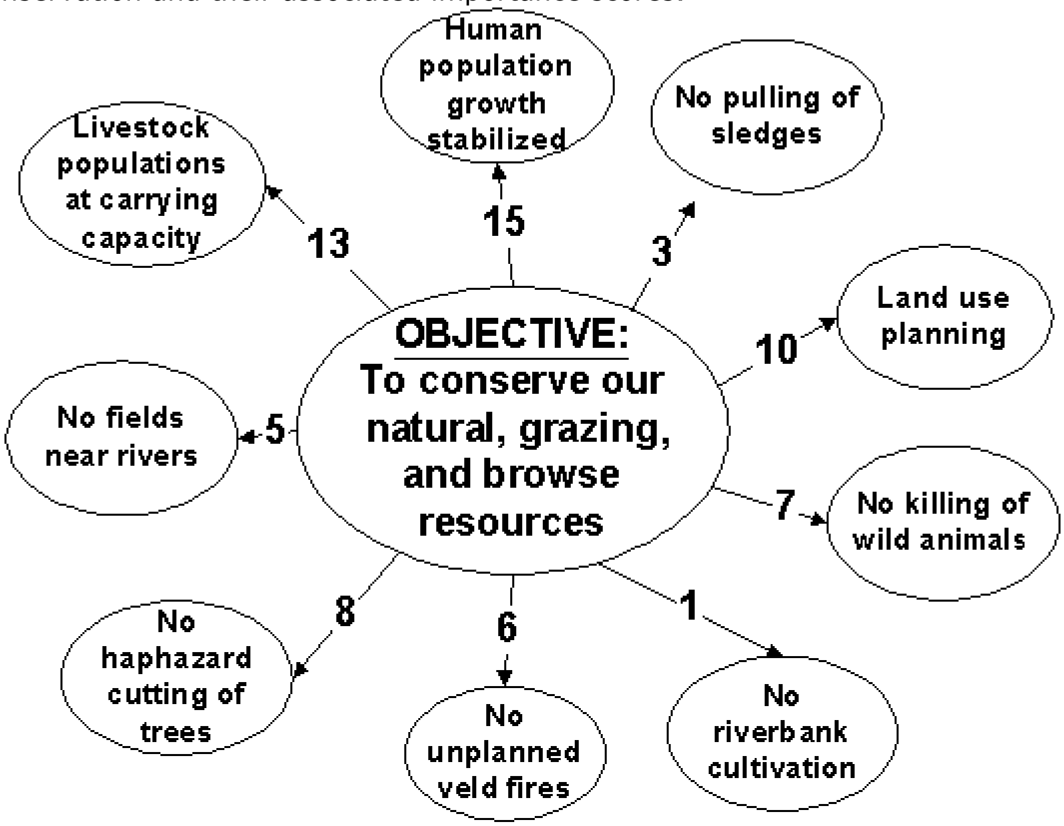
To begin with, several participatory rural appraisals were conducted to obtain a broad and general understanding of the structure and use of vegetation resources and to identify key problems from as many perspectives as possible. Thereafter, a focused workshop was held with the coordinating committee members, the Village Representatives, and the communications team members to identify the broad community objectives to be used as a guide for woodland resource management. Eight objectives for Mahuwe Ward were defined and agreed upon:

1. To conserve our natural, grazing and browse resources.
2. To protect and respect the traditionally sacred places, our spirit mediums and traditional leaders.
3. All residents to be aware of their rights pertaining to the use of common pool resources.
4. Residents to appreciate the importance of wise use of natural resources for the benefit of future generations.
5. To generate income from the natural, graze and browse resources.
6. For future generations to learn from these resources (so they know how to use and benefit from the resources).
7. To carry out research on how best to manage and use natural, graze and browse resources in partnership with other interested parties.
8. To carry out reclamation work so as to protect and improve the status of our natural resources.

In formal meetings held in each village, these objectives were first presented to village leaders and then to the entire village to seek their broad approval. The objectives were accepted unanimously, and thus provided a set of community-approved foci to guide project implementation.

These initially broad objectives were not appropriate for developing actual interventions; they were rather a basis for local policy-level goals. Thus, a second workshop was held to identify which of the objectives were most important and, subsequently, to develop a more refined set of objectives that would provide focused and tangible targets as well as guidance for the identification of project activities. A group rank-scoring exercise was carried out to identify the three most important of the original set of eight community natural resource management objectives. These were then explored in greater detail, and the major sub-objectives, which would result in achievement of the broad objective, were identified using a graphical representation (called spidergrams) that enabled people to identify components of an answer to a given question and to weight each component of the answer (Lynam 1999). The sub-objectives were ranked based on importance scoring (Fig. 1); then the most important of these were taken as workable objectives. Sub-objectives with the highest scores were ranked as the most important.

Fig. 1. Sub-objectives associated with the community objective of resource conservation and their associated importance scores.



It was recognized by workshop participants that the third most important sub-objective (identified as the need to plan different land uses within the ward and to demarcate different areas for each of these) was a necessary precursor to the other two most important sub-objectives of maintaining human and livestock populations at acceptable levels (Fig. 1). Thus, these first two were taken as workshop targets and the land-use planning sub-objective was accepted as a necessary sub-activity for each.

With these two objectives in place, workshop participants were asked to refine the definitions of each to make them unambiguous as well as directed toward achieving tangible outputs. The objective for people at carrying capacity was thereby redefined as:

"To stop accepting new settlers in Mahuwe Ward by 2003."

The objective for livestock at carrying capacity was redefined as:

"To adopt a grazing systems management plan in Ward 7 (i.e., Mahuwe Ward) by the year 2003 that would ensure the provision of adequate grazing resources for livestock."

The third sub-objective was redefined as:

"Demarcation of all six VIDCOs (Village Development Committees, the smallest unit of management in the current Zimbabwean rural administration) of Ward 7 into grazing, residential, fields, and kraals by the year 2002, accepted by the people."

Workshop participants were then asked to define what factors affected the achievement of each objective. To illustrate the method, we focus only on the question of developing a grazing management plan. It was recognized that the second objective (grazing systems management plan) had, in fact, two sub-components: the first was the development of the grazing systems management plan and the second was the acceptance of the plan by the community. Thus, the workshop group was given the task of developing spidergrams to address both of these issues (see Fig. 2 and Fig.3).

Fig. 2. Spidergram of factors affecting the amount of graze and browse available to livestock in Mahuwe Ward, Zimbabwe.

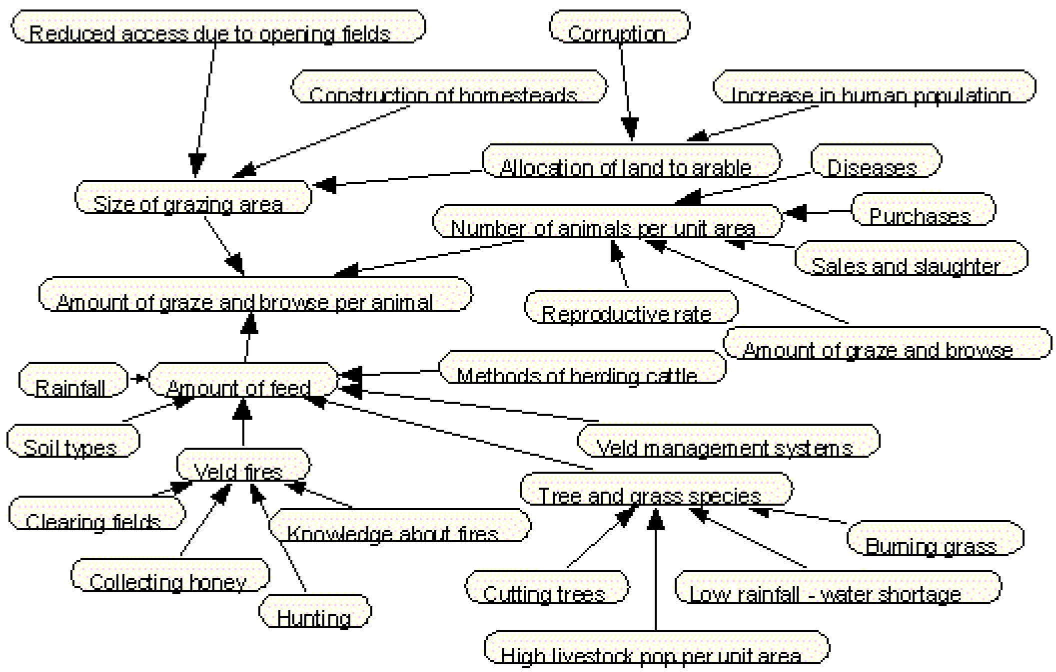
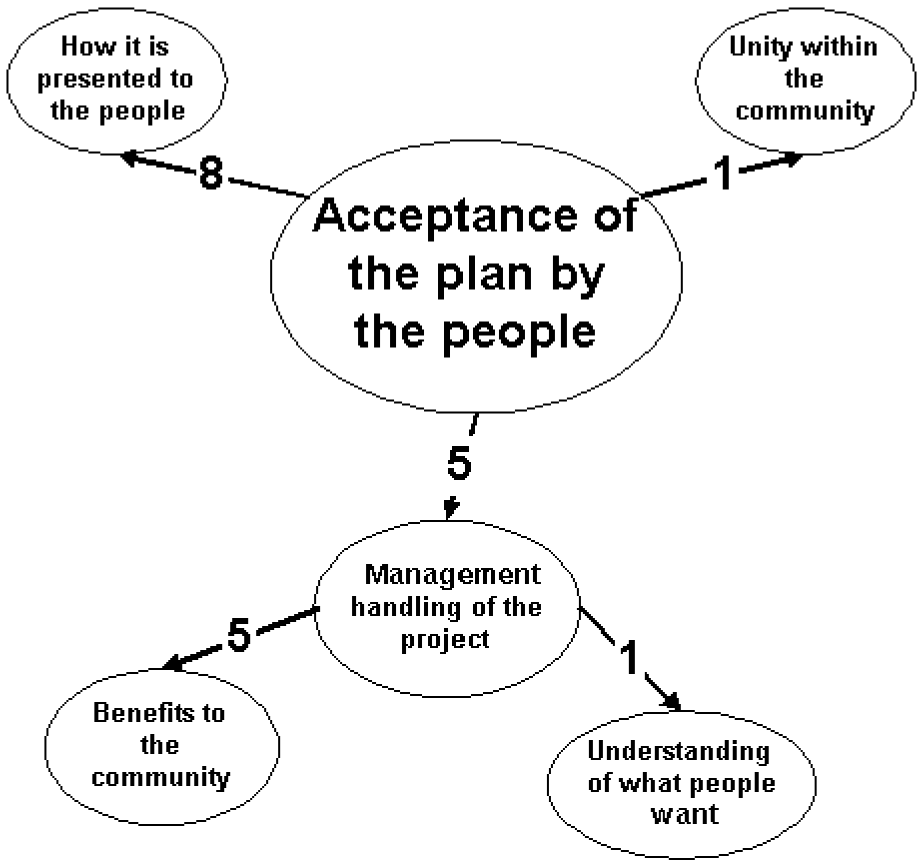


Fig. 3. Factors affecting the local acceptance of management plans developed through the research process. Numbers on the spidergram arms indicate the relative importance of each factor at each level; the least important factor is always scored with 1.



Once these factor spidergrams were developed, workshop participants defined the states that each node in the spidergram might adopt. Thereafter, the relationships between factor states in each of the input variables (nodes) and the core objective state were defined, using the probability tables wherein Village Representatives expressed their subjective probability assessments of response variable states, given the states of input variable nodes. Village Representatives quickly learned that large numbers of input variable states resulted in very large response variable probability tables. As a consequence, the number of states in the input variables was generally limited to two to four. Once the spidergrams and their associated states and probability tables were complete, the resulting network was simplified, where feasible, to ease the process of Belief Network development. Research staff developed the computer implementations of the BNs during the evening, and workshop participants manipulated these the following day. However, it was the development of the common representation of the problem that was the important output of the modeling process. Although the ability to manipulate the model was useful, it was not seen to be as important as building the model itself.

The resulting model of factors influencing the availability of graze and browse indicated that three sets of interacting factors were of primary concern. The first factor was the size of the grazing areas themselves, which were a major concern because corrupt local leaders were allocating grazing lands to new settlers for fields and home sites. The second component was the amount of graze or browse available on each unit of land, and the third component was the number of animals. This model provided a first iteration of a locally developed and manipulatable model of the issues that were of primary concern to the project. The project could thus focus attention on the aspect of the problem that was most important to local people: the amount of land available for grazing. Perhaps more importantly, the model provided a basic and common understanding of the problem and its causes, shared by all concerned, scientists as well as local managers. It was clearly recognized by all participants that the model was not necessarily correct, but it was recognized as being useful.

After development of the Bayesian Network model, a second modeling workshop was held to focus on the dynamics of land change (a key component of the Bayesian Network; Fig. 2). Following this second workshop, a presentation was made to local leaders about the results of both modeling workshops. At this feedback meeting, local leaders confirmed the problem explained by the Village Representatives. Land was being illegally allocated by illegitimate leaders trying to assemble a following (thereby to legitimate themselves) by assembling a local following. As a direct consequence of this feedback meeting and, hence, of the modeling activities, local government officials were asked to identify the legitimate leaders and their roles. Thus, by the process of identifying the problem through use of the Bayesian Network and then its effect through system dynamics modeling, the local community took direct action to stop the illegal allocation of land. The major research objectives of the researchers were also realigned to focus on the key objectives and problems identified in the exercise to set hierarchical objectives and in the Bayesian Network modeling.

It is acknowledged that problem recognition is no guarantee of developing and implementing a viable and locally acceptable solution. Neither the researchers nor their community counterparts were that naïve. The development of the models described in this section of the paper were the first step in a lengthy process of identifying management strategies that were considereded most likely to achieve the desired results. Once these were identified and tested in a modeling environment, the next step would be to identify the organizational and institutional changes required to ensure successful implementation of such locally desirable changes.

Senegal: Role games and multi-agent systems

As part of ongoing research activities in Senegal, various experiences in the use of role games for multi-agent design or restitution have been documented. We report here two experiences. In the first, a model of an irrigation scheme was developed before the workshop, and then role-play games were used to present results to the local community. In the second experience, a model of land use was developed during the workshop. Basically, the same protocol applied for the two experiments held in Senegal. Workshops lasting three days were organized with the stakeholders (farmers, politicians, etc.). During the first day, the rules were explained. The role game took place on the second day. The third day was the day of the computer simulations.

It was necessary to define a methodology in order to build a model with the stakeholders and, in so doing, to insure that all parties perceived the model as an acceptable common representation of the system. We suggested using role-playing game sessions and letting each person play a given role (defined as the translation of the corresponding agent in the MAS).

From the model to the role-play game

The first example was an experiment to create a role-play game to present the results of a model of an irrigated scheme on the Senegal River to the stakeholders. This model, called SHADOC, was created during Barreteau's (1998) dissertation work through an iterative process of fieldwork and computer modeling. The first step in developing the role-play game was to simplify the model. For instance, instead of simulating 100 time steps for a cropping season (each time step representing a day), the crop period was reduced to eight time steps. The game was subsequently tested in various villages. A three-day workshop was then organized. The rules of the game were explained on the first day. Every player was given a set of cards representing his or her social status (from noble to descendant of slaves), as well as his or her production objective (maximization to land tenure) and rules of reimbursement (from all debts to nothing).

There were three different phases in the game, each entailing some degree of coordination among the actors.

1. A credit phase, whereby each player had to identify an amount of money used for income and to pay for water. A player was chosen to play the role of banker. Players could also borrow money from other players.
2. An irrigation phase, where each player managed the water level in its plots, then planted rice and harvests (Fig. 4).
3. A learning phase, in which each player could change its rules (by changing cards).

Fig. 4. Irrigation phase in Podoor village, Senegal. Farmers discussed while the organizer updated the water level in the plots.

An important first set of activities with the model was its validation from the local perspective. This process had several aspects. The first was the verification of the main principle of the multi-agent system, such that from simple behavior of interacting agents, complex phenomena may emerge. For example, in this model and game, numerous players faced bad yields despite an abundance of irrigation water because the efficient allocation of water required complex coordination among the actors. This first validation was achieved through comparing some qualitative properties of the game with local observations of the real system.

The second level of validation involved discussions with the stakeholders. They were asked to compare the game, both the rules and the emergent properties, with reality. Thus, they were able to validate the model as it was presented to them, or they could propose modifications, which would bring the model performance more in line with their understanding of the real system. The discussions that were held among the actors following presentation of the game confirmed that the game was an accurate representation of the real world under consideration.

The last phase, during the third day, was to use the computer to explore the scenarios defined in the role-play game. Stakeholders were able to discuss a scenario as well as the hypotheses to be simulated. The players were, however, more interested in the role-play game and asked for a copy so that they could use it to serve as a discussion tool among themselves. They intended to use the game at various periods in the cropping season. The game and the computer model could be used in follow-up interactions with the local stakeholders. During a season or during the lifetime of a development project, the evolution of the model is the trace of the evolution of representations.

From the role game to the model

The second experiment dealt with land use. It was organized by P. d'Aquino, a geographer at CIRAD working on the decentralization process in Senegal. More precisely, the goal was to develop simulation tools to help the Rural Councils to explore new land-use rules. For example, it was intended to explore what parts of space would be reserved for specific activities; what the rules of access might be; which users might be encouraged and which might be controlled; etc. The Rural Councils were seen as the client group; they were sets of elected farmers in charge of managing resources of the Rural Community (20–300 villages). The goal was to find solutions that allowed multiple uses of a common space.

Workshops were organized in three villages. The theme of each of these workshops was the relationships between agriculture and livestock. About 25 farmers and herders of the villages participated in each workshop, with each workshop taking three days. The following was the general structure of the workshops.

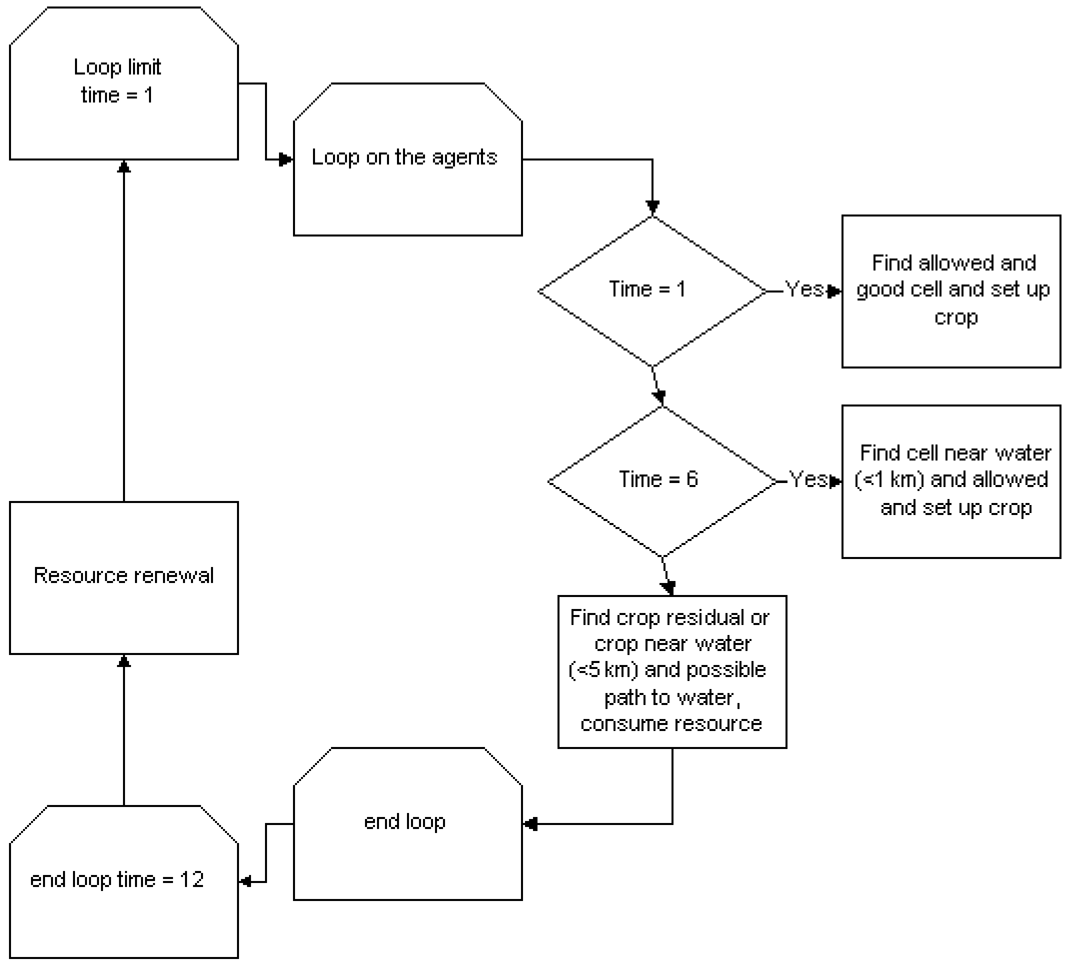
Day one: Identification of the needs of the different actors (soil quality, water salinity, distance to water, distance between plots, etc.).

Day one: Design a map representing the village area and the indicators defined in the previous step. A GIS was available for this purpose.

Day two: Role-play game to represent the dynamics of the system. Month-by-month, each player decided which activity he was engaged in and where, by moving a post-it on the map (Fig. 5 and Fig.6).

Fig. 5. Illustration of map for Ngnith Village, Senegal, used in a role game. Each month, the player comes and places a mark on the map to reflect his position on the spatial grid.

Fig. 6. General algorithm of the role game and the model. At each time step (monthly), all agents look for a good place to make crops or to harvest pasture. The agents represent the actors, who may be farmers or herders. At ime step 1 (July, in reality), they look for a good place for the wet season crop, and time step 6, they look for a good place for the dry season crop. At the end of the year, there is a regeneration of the resource.



Day two: Definition of the relevant problems encountered during the role-play game and envisioning different scenarios that might appear in the future.

Day three: Between the second and third day, the model was implemented (Fig. 7 and Fig. 8). The third day was simulation on the computer and discussions of various scenarios.

Fig. 7. The initial map of Ngnith village, Senegal. The lake is in blue and water holes are blue dots.

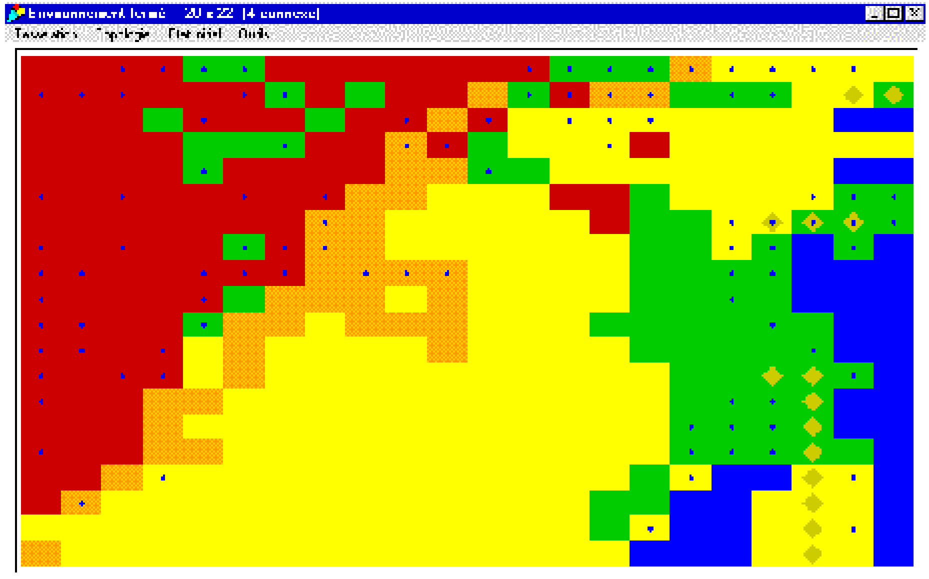
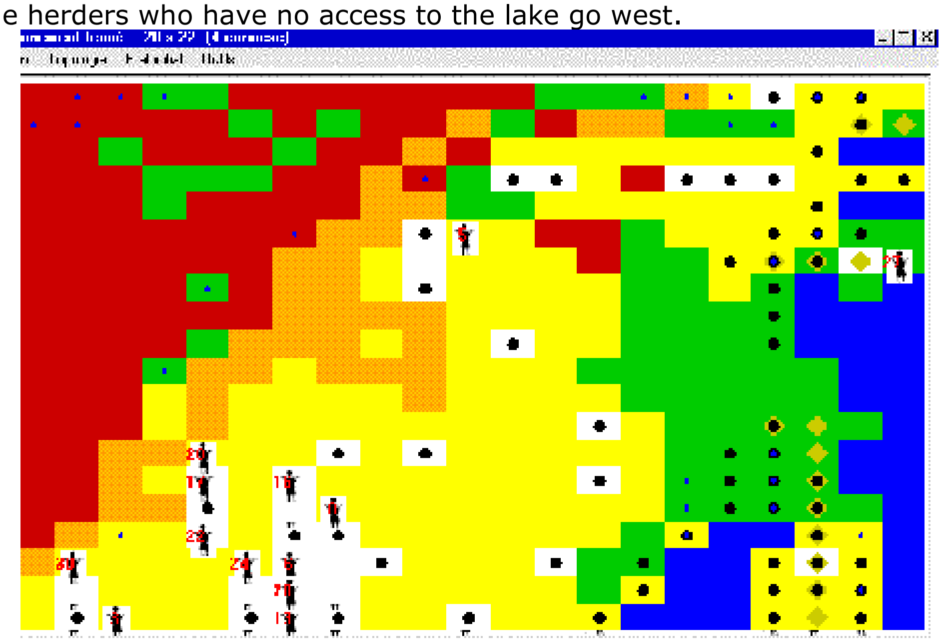


Fig. 8. End of a yearly simulation. Black dots are the crops and white dots are areas where resources have been consumed. On this screen copy, one can see that the herders who have no access to the lake go west.



As an example, we describe the case of Ngnith village, situated on the west side of Lake de Guiers. The main problem, as defined by local people, was a conflict between herders and farmers. The farmers cultivated crops along the riverside and the cattle had to cross the fields in order to have access to the river for drinking. Damage and conflicts often occurred.

The first day, the needs of each group were identified. Each player was alternatively farmer and herder, depending on the season. For the cattle, the distance to water was recorded, as was soil quality. The farmers cultivated two crops a year. For the crop cultivated at the beginning of the wet season, the soil indicator was the unique constraint. The second crop was for market garden produce, when the plots had to be near permanent water. The agents simply looked for places that satisfied their constraints. Consequently, problems emerged for the cattle, which had no access to water.

Once the role games were completed, the rules and spatial relationships that were presented in these role-play games were used to develop and parameterize the simulation model. This model was presented to the participants and was validated by them on the third day. The model was then used to explore different scenarios that could be used to resolve the conflict situations that had emerged (Figs. 7 and 8).

Despite the fact that most workshop participants had never seen a computer monitor, they could easily follow the computer simulations and understood the representations and outputs. Once a simulation reproduced the known situation, the aim was to simulate various scenarios. Discussion began on the water issue. Two alternative scenarios were tested. In the first, a number of water points were sunk in the west. In the second scenario, channels were defined from the lake to extend the reach of the lake into the grazing areas.

The first scenario resulted in overexploitation of pasture around the water points. Then discussion about the channels occurred. Without access rules these channels were not useful. Farmers located their crops all along the channel and herders found that there was no access to the water. Proposals were then suggested to prohibit agriculture on the last kilometer of channel to allow cattle to have access to the water. These proposals were simulated and resulted in a broadly acceptable solution to the conflict problem, which has since become the focus of a set of implementation meetings involving the stakeholders and the Rural Council.

LESSONS LEARNED

In comparing the Zimbabwean and Senegalese case studies, a number of common lessons were identified and serve to guide future activities of this kind. These are briefly discussed in this section.

First, in both cases, the models that were used performed a vitally important role, that of providing a common and manipulatable representation of the problem situation. In the Zimbabwean case, this was a detailed representation of the problem itself, whereas in the Senegalese situation, this was a model capable of exploring solutions to a social dilemma situation. The common understanding or representation is seen as a key step in developing broadly accepted and feasible solutions.

In both situations, the models were developed with the local stakeholders. This gave them a sense of ownership and, in both cases, has resulted in their making demands of the researchers for the outputs of the research. In the Zimbabwean case, the local community was demanding a greater degree of input from the researchers to keep the project momentum going and to develop the next steps of the project. It also led to pressure and direct action from within the community to clarify who local leaders were and what role they could legitimately play in land allocations. In the Senegalese situation, the villagers wanted to use the role-play game for their own discussions and simulations as the season unfolded.

In both situations, the researchers recognized the imperfections of the models, but recognized their importance as a record of the evolution of system understanding as well as a first step in an ongoing and iterative process of achieving local objectives.

The process that both studies had independently experienced was one of adapting scientific objectives as local management objectives emerged. This calls for great programmatic flexibility. It is often difficult, both for donors as well as output-oriented researchers, to allow project realignment when original project plans do not match with local needs. Local needs change, sometimes quite rapidly, and when dealing with adaptive managers, it is perhaps wisest to allow for flexibility in defining project activities.

In both situations, it was clear that the research process contributed significantly to overcoming the high transaction costs of getting the key stakeholders together, focusing their attention in a nonconfrontational way on the problem at hand, and then working toward identifying potential solutions. Similarly, it is to be expected that significant transaction costs would be incurred as communities attempt to implement solutions to these common-pool resource problems. In both situations, the researchers, through their respective projects, bore much of the transaction costs. It is not at all clear how easily this could be replicated where these levels of resources may not be available.

Local managers are, almost by definition, adaptive: in a community of several hundred households, there are always a few people who are trying different things and those who are watching to see what works. In the adaptive management literature, these are what are called passive adaptive managers. Active adaptive management requires that managers probe the systems to explore the fullest possible range of outcomes. This is clearly a risky strategy, particularly when the experiments are being implemented on the only set of resources of a kind. It is difficult to see how local communities could become more active in their adaptations without some means of spreading the risk. Modeling can certainly go some way toward reducing the risks and costs, but not all the way.

The focus of capacity-building research, such as that described in this contribution, should be on making the understanding that local managers develop from their experimentation, observation, and analyses, be as efficient and effective as possible. This will, in all likelihood, be a slow process, but one that stands at least a reasonable chance of producing sustainable production systems in the developing world.

RESPONSES TO THIS ARTICLE

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Acknowledgments:

The comments of two anonymous reviewers are gratefully acknowledged. The Zimbabwean research team gratefully acknowledges the UK-Department for International Development (DFID) grant number R7432 that supports their research. The French research team gratefully acknowledges the Scientific Direction of the CIRAD, which supported this research.

LITERATURE CITED

Barreteau, O. 1998. *Un Système multi-agent pour explorer la viabilité des systèmes irrigués : dynamique des interactions et modes d'organisation.* Dissertation. Ecole Nationale du Génie Rural, des Eaux et des Forêts, Montpellier, France.

Barreteau, O., and F. Bousquet. 2000. SHADOC: a multi-agent model to tackle viability of irrigated systems.*Annals of Operations Research* **94**:139-162.

Bousquet, F. 1994. Distributed artificial intelligence and object-oriented modelling of a fishery. *Mathematical Computer Modelling* **2018**:97-107.

Bousquet, F., O. Barreteau, C. Le Page, C. Mullon, and J. Weber. 1999. An environmental modelling approach: the use of multi-agent simulations. Pages 113-122 *in* F. Blasco and A. Weill, editors. *Advances in environmental modelling.* Elsevier, New York, New York, USA.

Cain, J. D., C. H. Batchelor, and D. K. N. Waughray. 1999. Belief networks: a framework for the participatory development of natural resource management strategies. *Environment, Development and Sustainability* **1**:123-133.

Chambers, R. 1983. *Rural development: putting the last first.* Longman Scientific and Technical, Harlow, UK.

Cumming, D. H. M., and T. J. P. Lynam. 1997. *Landuse changes, wildlife conservation and utilisation and the sustainability of agro-ecosystems in the Zambezi Valley.* World Wide Fund for Nature (WWF), Harare, Zimbabwe.

Fresco, L. O. 1986. *Cassava in shifting cultivation. A systems approach to agricultural technology development in Africa.* Royal Tropical Institute, Wageningen, The Netherlands.

Holland, J. H. 1995. *Hidden order. How adaptations build complexity.* Addison-Wesley, New York, New York, USA.

Holling, C. S., editor. 1978. *Adaptive environmental assessment and management. International Series on Applied Systems Analysis.* John Wiley, New York, New York, USA.

Janssen, M. A., B. H. Walker, J. Langridge, and N. Abel. 2000. An adaptive agent model for analysing co-evolution of management and policies in a complex rangeland system. *Ecological Modelling* **13**(2-3):249-268.

Jensen, F. V. 1996. *An introduction to Bayesian networks.* UCL Press, London, UK.

Johannes, R. E. 1998. The case for data-less marine resource management: examples from tropical nearshore fisheries. *Trends in Ecology and Evolution* **13:**243-246.

Kohler, T. A., and G. J. Gumerman. 2000. *Dynamics in human and primate societies. Agent-based modeling of social and spatial processes.* Oxford University Press, Oxford, UK.

Lynam, T. J. P. 1999. Adaptive analysis of locally complex systems in a globally complex world. *Conservation Ecology* **3:**1 [online] URL: http://www.consecol.org/Journal/vol3/iss2/art13

Rogers, K. H., and R. B. Bestbier. 1997. *Development of a protocol for the definition of the desired state of riverine systems in South Africa.* Department of Environmental Affairs and Tourism, Pretoria, South Africa.

Scoones, I., editor. 1996. *Hazards and opportunities. Farming livelihoods in dryland Africa: lessons from Zimbabwe.*Zed Books, London, UK.

Varis, O. 1997. Bayesian decision analysis for environmental and resource management. *Environmental Modelling & Software* **12**:177-185.

Walters, C. 1986. *Adaptive management of renewable resources.* MacMillan, New York, New York, USA.

Walters, C. 1997. Challenges in adaptive management of riparian and coastal ecosystems. *Conservation Ecology***1:**1. [online] URL: http://www.consecol.org/vol1/iss2/art1